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

October 11, 2022

Nuclear Damage Compensation and

Decommissioning Facilitation Corporation

Table of Contents

Table of figures

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.

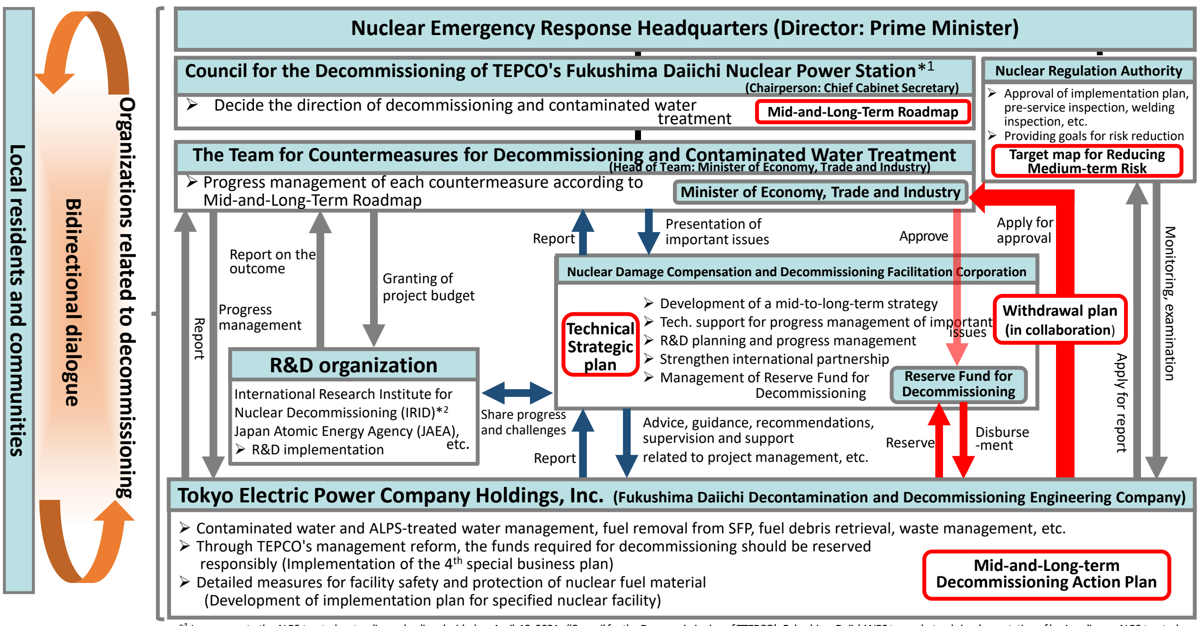
In March 2022, the earthquake occurred with its seismic center off the coast of Fukushima Prefecture, measured a lower 6 on the Japanese seismic intensity scale of 7. However, there was no leakage of radioactive materials into the environment and no significant impact on the plant operations. The Fukushima 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 (Attachment 1), 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

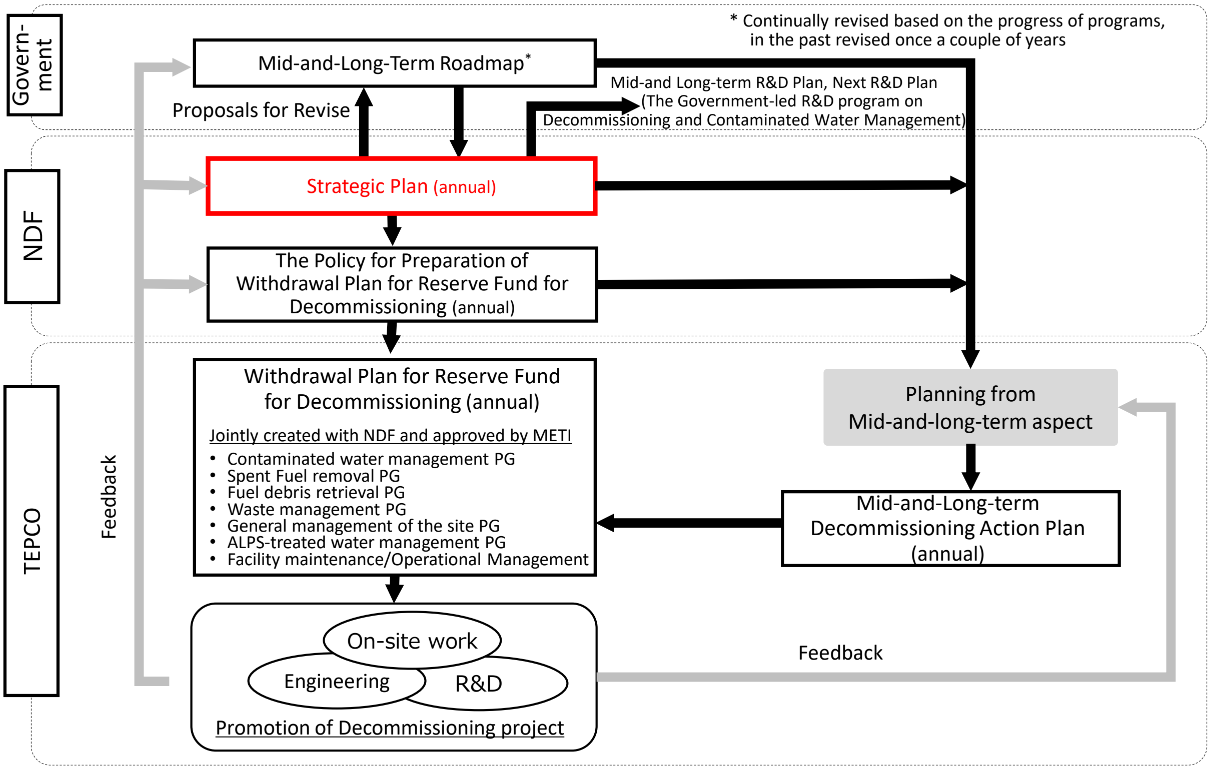


Fig. 2 Positioning of the Technical Strategic Plan based on the Reserve Fund

1.2 The Technical Strategic Plan 2022

The Technical Strategic Plan 2022 consists of six chapters and 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. Followings are the contents after Chapter 2.

- Chapter 2 presents the approach to risk reduction and ensuring safety as well as the basic policies of them. For the approach to risk reduction, it describes the immediate targets in implementing strategies and risk reduction process and its progress of major risk sources. For the approach to ensuring safety, it describes the basic policy of ensuring safety based on the characteristics of the Fukushima Daiichi NPS, incorporating the safety perspective and the operator’s perspective.

- In Chapter 3, sector-specific goals are set for each of the major four areas (fuel debris retrieval, waste management, Contaminated Water/Treated Water management, and fuel removal from SFP), and describes current progress, major issues to achieve them and the technical strategies to realize them respectively

- Section 3.1 (Fuel debris retrieval) describes the status of the primary containment vessel (hereinafter referred to as "PCV”) internal investigation of Unit 1 as well as the preparations for trial retrieval (internal investigation and fuel debris sampling) of Unit 2. This section also describes the status of studies on subsequent gradual expansion of fuel debris retrieval and the process to develop retrieval method for further expansion of fuel debris retrieval in scale.

- Section 3.2 (Waste management) describes examination status for establishing waste stream in accordance with the characteristics of solid waste, which is being studied based on “the Prospects of processing/disposal method and technology related to its safety” presented in FY2021.

- Section 3.3 (Contaminated water and treated-water management) describes the progress and the issues for discharge of ALPS-treated water into the sea, which was indicated to be implemented in two years’ time under the government’s basic policy in 2021, in addition to the examination status for the issues focused on further decommissioning processes including treatment of stagnant water in the buildings and fuel debris retrieval.

- Section 3.4 (Fuel removal from spent fuel pools) describes the progress and the issues of the efforts being made in Units 1 and 2 to complete fuel removal from Units 1 to 6. This section also describes the direction of efforts to determine the future processing and storage methods, such as evaluating the long-term integrity of the fuel in SFP.

- Chapter 4 (Analysis strategy for promoting decommissioning) describes, for the significance and system of analysis, the importance of building and maintaining analytical facilities and functions required for handling waste and fuel debris, and establishing a system including human resource development, as well as the application of a method to evaluate the amount of nuclear fuel without destructing samples to retrieve fuel debris.

- Chapter 5 (Efforts to facilitate research and development) describes the individual research and development described in Chapters 3 and 4 with a view to the medium and long term as a whole, and summarizes the approaches expected of the government, project operators, and related research organizations.

- Chapter 6 (Activities to support our technology strategy) describes the significance, current status, and major issues and strategies in the following areas: further enhancement of project management, improvement of capabilities as a decommissioning operator, enhancement of international collaboration, and regional symbiosis.

  - Section 6.1 (Project management) describes the efforts to enhance owner’s engineering capabilities (project management capability and engineering capability based on safety and operator’s perspectives) with the increasing difficulty of the project.
  - Section 6.2 (Strengthening international cooperation) describes the efforts to promote decommissioning in a mutually beneficial manner that is open to the international community, including returning to the international community the knowledge and lessons learned from the decommissioning of the Fukushima Daiichi NPS.

- Section 6.2 (Local community engagement) describes the efforts to realize "Commitment to the people of Fukushima to achieve both reconstruction and decommissioning" including the organization of a new company for the concentration of decommissioning-related industries in Hamadori region, that TEPCO is promoting.

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

<Basic policy for the decommissioning of the Fukushima Daiichi NPS>
Continuously and quickly reduce the risks arising from the radioactive materials caused by the accident that do not exist in normal nuclear power plants

The Fukushima Daiichi NPS has the necessary safety measures required by the NRA in place for the matters for which measures should be taken and it is being maintained in a state with a certain level of stability.

However, there are still enormous risks at the Fukushima Daiichi NPS because fuel debris and spent fuel still remain in the reactor buildings damaged by the accident, part of the status of the NPS has not yet been sufficiently ascertained, and the site has radioactive contaminated water and enormous amounts of extraordinary radioactive wastes. If left unaddressed, these risks may increase due to aging degradation of the facilities and other factors. Quickly and swiftly reducing these risks is an urgent matter for the NPS.

Accordingly, 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. Generally, the following measures are effective for reducing risks at facilities where an accident has occurred; (1) Improving the containment functions of the damaged facilities; (2) Changing the properties and form of the contained radioactive materials to be more stable; and (3) Strengthening monitoring and control over the equipment to better prevent or mitigate the occurrence or propagation of abnormalities. In order to achieve these measures in an integrated way, in addition, (4) Collecting radioactive materials from the damaged facilities or insufficient containment conditions and placing them in more robust storage is effective.

Since the accident, these diverse measures for risk reduction have been taken with careful preparations aimed at preventing accidents and radioactive exposure of workers (Attachment 2)

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 gradual expansion of fuel debris retrieval in scale.
- 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 PCVs 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 fuel debris retrieval, 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 the 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 term “risk” has various meanings depending on the field or situation in which it is used. In general, in the context of appropriate risk management, “risk” can be understood as an expectation value of the negative impact of an event. In other words, the magnitude of a risk (risk level) posed by a subject (risk source) can be expressed as the product of the level of impact and the likelihood of occurrence of an event.

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. The risk level expressed by SED is given by the calculation formula below.

Risk Level expressed by SED = “Hazard Potential” × “Safety Management”

“Hazard Potential” here, is an index of the impact of the event, namely, the impact of internal exposure in the event of human intake of radioactive material contained in the risk source. It can be expressed as the product of Inventory, which is the amount of radioactive material contained in the risk source (taking account of toxicity of the radioactive material), and factors that depend on the form of the risk source and the time allowable until the manifestation of the risk. “Safety Management” is an index of the likelihood that an event will occur. It is determined by factors that depend on the integrity and other aspects of the facility and on the packaging/monitoring status of the risk source (Attachment 3).

The major risk sources of the Fukushima Daiichi NPS are summarized in Table 1, and Fig. 3 shows the risks of the Fukushima Daiichi NPS as the sum of these risk sources. The current risk levels assigned to the respective risk sources are expressed in Fig. 4 with “Hazard Potential” and “Safety Management” as the axes.

In the Mid-and-Long-term Roadmap, management of these risk sources is broadly classified into three major categories: (1) Relatively high risks given high priority (stagnant water in buildings and fuel in SFPs), (2) Immediate risk unlikely, but risk may grow when handling with haste (fuel debris), and (3) Increased risk unlikely in the future, but appropriate decommissioning efforts are required (solid waste such as sludge generated by the decontamination device). Their priorities are set, and appropriate measures are being taken. In Fig.4, above (1) is represented in pink, (2) in yellow, and (3) in green, with the risk sources in the “sufficiently stable management” region (in pale blue area) are shown in light blue.

Major risk sources identified at the Fukushima Daiichi NPS are shown in Table 1. In addition, the overall decommissioning work over the long term includes waste that existed before the accident and the risk sources that have low hazard potential but are not adequately controlled in a stable manner. Since the Technical Strategic Plan 2019, these issues have also been presented. In particular, regarding the facilities containing risk sources that were not expressly considered before, investigations and examinations are being conducted in consideration of external events such as earthquakes, tsunamis, and rainwater. Once information on the risk sources has been identified through investigation and review, those that have been determined to be prioritized and addressed in the same manner as major risk sources will be evaluated for risk levels in the future. (Attachment 4).

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[1] 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[2]. 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[3], 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

[1] Tokyo Electric Power Company Holdings Inc., “Report on the accident event of the drainage at the shallow draft wharf and storage of rubble,” study group on monitoring and assessment of specified nuclear facilities meeting (90th), Material 4, April 19, 2021

[2] Tokyo Electric Power Company Holdings Inc., “Judgment of Item 10, Article 18 of the 1F Regulation (An event of a high activity alert on the PSF monitor at the shallow draft wharf drainage),” Meeting of the Secretariat of the Team for Decommissioning and Contaminated Water/Treated Water Management (90th), Material 3-6, May 27, 2021

[3] Tokyo Electric Power Company Holdings Inc., “Additional system inspection and seismic evaluation in response to the earthquake on February 13 at the Fukushima Daiichi Nuclear Power Station,” study group on monitoring and assessment of specified nuclear facilities meeting (90th), Material 5-1-3, April 19, 2021

storage area was confirmed[4]. 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.

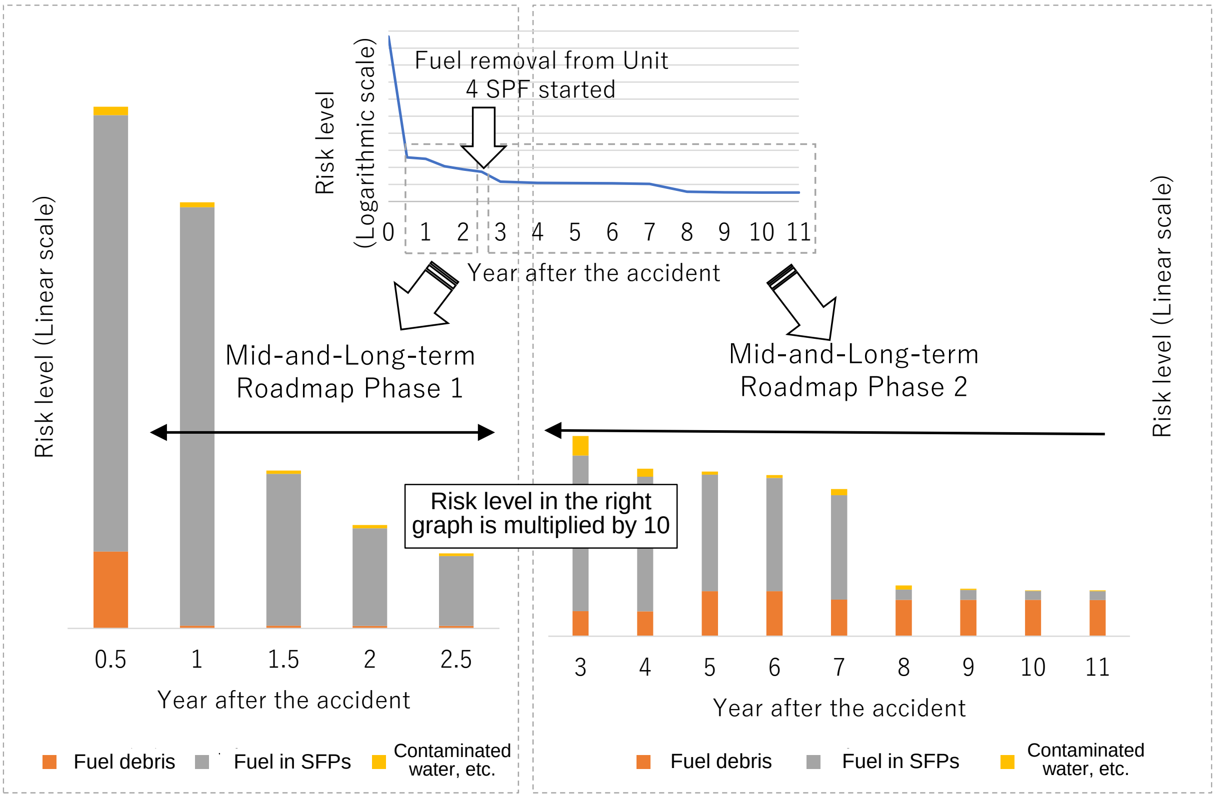
Although none of the above events resulted in significant consequences, it is important to carefully analyze the events using methods such as root cause analyses, and to identify risks that had not been anticipated to in order help prevent the occurrence of significant consequences. For this purpose, 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 HIC)	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 liquid waste, etc.	Concentrated liquid waste generated by evaporative concentration of concentrated salt water with further volume reduction by concentration, and carbonate slurry collected from the concentrated liquid waste

[4] Tokyo Electric Power Company Holdings Inc., "Condition of the Fukushima Daiichi Nuclear Power Station after the earthquake on March 16," study group on monitoring and assessment of specified nuclear facilities meeting (the 99th), Material 1-1, April 18, 2022

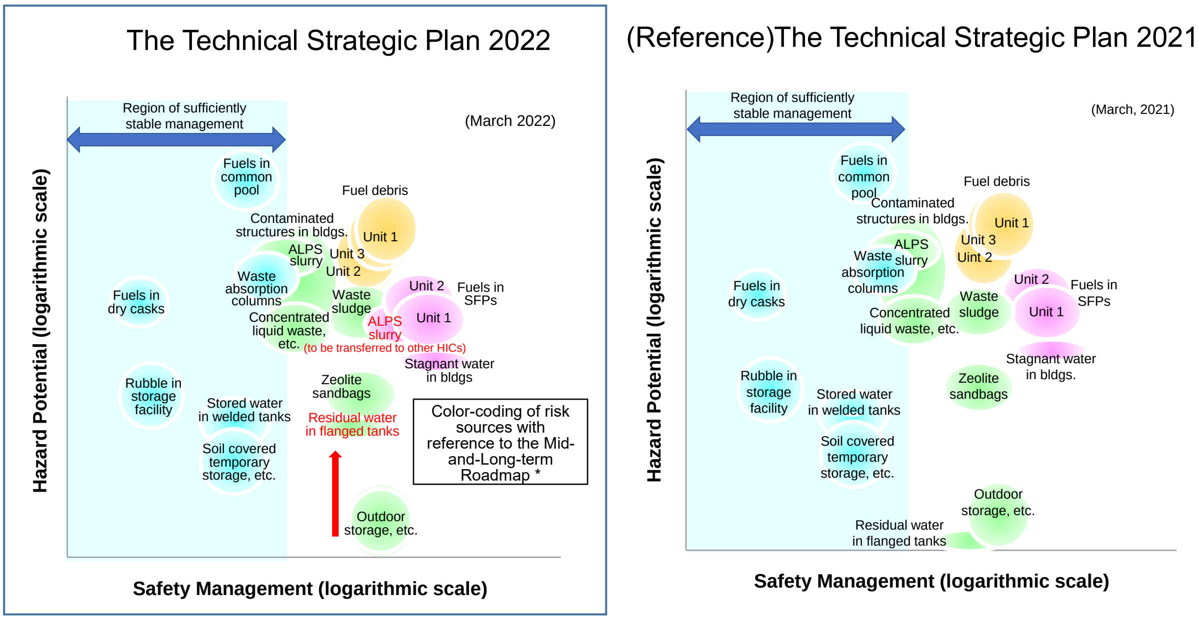
Rubble, etc.	Solid waste storage facility	Rubble (30 mSv/h and above) stored in the solid waste storage facility
	Soil-covered temporary storage, etc.	Rubble stored in the soil-covered temporary storage facility and containers (1-30 mSv/h), felled trees stored in the temporary storage pool
	Outdoor storage, 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



*1 The risk level was high due to fuel debris right after the accident, however, it became significantly lower because the hazard potential was decreased a lot by attenuation of the radioactive materials inside the fuel debris during the one year after the accident.

*2 In the evaluation eight years after the accident, as a result of incorporating the insight that the rise in the water temperature after cooling shutdown was slower than expected, the risk associated with fuel in SFPs is lower than previously estimated, because the time margin before the risk becomes apparent is increased.

Fig. 3 Reduction of risks present in the Fukushima Daiichi NPS



* 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. 4 Risk levels posed by major risk sources at the Fukushima Daiichi NPS

2.2.2 Risk reduction strategy

2.2.2.1 Interim targets and progress of the risk reduction strategy

Measures for risk reduction include the reduction of the “Hazard Potential” and the reduction of the “Safety Management” level. Examples of reduction of the “Hazard Potential” include the decrease in inventory and decay heat associated with radioactive decay, and changing the form of liquid and gas into a less moveable form. Processing contaminated water to change it into secondary waste is an example of form change.

Examples of reduction of the “Safety Management” level include transferring fuel in SFPs to the Common Spent Fuel Storage Pool, and placing rubble stored outdoors into storage. 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. 4.

Regarding the progress of work from Technical Strategic Plan 2021 toward this goal, Fig. 4 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[5] that received the residual bottom water when dismantling tanks in each tank area, recovery of the remaining water is currently underway[6]. 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 HIC's structural integrity against drop[7])[8] 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[9] is shown in pink in Fig. 4. 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

[5] Tokyo Electric Power Company Holdings Inc., "Policy to respond to α-nuclide detected in remaining water in the E area (flanged) tank," Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water and Treated Water Treatment (94th), Material 3-1, September 30, 2021

[6] Tokyo Electric Power Company Holdings Inc., "Future policy toward dismantling E area tanks," Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment (100th), Material 3-1, March 31, 2022

[7] Tokyo Electric Power Company Holdings Inc., "Design for slurry stabilization process," study group on monitoring and assessment of specified nuclear facilities meeting (88th), Material 1-2-1, February 22, 2021

[8] The allowable strain was established from the material test results of HIC polyethylene specimens irradiated with 5,000 kGy of β-rays. It was confirmed that the maximum strain obtained from the drop analysis was less than the allowable strain.

[9] Tokyo Electric Power Company Holdings Inc., "Status of HIC slurry transfer work," study group on monitoring and assessment of specified nuclear facilities meeting (98th), Material 3-6, March 14, 2022

reviewing the design of containers with long-term integrity in the design for stabilizing slurry[10], 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.

In response to the “Risk in external events”, TEPCO is proceeding with studies related to natural disasters, including measures against tsunami and large-scale rainfall, and building integrity evaluations, as stated in the Mid-and-Long-term Decommissioning Action Plan 2021[11] and 2022[12]. TEPCO should continue verification on the system and facility integrity against external events including natural disasters, and develop their actions commensurate with the degree of risk.

2.2.2.2 Risk reduction process for major risk sources and its progress

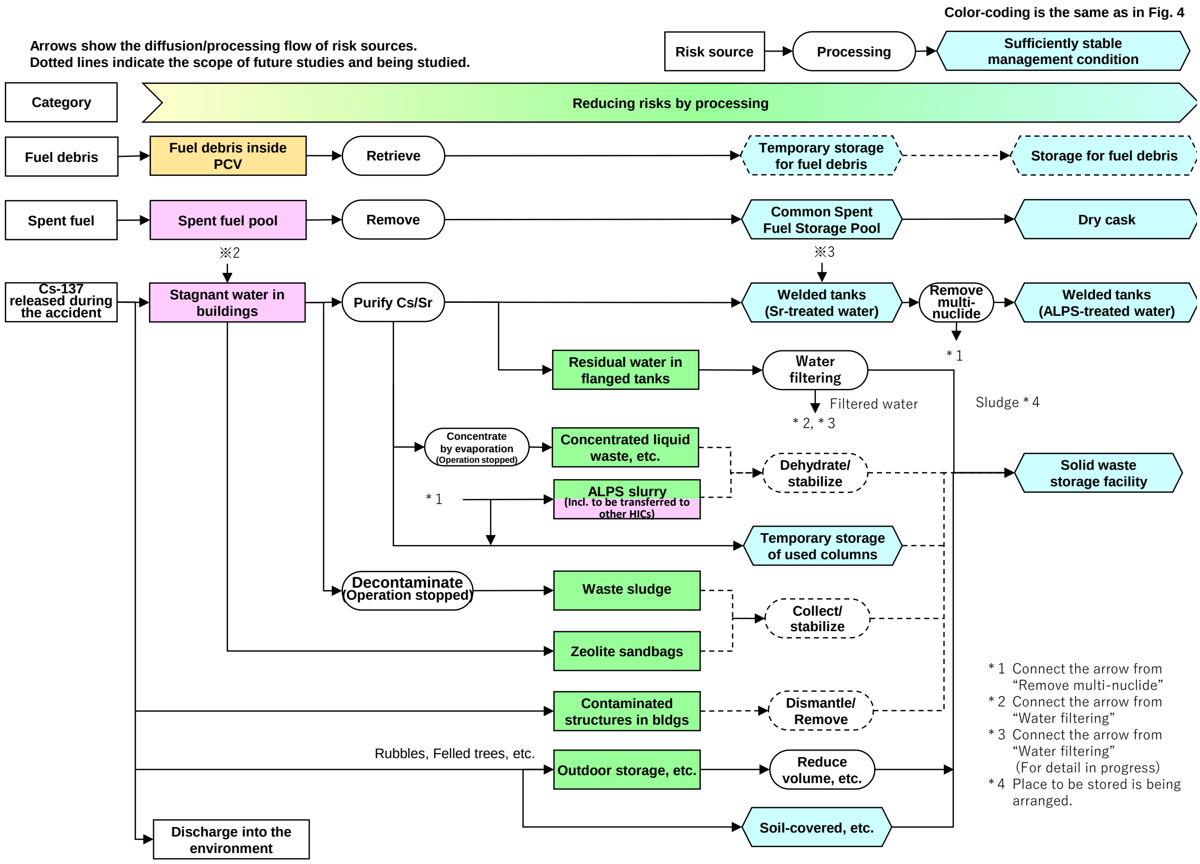
Fig. 5 shows the process to bring major risk sources into the “Sufficiently stable management” region as the interim goal, and representing the decommissioning work progress along this process. Fig. 5(a) shows the outline flow of the decommissioning work to date and the future plans to represent the overall decommissioning process in a comprehensive way. Using the coloring in Fig. 4 to indicate the risk level of each risk source, Fig. 5(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. 5(b), and for Cs-137, the estimated radioactivity (Bq) common to various risk sources as an indicator in Fig. 5(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. 5(b) has made no progress since Technical Strategic Plan 2021. Fig. 5(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.

---

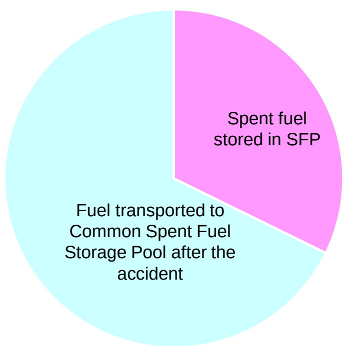
[10] Tokyo Electric Power Company Holdings Inc., “Design for slurry stabilization process,” study group on monitoring and assessment of specified nuclear facilities meeting (92nd), Material 2-2, July 12, 2021

[11] Tokyo Electric Power Company Holdings Inc., “Mid-and-Long-term Decommissioning Action Plan 2021”, March 25, 2021

[12] Tokyo Electric Power Company Holdings Inc., “Mid-and-Long-term Decommissioning Action Plan 2022”, March 31, 2022

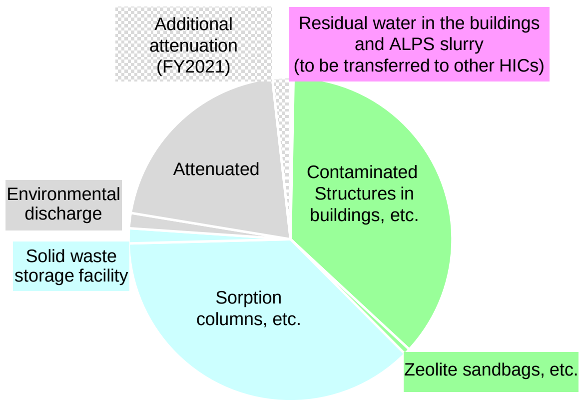


(a) Risk reduction process



*New fuel not included

(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. 5 Risk reduction process for major risk sources and its progress (as of March 2022)
(Attenuation in Fig. 5 (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 primary containment vessels (hereinafter referred to as "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
  (Issues such as containment of radioactive materials [environmental impact], exposure of workers to radiation, assessment of the effect of risk reduction)
- Proven: Highly reliable and flexible technologies
  (Issues such as conformity to requirements, effectiveness and flexibility against uncertainty)
- Efficient: Use resources effectively (e.g., people, things, money and space)
  (Issues such as reduction of waste generation, cost, efficiency, securing necessary work area and site)
- Timely: Be conscious of time
  (Issues such as the early start of fuel debris retrieval and estimation of time required for fuel debris retrieval)
- Field-oriented: Comprehensive three-reality policy by checking actual site, actual things, and actual situation
  (Issues such as workability including environment-friendliness, accessibility, and operability, and maintainability including ease of maintenance and troubleshooting)

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[13]). 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.

[13] Abbreviation of As Low As Reasonably Practicable. This is the principle that the radiological impact must be as low as reasonably achievable.

・ 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.

In the actual study of the decommissioning work, TEPCO, as the decommissioning project executor, should clearly define the "requirements" for the work in advance, and should consider specific safety measures to achieve them. In doing so, it is essential to apply the safety perspective and the operator's perspective to handling the characteristics (peculiarities) of decommissioning the Fukushima Daiichi NPS. Specifically, requirements should be established in consideration of "the safety perspective" and "the operator's perspective", and specific safety measures selected for the work that should satisfy the requirements, considering the two perspectives. In each stage of reviewing the decommissioning work, in this manner, sufficient attention should be paid to "the safety perspective" and "the operator's perspective".

In this decommissioning work with significant uncertainties, it is frequently difficult to clearly define requirements in advance. Even in such cases, the decommissioning work should be carried out flexibly and promptly with by verifying and improving the selected, specifical safety measures as the "preliminary implementation and utilization of the obtained information in the latter stages" and "iteration-based[14] engineering" as described later.

This section first calls for promulgation of the "Safety First" by operators. Next, the 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 while requesting spread of "Safety first" performed by project operator. Lastly, the section refers to the importance of ALARP judgment.

2.3.1.1 Promulgating the "Safety First" principle that safety perspective comes first

The use of any method or device is basically unacceptable unless the safety perspective is sufficiently reflected in them. Therefore, it is important that all who work in the processes (projects)

[14] A method that gradually increases the level of completion of engineering by obtaining the next result from one result and repeating this process.

leading up to the use of methods and devices on the site, keep the safety perspective first in mind as they engage in their work (safety first). The specific application of the general “safety first” principle in the projects means, “Conducting extensive assessments on safety matters associated with methods and devices when reviewing any project and, upon verifying that necessary and sufficient levels of safety have been ensured, taking into account factors such as technical reliability, reasonableness, speed, actual site applicability and project risks in a comprehensive manner to decide which methods or devices to use, and which safety measures to apply consequently”.

Since the accident at Fukushima Daiichi NPS, leaders of nuclear operations at TEPCO have stepped up to the plate and continue to work hard to raise awareness on the issue of nuclear safety, such as through dialogue amongst themselves, as well as through messages that they communicate to other TEPCO employees. In order to thoroughly disseminate the “safety first” principle to all persons involved in the projects including on-site workers, the attitude of top management (the approach to reiterating the special nature of nuclear safety and that special attention is needed accordingly) is important.

2.3.1.2 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 the section 2.3.1.3.

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).

2.3.1.3 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.

“The operator’s perspective” is also important for ensuring safety from the following perspectives, which are different from those of normal reactors.

・ Complementation of design by operations, including operating controls:

Due to significant uncertainties, there is a limit to addressing all situations by design alone. Therefore, it is effective to supplement the design with operator response and on-site operation, and improve safety collectively with operation. For example, information which contributes to criticality safety, (the composition of fuel debris and subcriticality, etc.) at the current Fukushima Daiichi NPS has high uncertainty due to difficulties in the measurement environment on site, even if it can be acquired. Even in such an environment, it is necessary to proceed with fuel debris retrieval with a certain operational scale, while ensuring safety in criticality. To this end, fuel debris retrieval operators should be aware of the signs of criticality that change with each work step as significant fluctuations of measured value. Even if cutting and other work of sufficient magnitude to cause noise, identifiable and significant fluctuations in measured values are performed with relatively small subcriticality, it is possible to take action by maintaining subcriticality or identifying signs of criticality through operations based on design and actual measurement values. In other words, as described above, in environments with significant uncertainties, the development of detection technologies to enable operational responses will become even more important.

・ Utilization of information in design obtained through monitoring, analysis, etc.:

To cope with significant uncertainties, it is important to utilize information obtained through on-site operations such as monitoring and analysis, etc., in designing safety measures. When utilizing such information, it should be linked with calculational evaluation, etc., to “make a comprehensive use of it”.

・ Handling an abnormality:

Although it is essential to take all possible measures to prevent progress of an abnormality, on-site response as a precaution to prevent the occurrence of an abnormality is effective considering the characteristics that the progress of abnormalities is moderate and there is sufficient time to respond[15].

2.3.1.4 ALARP judgment based on safety

For safety, there is a minimum level of safety standards that must be met before the relevant retrieval method or equipment can be used. At levels above the level that meets this minimum level, there is a range of choices and, within this range, retrieval methods and equipment to be adopted will be determined based on trade-off between the safety level to be achieved and project cost and duration (note that retrieval method and equipment involving long-term large safety measures are not necessarily beneficial to safety, especially at Fukushima Daiichi NPS), a kind of ALARP. There is also an issue as to whether such retrieval methods and equipment are feasible in the field.

Based on the above, in the process of determination, it is important to decide retrieval methods and equipment to be employed eventually through the cycle of "defining the safety standards (safety perspective)", "indicating the feasibility on-site (operators' perspective)", and "examining and discussing at projects (project management)" as shown in Fig.6. As shown in this figure, the safety perspective and the operator's perspective are not independent from each other. The ALARP judgement made by the project based on the safety perspective will be linked to the decision of the retrieval method and equipment after going through the feasibility check based on the operator's perspective. The operator's perspective is essential to actually incorporate the safety perspective into the site, and the judgment based on the safety perspective is needed to utilize the operator's perspective.

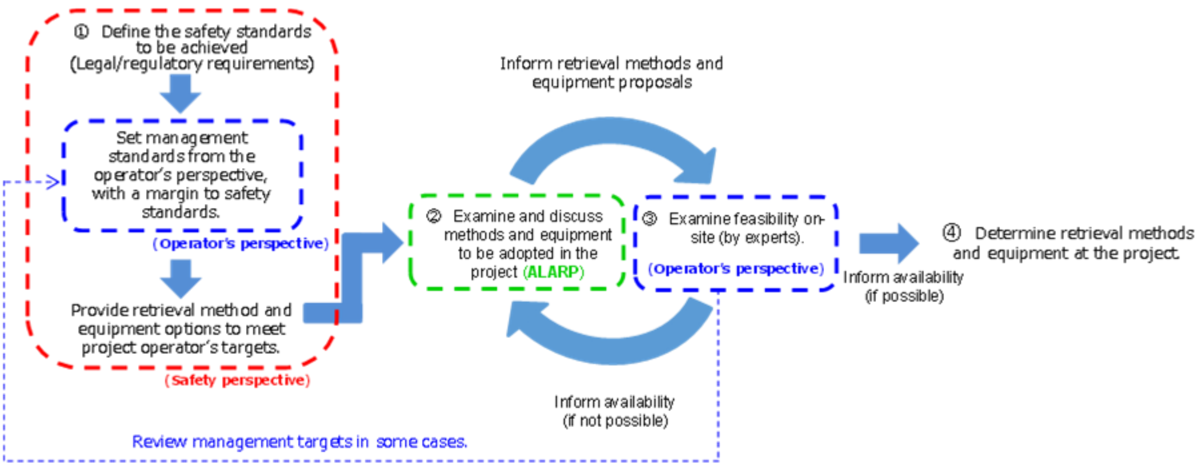


Fig.6 ALARP centered on safety (conceptual diagram)

[15]Since a long time has passed since the accident at the Fukushima Daiichi NPS, the intrinsic energy (decay heat) that drives dispersion of radioactive materials is small. Therefore, in general, abnormalities have the characteristic of progressing slowly so there is a large time margin to respond.

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[16], 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[17]. 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[18].

In a case that uses a similar approach, TEPCO has been conducting reactor water injection shutdown tests since FY 2019. One of the purposes of these tests is to contribute to determining whether or not to terminate water injection in the future, which also takes into account maintaining flexibility in selecting fuel debris retrieval methods. Knowledge on whether or not to terminate water injection has been accumulated by identifying different risks (rising temperature of fuel debris and the RPV bottom, increased dust scattering outside the PCV, and re-criticality when resuming water injection), and by gradually extending the testing time while taking certain risks. 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, i.e., obtaining information on the number of pumps

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

[17] Some example measures include installing nuclear instrumentation to the extent feasible; limiting the amount of debris fabrication; and setting the value for managing radioactive dust concentration and regulating operations.

[18] This is stated in the Decommissioning Implementation Plan (March 17, 2021, Tokyo Electric Power Company Holdings Inc.), which summarizes the policies on implementing decommissioning at the Fukushima Daiichi Nuclear Power Station. https://www.tepco.co.jp/press/release/2021/1585525_8711.html

required for water injection, the appropriate amount of water injection and changes in the cooling conditions of fuel debris due to differences in the points of water injection.

These reactor water injection shutdown tests have resulted in the clarification of the relationship between the lowering of the PCV water level and pressure in Unit 1. According to the information on the damaged piping that was obtained from the on-site investigation conducted before the tests, it was assumed that the PCV pressure might decrease when the water level reached the pertinent damaged area. In fact, the occurrence of the event, which developed as predicted, further enhanced the degree of confidence of the presumed cause that “the PCV pressure dropped as a result of exposing the damage area due to the lowering of the PCV water level”.

This example yielded results that led to reducing the uncertainty through examination in combination with the information gained from on-site investigations, although this information is not directly related to the purpose of the test.

Hereafter, it is recommended to make it clear as a policy that the information to be gained through on-site operation should be fully incorporated and accumulated as knowledge in consecutive activities for ensuring safety. For example, the same applies to risk identification associated with hydrogen at the time of fuel debris retrieval. Testing to reduce nitrogen supply for an experimental purpose may help identify hydrogen risk, and determine requirements on the necessary amount of nitrogen supply and reliability of the exhaust systems to ensure safety.

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.

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

While the decommissioning work is striving for prompt risk reduction from a medium-and-long-term perspective, careful deliberation of the possibility that the performance of decommissioning work may temporarily change the risk levels and may increase the radiation exposure of workers is required. Executing the decommissioning work involves taking some action on the current situation of the NPS, which is maintained in a state with a certain level of stability despite some risks. Such risks may materialize, depending on the way action is taken. For example, accessing the inside of the reactor to retrieve fuel debris will affect the current containment status, and the special operations and maintenance performed in the retrieval work will increase the exposure of workers involved in these activities.

The possibility of a temporary increase in the risk level and a rise in workers’ exposure arising from such decommissioning work must be addressed by taking measures to prevent and restrict them. In particular, as for the radiation safety of workers, it is imperative to limit the increase in the risk level during decommissioning as much as practicably possible by thorough preparations as achieved through application of the concept of ALARA (to suppress radiation exposure to As Low As Reasonably Achievable).

Note that the basic stance for promptly implementing the decommissioning must stand firm because if the decommissioning work is delayed excessively, it means that existing major risks will remain over the long term and their risk levels may gradually rise as the buildings and facilities deteriorate over time. Therefore, with regard to the selection of work methods, the design and manufacture of equipment and safety systems, and the development of work plans for the decommissioning work, cautious and comprehensive decision making is required for early implementation of decommissioning in consideration of many constraints such as time, cost, and worker's exposure needed for relevant preparations and work, while giving priority to limiting the risks involved in the decommissioning work (Attachment 5).

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. Therefore, it is necessary for the local community, the government (METI, NRA), NDF, TEPCO, and others to cooperate with each other to reduce risks based on the approach to ensuring safety taking their respective positions into account. 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 in 2.2.2.2. 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 (for the fuel debris targeted for retrieval, see Attachment 6).

(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)

Fig. 7 shows the estimated fuel debris distribution, access route and surrounding structures of Units 1 to 3. The progress in each unit is also shown below.

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. To construct this access route, installation of isolation valves on the penetration X-2, drilling of holes in the outer and inner doors, removal of obstacles in the PCV, and installation of a guide pipe, etc., were completed in October 2021. Afterward, before investigation started problems occurred due to underwater ROV dosimeter noise and a camera monitor display malfunction, but after taking measures to prevent a recurrence based on the results of an investigation of the cause, the investigation began in February 2022. 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. TEPCO is also considering the impact of the pedestal damage on the plant based on the currently available information, assuming that TEPCO will continue to expand and evaluate its findings through internal investigations[19]. According to the consideration, based on the observations of the external surface of the pedestal, TEPCO assumes that the movement, collision, or fall of structures to be supported, which is considered to be caused by damage to the pedestal, is unlikely to lead to large-scale damage or other problems. In addition, as a result of examining the impact on the cooling of fuel debris, dust dispersion, and criticality as the impact on safety in the case where the pedestal support function declines and the RPV and other structures incline or sink, TEPCO has concluded that there is no significant risk of radiation exposure to the surrounding public. NDF believes that it is necessary to expand and evaluate knowledge through internal investigations in the future and will validate the results of internal investigations conducted by TEPCO and the impact assessment on the plant based on these results.

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.

As a future action, lowering the water level is planned to improve the seismic resistance of the S/C. As preparations to lower the water level, such as by water intake using existing piping and water quality surveying of the S/C water, an investigation of the northern side of the first floor of the reactor building is underway to improve the on-site environment.

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.

[19]The 100th meeting of the Study group on monitoring and assessment of specified nuclear facilities, “Material 3: Status of primary containment vessel internal investigation in Unit 1 (International Research Institute for Nuclear Decommissioning, Tokyo Electric Power Company Holdings Inc.)”

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. (See Section 3.1.2.2 for details).

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. 8, Fig. 9).

In response to the unprecedented approach to retrieving fuel debris from the first implementing unit, NDF continues working while verifying the actual site applicability of the device and the results of the review on modifications to the safety system from the perspectives of safety, reliability, reasonability, timeliness, and a field-oriented stance, in accordance with the progress of engineering at TEPCO.

③ Unit 3

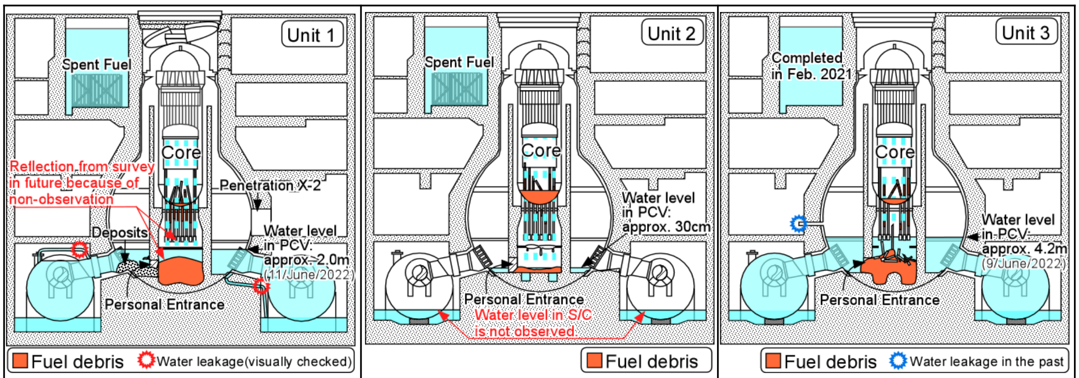
Regarding Unit 3, due to the high water level in the PCV, the plan is to lower the PCV water level in two steps, taking into account the conducting of the PCV internal investigation and the improved seismic resistance of the S/C. The plan for lowering the water level in Step 1 was to drain the PCV water 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.[20] 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[21]. 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. (Refer to 3.1.2.1.4 for detail)

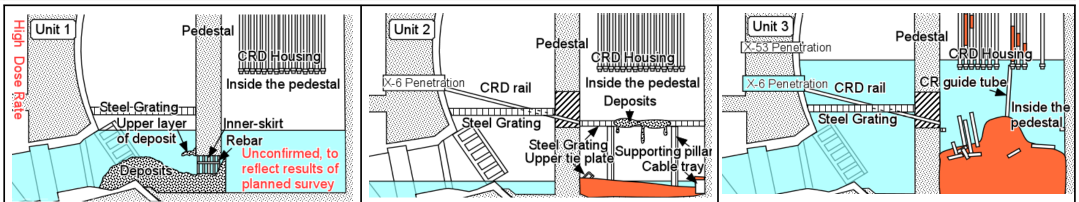
---

20. Tokyo Electric Power Company Holdings Inc., Fukushima Daiichi Decontamination and Decommissioning Engineering Company, July 19, 2022, “Completion of Fukushima Daiichi NPS Unit 3 reactor water injection shutdown tests”

21 The 103rd Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated/Treated Water, “Reference 3-5: Unit 3 reactor water injection shutdown tests”



	Unit 1	Unit 2	Unit 3
Core region	· Little fuel debris remains.	· Little fuel debris remains. (Partially intact fuel might exist in the peripheral region)	· Little fuel debris remains.
At RPV lower head	· A small amount of fuel debris is present. · A small amount of fuel debris is present inside and on the outer surface of the CRD housing.	· Large amount of fuel debris is present. · A small amount of fuel debris is present inside and on the outer surface of the CRD housing.	· Part of fuel debris is present. · A small amount of fuel debris is present inside and on the outer surface of the CRD housing.
At the PCV bottom (Inside the pedestal)	· Most of the fuel debris is present.	· A certain amount of fuel debris is present.	· Amount of fuel debris in Unit 3 is more than that in Unit 2.
At the PCV bottom (Outside the pedestal)	· Fuel debris may have spread outside the pedestal through the personal entrance(Deposits have been observed).	· The possibility of fuel debris spreading outside the pedestal through the personal entrance is low.	· Fuel debris may have spread outside the pedestal through the personal entrance.
Radiation dose in operation site*1	· Radiation dose around the penetration X-6 on the first floor of R/B is high (145 mSv/h).	· Radiation dose on the first floor of R/B had reduced to approx. 5 mSv/h as a whole.	· Radiation dose on the first floor of R/B reaches several to tens of mSv/h or higher than those, indicating a high dose level.



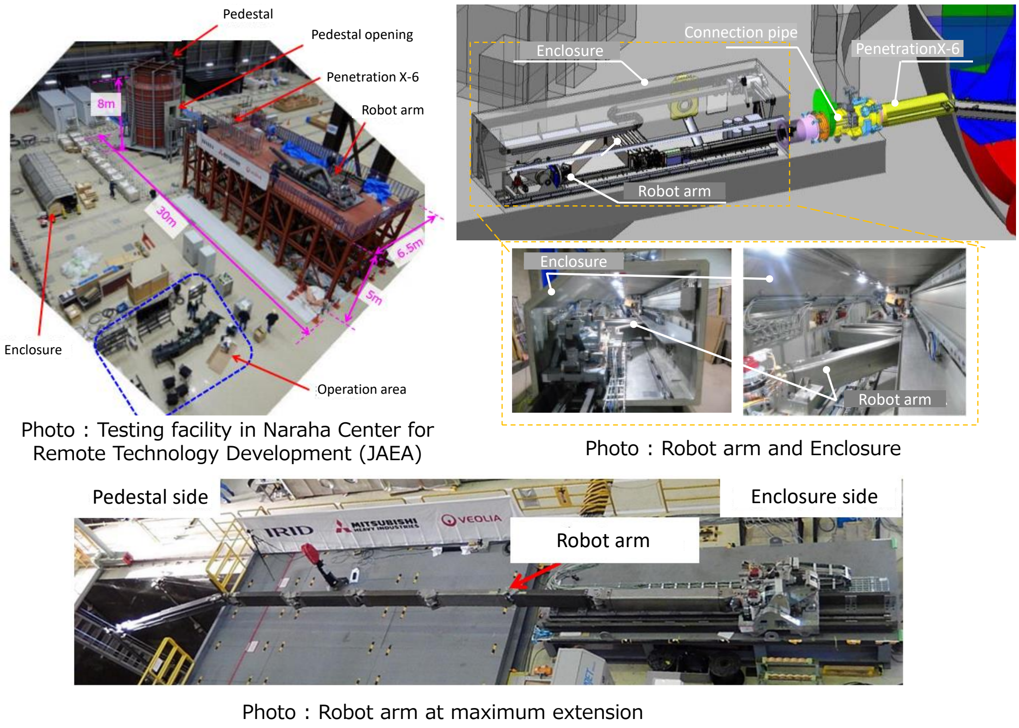
· Exposed rebars were observed around the personal entrance.

	Unit 1	Unit 2	Unit 3
Information on the access route to fuel debris*2	· The D/W bottom outside the pedestal is accessible from the upper side of the steel grating. · Condition around the CRD rail connecting into the pedestal from the penetration X-6 has not been observed.	· No large obstacles have been observed on the CRD rail and around the pedestal entrance. · The bottom inside the pedestal is accessible through the pedestal entrance.	· The bottom inside the pedestal is accessible through the pedestal entrance.
Information on the condition of structures around the access route	· At personal entrance, the inner rebar and inner-skirt are exposed, and the PCW system piping is missing. · A deposit approx. 1.0 m thick has been observed around the personal entrance of outside the pedestal (condition, e.g. cavities, of the deposit inside could not be confirmed) · No significant damage has been observed on the wall surface outside the pedestal on the steel grating upper side.	· While a part of fuel assemblies have fallen, no damage has been observed on the CRD housing support in the examined range . · No damage has been observed on the wall surface and the structures (CRD exchanger, etc.) inside the pedestal.	· Some damaged structures and fallen objects (which may include internal structures), and the fall and deformation of a part of the CRD housing support have been observed inside the pedestal. · No damage has been observed on the wall surface inside the pedestal.

*1 Data provided by TEPCO
*2 Results obtained through PCV internal investigation performed up to date were presented for judging whether any obstacles such as fallen objects may exist on the route to the inside of the pedestal from X-6 penetration, which is considered as a dominant access route for fuel debris retrieval by the side access method.
Other access routes through the equipment hatch and others have been investigated under the Governmental-led R&D program on Decommissioning and Contaminated Water Management.
Due to high dose rate around X-6 penetration of Unit 1, an access route through the equipment hatch may be used in case that it is difficult to improve the environmental condition around X-6 penetration.
PCV internal investigation of Unit 1 will be performed through X-2 penetration (equipment hatch) considering accessibility of devices for PCV internal investigation.

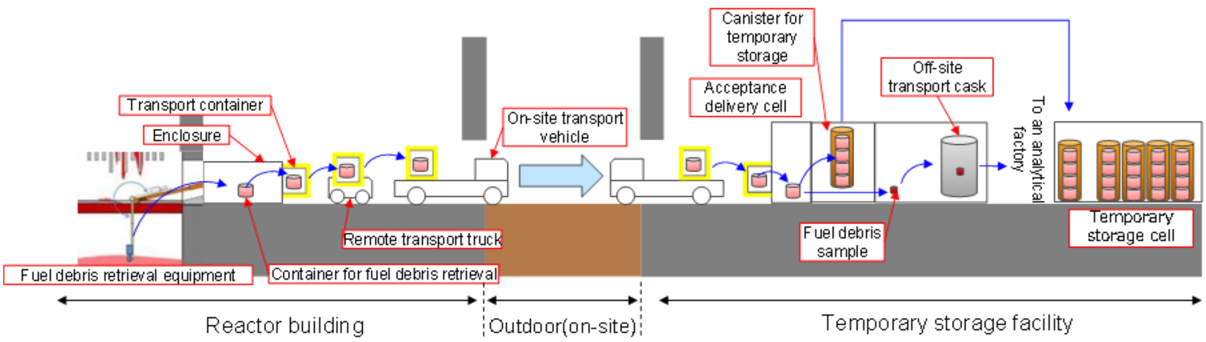
(Prepared in reference to “Material 4-1: Progress of treatment of stagnant water in buildings”, the 81st meeting of the Study group on monitoring and assessment of specified nuclear facilities)

Fig. 7 Estimated fuel debris distribution, access route and surrounding structures of Units 1 to 3



(Prepared by NDF based on TEPCO and IRID materials)

Fig. 8 Image of fuel debris retrieval system
(Trial retrieval and gradual expansion of fuel debris retrieval)



(TEPCO material edited by NDF)

Fig. 9 Image from retrieval to temporary storage of fuel debris
(Gradual expansion of retrieval scale)

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 the further expansion of fuel debris retrieval in scale for Unit 3 is planned. TEPCO has established *Toso Mirai Technology Company* (Decom. Tech) (hereinafter referred to as the “New Engineering Company”) to be engaged in the basic design and R&D of systems and installations for further expansion of fuel debris retrieval in scale [22]. From now on, under the strong leadership of TEPCO, it is necessary to proceed with decommissioning with cooperation between TEPCO as a parent company, the New Engineering Company, manufacturers, researching institutions, and other related organizations based on proper role assignment. It is also important to effectively leverage the technologies cultivated mainly in the New Engineering Company through these initiatives to improve TEPCO’s technical capabilities built on safety and operator's perspective, as mentioned later.

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 the further expansion of fuel debris retrieval in scale, it is necessary to promote R&D and engineering to apply the results on-site and then incorporate into equipment design, retrieval procedures, and safety assessments for the use of the knowledge gained through trial retrieval in Unit 2, e.g., conditions of existing structures and sediment distribution, gamma-ray and neutron count distribution, the degree of impact on containment functions caused by loading/unloading equipment, and information on fuel debris to be collected during retrieval. In addition, the retrieval methods should be examined based on 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.

[22] Tokyo Electric Power Company Holdings Inc., “Establishment of ‘*Toso Mirai Technology Company*’ toward fuel debris retrieval at Fukushima Daiichi NPS”, October 3, 2022

• 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 the 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 (composed of a robot carrying-in room, etc.) to be built during opening the penetration X-6 (Fig. 10), and an enclosure to be newly provided (which encloses a robot-arm, etc.) (Fig. 11), 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. 12). 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 gloveboxes 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.

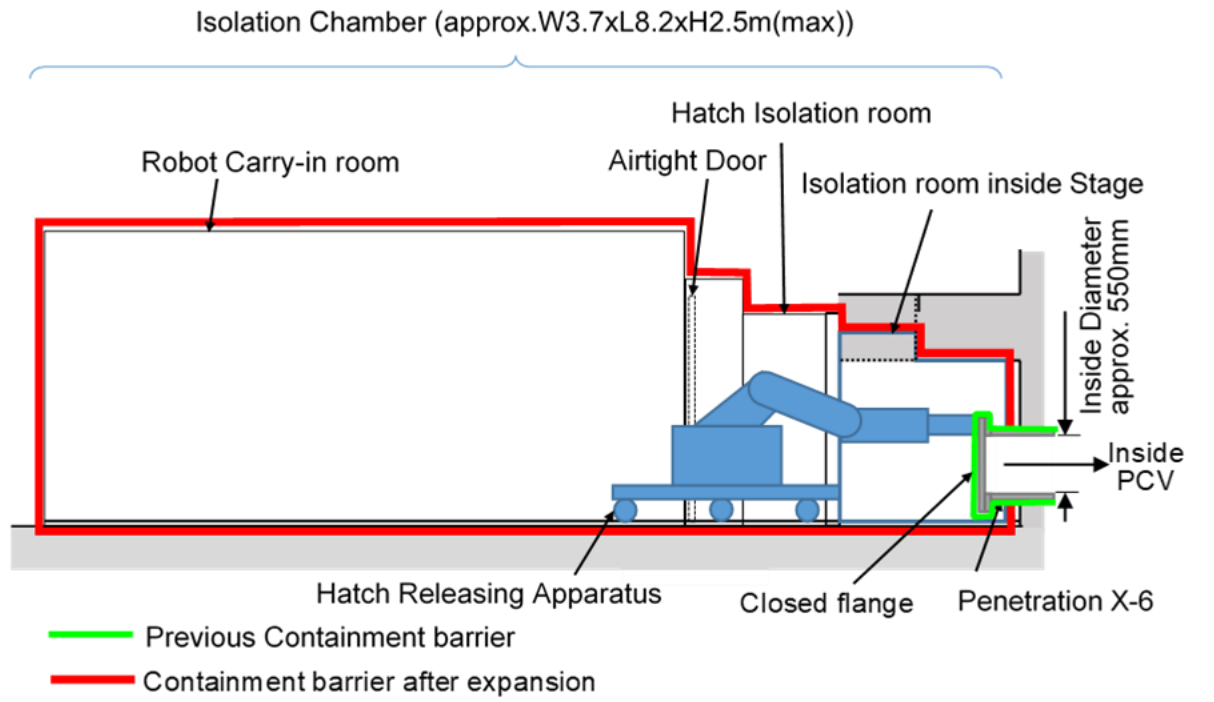
Verification tests of the newly developed robot arm were conducted in Kobe (Kobe Shipyard & Machinery Works, Mitsubishi Heavy Industries) from July 2021 until January 2022, following verification tests at a factory in the UK. Since February, verification tests (mock-up tests) have been conducted in an 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 carry-in room 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.).

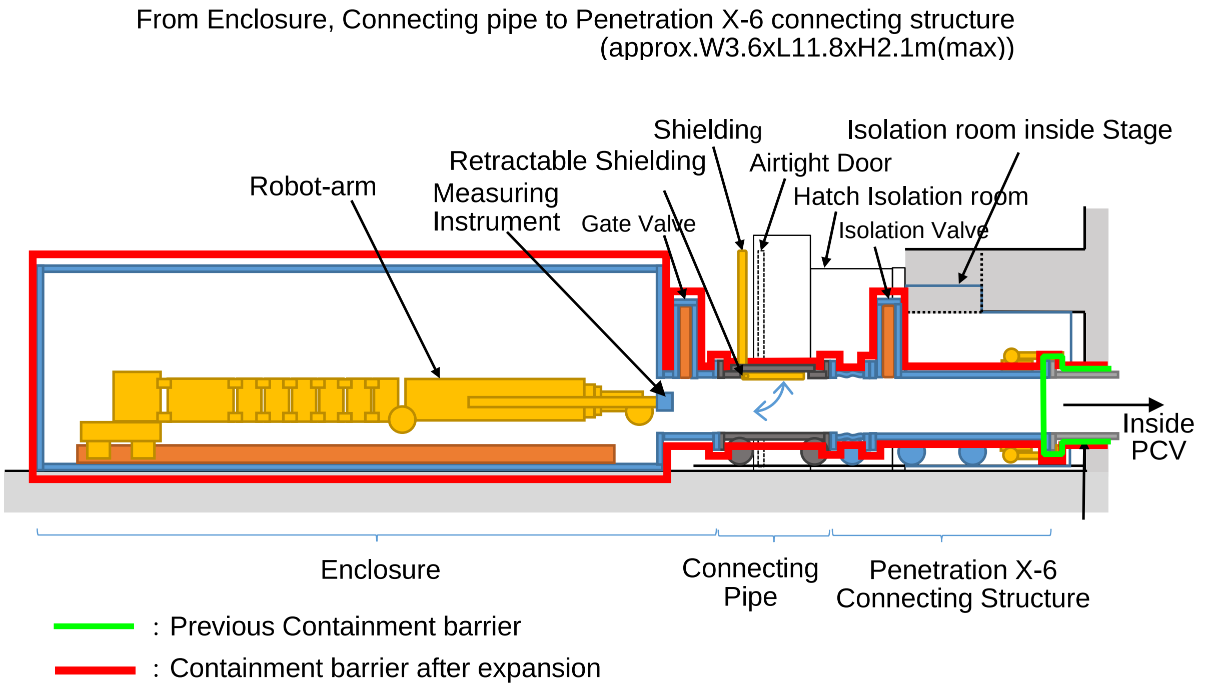
During the installation of the isolation chamber, leakage from the newly installed isolation room inside stage was observed in an airtight leak test (leakage from rubber containment barrier). This event reaffirmed that expanding the containment barrier outside the PCV, which interfaces with the existing 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 verifications.



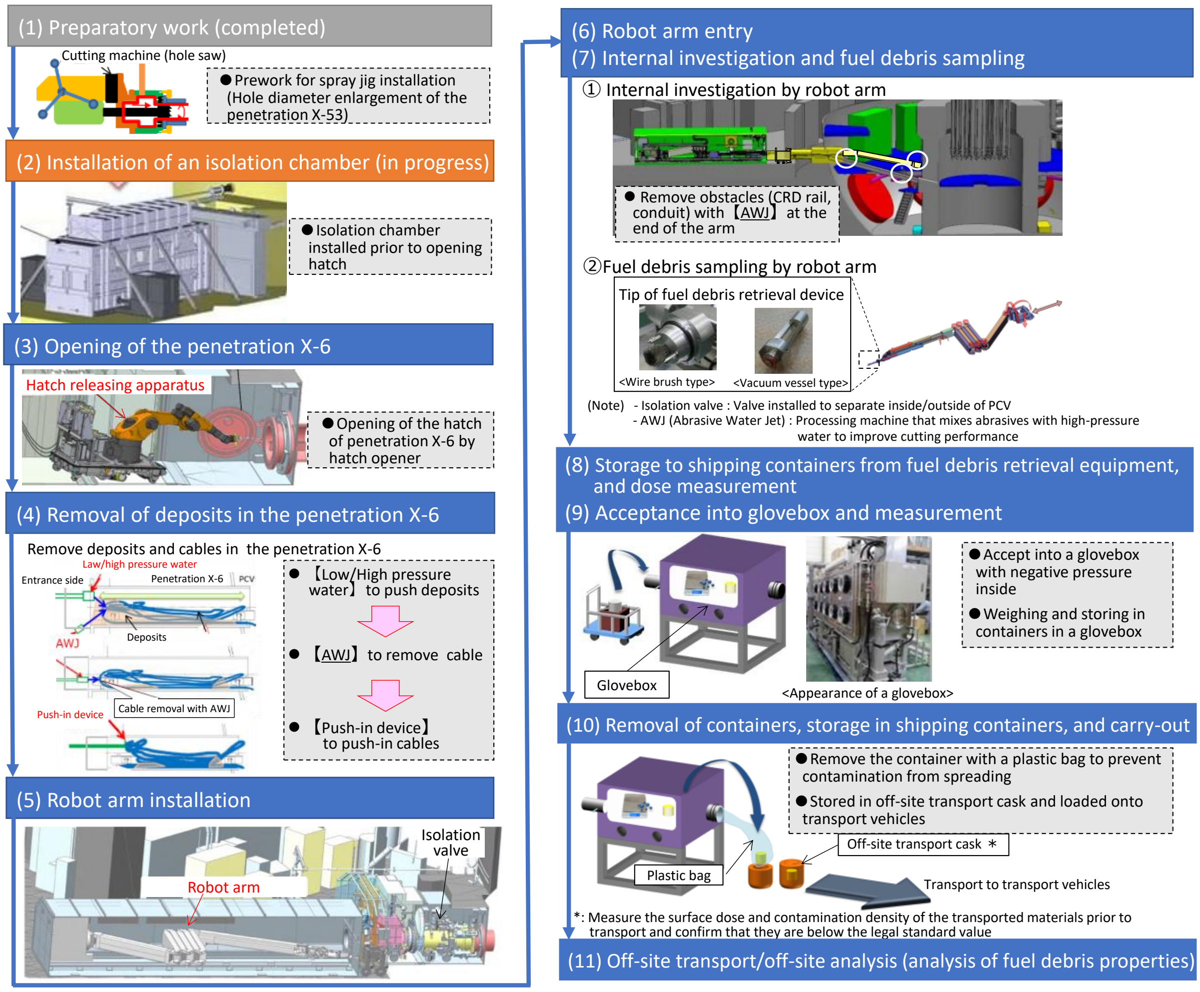
(TEPCO material edited by NDF)

Fig. 10 Schematic drawing of containment barrier during opening operation of the Penetration X-6



(TEPCO material edited by NDF)

Fig. 11 Schematic drawing of containment barrier during trial retrieval
(Internal investigation and fuel debris sampling)



(TEPCO material edited by NDF)

Fig. 12 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 arm 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 and enhancing accessibility while complying with specifications of the devices for trial retrieval (internal investigations and fuel debris sampling).

It is planned to expand the range of retrieval step by step while making achievements, starting with retrieval of fuel debris that can be gripped and sucked, and expanding it to fuel debris retrieval with cutting. Consideration will also be given to the possibility of cutting platform beams and the range of cutting. The enclosure containing the robot-arm, etc. is connected to the PCV via penetration X-6 connection structures to secure containment functions. In order to bring fuel debris into the enclosure, it is necessary to consider shielding, measures against hydrogen and prevention of the spread of contamination, methods for transferring fuel debris from the enclosure, and methods for confirming the maintenance of boundary and dynamic equipment functions and for remote maintenance.

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.

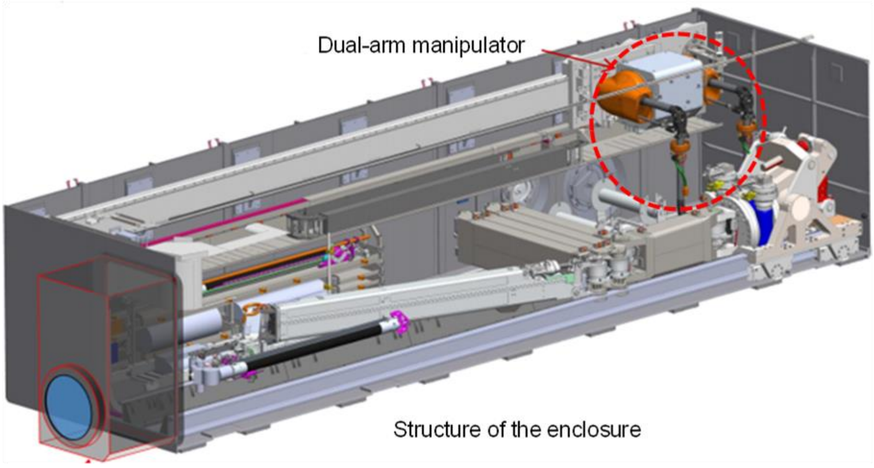
・ Ensuring containment performance of enclosure for fuel debris

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 (Fig.13)

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.



(IRID material edited by NDF)

Fig. 13 Enclosure and manipulator

- 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.

Thus, the device to carry 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 fuel debris retrieval 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. (For reference, Attachment 7 shows the transition of retrieval method considerations in the Technical Strategic Plans in the past.)

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[23] (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.

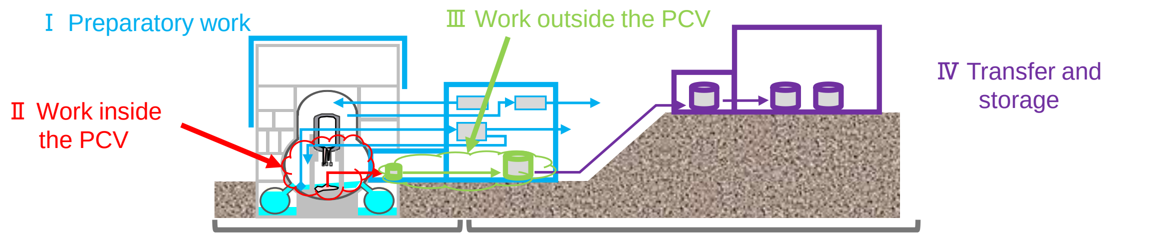
・ Specific procedure and approach for examining retrieval methods

---

23. Method for determining the relative merits and demerits for decision-making based not only on one attribute (evaluation item) but also on multiple attributes (evaluation items). This methodology is applied to the process of examining the methods, and those with a high score calculated from “Σ (evaluation of each attribute (evaluation item)) x (weight of each attribute (evaluation item) = importance)” will remain. This was used to examine retrieval methods, it is considered that evaluation by this methodology will be effective in narrowing down multiple method options (e.g. access device, etc.) hereafter.

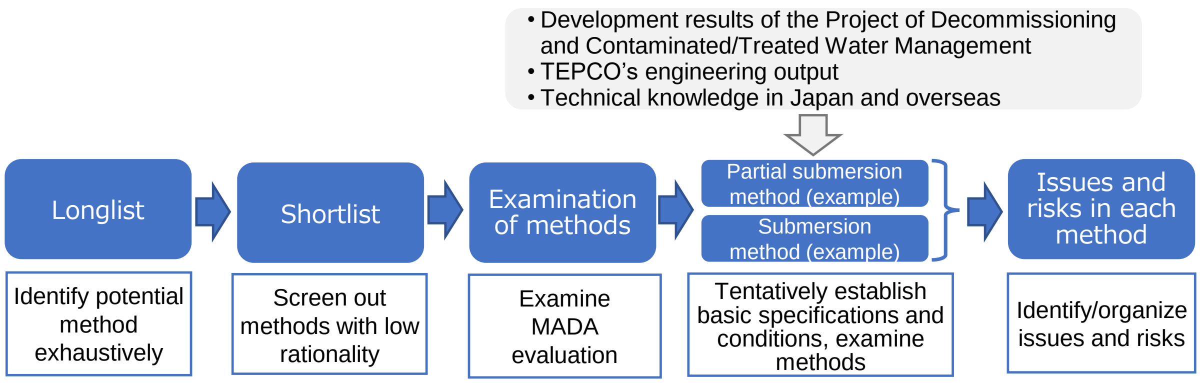
Followings are the works implemented in FY2021. In examining methods, the work process was roughly divided into two processes, the retrieval process, and the transfer/storage process. The retrieval process was further divided into preparation work and work inside the PCV. The transfer/storage process 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. 14). 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. 15). 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. 14 Conceptual diagram of each work phase (a division of process)



(TEPCO material edited by NDF)

Fig. 15 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. 16 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. 17 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[24] as a boundary. (See Fig. 18 for a conceptual drawing of the current submersion method (shell method))

[24] 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.

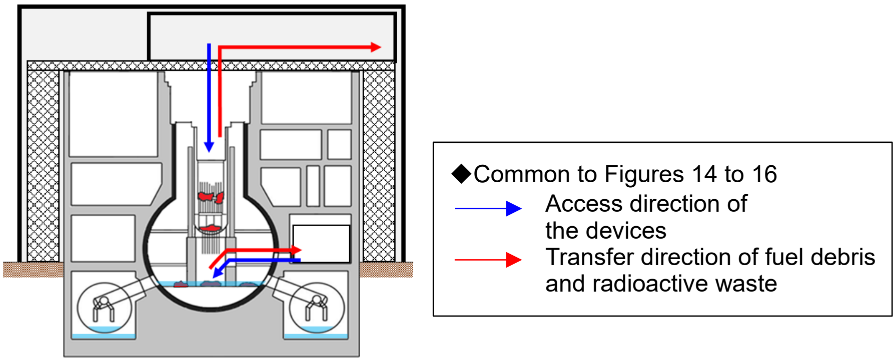


Fig. 16 An example of partial submersion method
(Conceptual drawing of combination of top and side access)

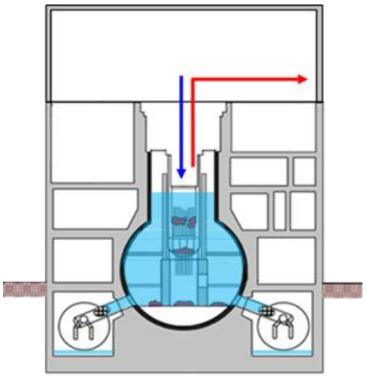


Fig. 17 Reference : Conventional submersion method
(Conceptual drawing of the PCV submersion method)

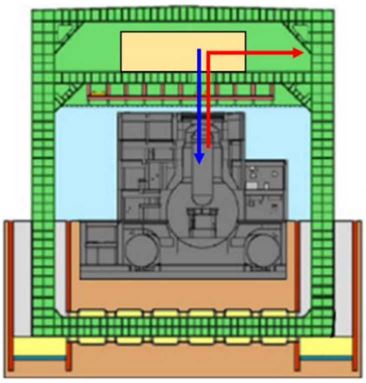


Fig. 18 An example of submersion methods
(Conceptual drawing of shell method)

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. As an example of a common issue for all methods, preparatory work in the reactor building involves work in an extremely harsh, high-dose environment. Therefore, the feasibility of the construction work needs to be verified in consideration of exposure to workers. Moreover, construction of containment barriers and safety systems involves the removal of surrounding buildings/facilities and the installation of new large structures, resulting in enormous work and the associated waste. Furthermore, during fuel debris retrieval, a function is required to reliably contain without fail the radioactive materials resulting from fuel debris fabrication, such as cutting. In addition, systems and operations should be capable of early detection and transition to a subcritical state so that workers and the environment are not affected in the event of a criticality. To solve these issues, it is important to summarize common conditions for study, such as preconditions and requirements, rather than examining each method alone, share and utilize the results obtained through internal investigations and R&D activities.

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. 19).

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.

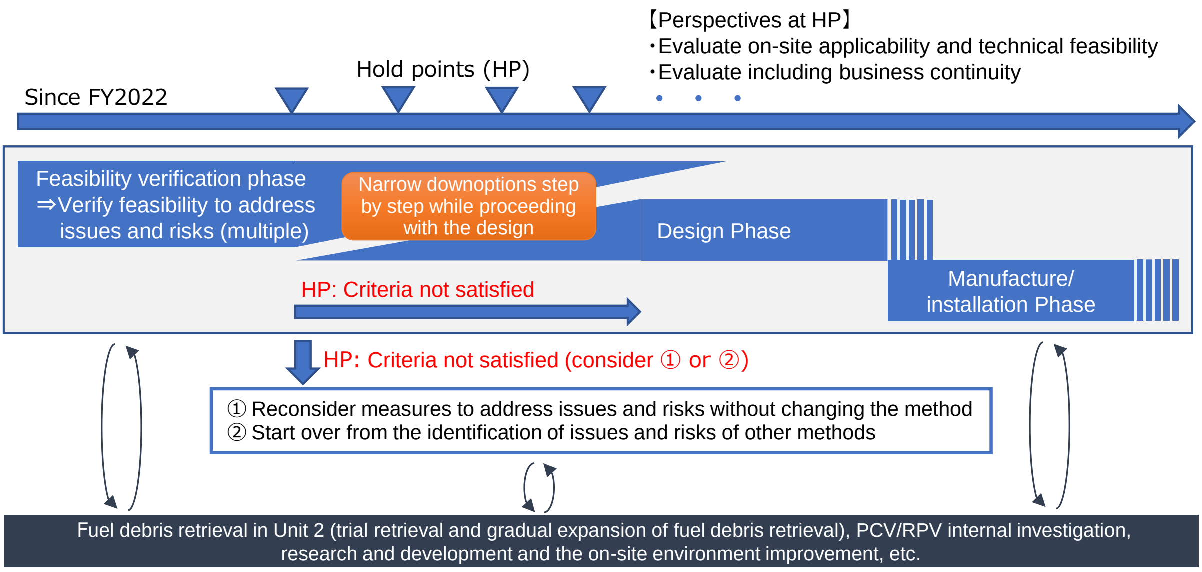


Fig. 19 Conceptual diagram of how to proceed with examining methods after FY 2022

[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, 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[25].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[26,27,28]. Moreover, TEPCO is carrying out independent

---

[25] The 84th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment, “Material 3-3: Analytical results of samples related to the Unit 1-3 PCV internal investigations and others”

[26] IRID, supplementary budget in FY 2018, “Subsidies for the Project of Decommissioning and Contaminated Water Management” (Development of analysis and estimation technologies for characterization of fuel debris), results for FY 2020, (2021)

[27] The 29th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, “Material 1-1: Analysis results of gases generated by pyrolysis of organic materials in BWR primary containment vessel”

[28] The 29th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, “Material 1-2: Evaluation test results of the amount of combustible gases generated from cables, paints, and insulators”

investigations of the operating floor [29,30,31] and standby gas treatment system [32,33] (hereinafter referred to as "SGTS") and so forth in each unit.

The Secretariat of the Nuclear Regulation Authority (NRA), which is responsible for [34]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[35]. 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[36] in the holes bored in the shield plug of Unit 2 and geometry measurements[37] to check 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 [38,39] 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[40], 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

29 The 69th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment, “Material 3-2: Investigation on obstacles in the SFP and well-plugs of the Unit 1 reactor building”

30 The 88th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment, “Material 3-2: Preliminary report on investigations of the operating floor of the Unit 2 reactor building”

31 The 24th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment, “Material 3-2: γ-ray spectrum measurement results of the operating floor of the Unit 3 reactor building”

32 The 84th meeting of the study group on monitoring and assessment of specified nuclear facilities, “Material 4-3: Surveillance results for removal of SGTS piping at Units 1 and 2”

33 The 30th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station “Material 2: Partial removal of SGTS piping of Units 1 and 2 of Fukushima Daiichi Nuclear Power Station”

34 Article 4, Paragraph 1, Item 11 of the Act for Establishment of the Nuclear Regulation Authority stipulates the scope of authority as “Affairs concerning investigations of causes of accidents that have resulted from the operation, etc., of reactors and causes of damage that has arisen from nuclear accidents.”

35 The 19th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, “Material 4: Interim report on investigation/analysis of the accident at the TEPCO Fukushima Daiichi NPS”

36 The 27th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, “Material 2-1, Attachment 1: Measurement inside new holes of the Unit 2 shield plug”

37 The 28th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, “Material 2-1-3: Deformation of the Unit 2 shield plug”

38 NRA, "Material 2: Continuous survey and analysis on the accident of the Fukushima Daiichi Nuclear Power Station” (27th meeting)

39 The 7th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, “Material 2: Continuous survey and analysis on the accident of the Fukushima Daiichi Nuclear Power Station”

40 The 21st Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station “Material 5-1: Partial removal of SGTS piping of Units 1 and 2 of the Fukushima Daiichi Nuclear Power Station”

started in September 2021[41] to improve the cutting process by checking the injection point of urethane foam with a camera and a laser pointer[42]. 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[43] 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 shielding 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

[41] The 95th Meeting of the Secretariat of the Team for Decommissioning and Contaminated Water/Treated Water Management, “Material 3-3: Progress status of partial removal of SGTS piping in Units 1 and 2”

[42] Tokyo Electric Power Company Holdings Inc., Fukushima Daiichi Decontamination and Decommissioning Engineering Company, June 9, 2022, “Resuming partial removal of SGTS piping in Units 1 and 2 of the Fukushima Daiichi Nuclear Power Station”

[43] Tokyo Electric Power Company Holdings Inc., “The 5th progress report on the Investigation and Exasmination of Unconfirmed and Unresolved issues on the Fukushima Daiichi Nuclear Accident”

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

In general, when considering ensuring safety at a nuclear facility, a series of evaluations are conducted by assuming accident scenarios in which the potential hazards of the facility become materialized, evaluating that these scenarios fall within the safety standards, and confirming that the safety measures are appropriate. In an ordinary nuclear power plant, such a series of safety assessment procedures are established and standardized by national regulations and guides. However, since there are no established and standardized regulations and guides for the decommissioning work at the Fukushima Daiichi NPS, it is necessary to organize an approach to ensuring safety based on the safety-related features of the Fukushima Daiichi NPS and to share it with the parties concerned.

Decommissioning work 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

Based on these characteristics, NDF is organizing an approach to ensuring safety with the following as the basis:

- Optimization of judgement with safety assessment as its basis:

  When making decisions by comprehensively considering technical reliability, reasonableness, promptness, etc., safety assessments should be fully used to avoid a great variance in decisions for safety measures to avoid (too excessive or too insufficient resource input).

- Ensuring timeliness in decommissioning activities:

  While paying attention to the prevention of accidents and the mitigation of their impacts, measures should be taken with concentration on the time axis so as not to prolong the decommissioning period, in consideration of high radiological impacts that have already become apparent, as well as further deterioration of containment barriers, etc.

- Complementing design by operating controls, monitoring, analysis, and on-site operation in the event of an abnormality:

  Due to significant uncertainties, there is a limit to addressing all situations by design alone. For this reason, the information obtained at the operation stage, including that obtained through monitoring and analysis, should be utilized in design, and design should be complemented by operators' efforts and on-site operation to enhance safety in total with operations. In preparations for abnormalities, consideration should be given to on-site response considering the characteristics that the progress of abnormalities is moderate and there is sufficient time to respond.

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 as shown in the following Sub-sections 3.1.2.6.1.1 to 3.1.2.6.1.6.

3.1.2.6.1.1 Establishing the containment functions (gas-phase)

Leakage of radioactive materials in an ordinary operating nuclear power plant is prevented by implementing static containment for a PCV and keeping the interior of a reactor building under negative pressure against the ambient air (active containment function by negative pressure control). However, the reactor buildings, PCVs, etc. of the Fukushima Daiichi NPS were partially damaged by the hydrogen explosion and their containment function is deteriorated. Due to this, establishment of an active containment function by negative pressure control is being considered during fuel debris retrieval work. Moreover, from the perspective of prevention of hydrogen explosions due to steadily generated hydrogen by the process of radiolysis of water and of corrosion (inactivation) of structural materials due to the presence of oxygen, nitrogen is injected into the PCV to maintain it in a nitrogen atmosphere. As for the exhaust from inside the reactor buildings, the release of radioactive materials has been prevented by the PCV gas control system, which is furnished with filters to remove radioactive materials and measure radioactivity[44].

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

---

[44] TEPCO, evaluation results of the additional release amount from the Units 1 - 4 reactor buildings (June 2020), the Team for Countermeasures for Decommissioning and Contaminated Water Treatment/Secretariat (80th) material 3-6, May 28, 2020 https://www.tepco.co.jp/decommission/information/committee/roadmap_progress/pdf/2020/d200528_11-j.pdf

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.

The issues involved in constructing system installations to maintain containment functions are outlined in section 3.1.2.6.2.3.

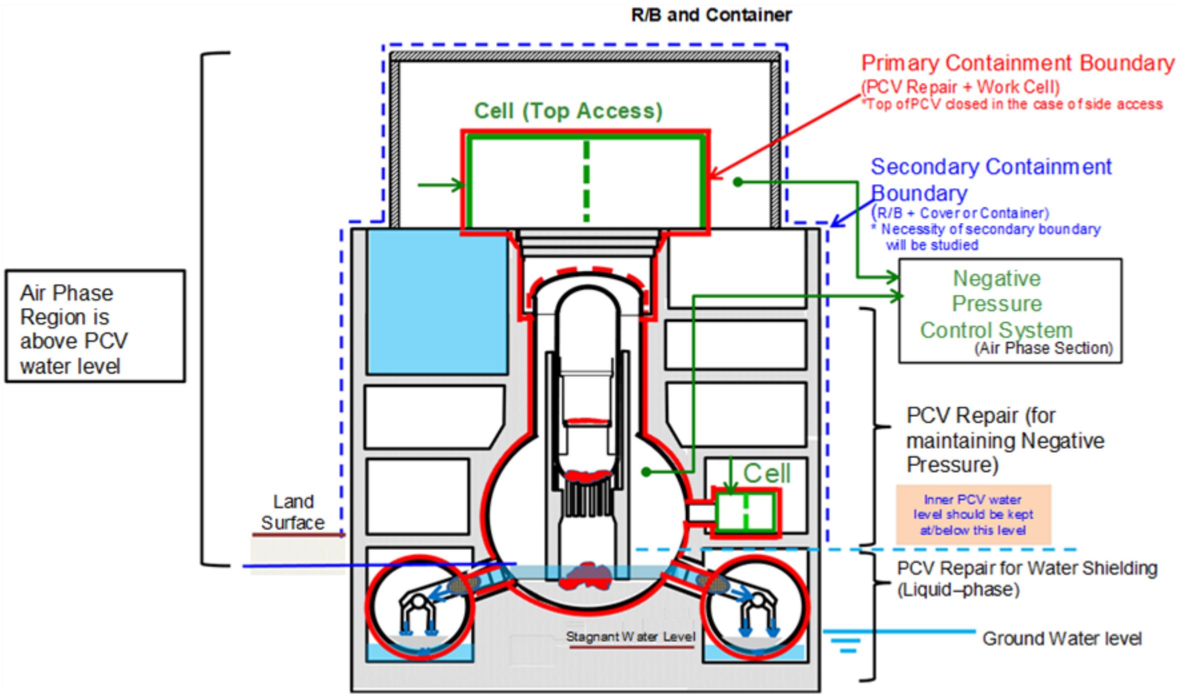


Fig. 20 An example of building containment function (gas-phase) by negative pressure control

In establishing the containment function (gas-phases), technical issues to be addressed immediately for further expansion of fuel debris retrieval in scale are as follows:

(1) Understanding of the dispersion rate of α-dust

As described above, for fuel debris retrieval work, it is necessary to understand the impact of α-dust dispersion and establish measures to suppress the transition of α-dust to the gas phase as much as possible.

To understand the impact of α-dust dispersion, a plan is required to measure data on dispersion in trial retrieval and gradual expansion of fuel debris retrieval and then demonstrate and verify safety assessment methods. It is necessary to understand the general and approximate behavior of α-dust dispersion for proceeding with technical studies and R&D related to fuel debris retrieval methods and systems in situations where these demonstration data have not been obtained. In addition, tests are planned to obtain dispersion data for several fabrication methods to determine the α-dust dispersion rate. Currently, tests to analyze differences among several methods are ongoing, and tests to improve applicability to on-site environmental conditions are also planned.

In order to suppress the transition of α-dust to the gas phase, it is desirable to submerge the fuel debris and to fabricate it underwater as much as possible. However, the water level in the PCV is to be adjusted with other technical requirements such as the building of the containment function of the liquid phase described in the next section. Therefore, not all fuel debris can be fabricated underwater, and transition of α-dust to the gas phase is considered to be mitigated by splashing water on the fuel debris that is not submerged.

(2) Ascertaining the feasibility of negative pressure control in the PCV

A. Technical feasibility of negative pressure control based on the site conditions

In order to maintain negative pressure in the PCV, sufficient gas exhaust system capacity that considers the condition of PCV damage is required. Although damaged parts have not been identified yet, the exhaust capacity is currently established based on the relationship between actual nitrogen supply volume and actual PCV internal pressure. At this time, it is necessary to maintain sufficient differential pressure to respond to the internal pressure rise of the PCV due to abnormal events such as an internal temperature rise or shutdown of the gas exhaust system. In order to achieve this, repair of the damaged parts of the PCVs will be considered as necessary, but some difficulties such as remote work or exposure of workers are assumed due to work under high radiation dose conditions.

In this way, it is necessary to ascertain the technical feasibility of maintaining the negative pressure in the PCV based on the site conditions and the information obtained during trial retrieval or the gradual expansion of fuel debris retrieval.

B. Effect of air flow into the PCV during negative pressure control

Since air flows into the PCV in case of negative pressure control, measures of maintaining inactivated condition in the PCV by increasing nitrogen gas supply into the PCV will be examined as necessary based on evaluation on occurrence of accidents such as fire and hydrogen explosion using accumulated information regarding volume of hydrogen generated by radiolysis of water in the PCV and inflow volume of air (oxygen) into the PCV.

C. Study on the necessity of a secondary containment function

As illustrated in Fig. 20, for fuel debris retrieval, it is assumed that a working cell is newly installed, which will be connected to the PCV under negative pressure control, and the operation from retrieving the fuel debris to storing the container for fuel debris in a transfer cask is performed in this cell. The PCV and this working cell have a primary containment function to prevent α-dust to the exterior (out-leakage).

In addition to this, in order to respond to an event in which radioactive materials are dispersed from the containment boundary caused by loss of primary containment function through negative pressure control, the necessity of the secondary containment function has been investigated by installing building covers and containers in the existing reactor buildings and maintaining slightly negative pressure inside of the reactor buildings to recover and treat radioactive materials. However, a large capacity gas exhaust system is considered to be required to maintain negative pressure in the secondary containment boundary since the reactor building has a large volume and its leak tightness may have deteriorated due to the accident. Therefore, based on the accumulated results of the tendency of dust dispersion obtained hereafter, it will be necessary to ascertain the required functions to establish a secondary containment function and to proceed with research and development accordingly.

D. Deterioration control of the containment function of the PCV

In order to maintain negative pressure in the PCV during the fuel debris retrieval work, it is necessary to manage risks of earthquakes and aging after considering how to handle deterioration of the primary containment function consisting of the PCV and the attached cell. This is outlined in Section 3.1.2.3.1.5.

(3) Study on exhaust gas management

In control of exhaust gas associated with negative pressure control, it should be confirmed that radioactive materials in gases that may contain nuclear fuel materials derived from fuel debris are maintained below the radiation dose standard for the public in the vicinity of the facility by measuring and controlling the release concentration and the release amount. In addition, α-nuclides derived from fuel debris should be included in the assessment and constantly monitored/measured during fuel debris handling so as to evaluate their normal fluctuation range in advance. By using such data, a system for early detection of abnormal events such as leakage and implementing appropriate impact mitigation measures should be established for preventing any impact on environment and workers.

The reliability and accuracy of the mechanical properties and chemical composition of the fuel debris needs to be improved because these are essential information for designing the decontamination equipment for efficient collection of radioactive dust.

As described above, regarding establishing a containment function (gas-phase), TEPCO has been ascertaining the feasibility of negative pressure control in the PCV through their engineering work, and in parallel, it has been examining the necessity of a secondary containment function and its establishment. In the future, TEPCO will incorporate the results gained from the Project of Decommissioning, Contaminated Water and Treated Water Management, trial retrieval and gradual expansion of the retrieval scale, and give shape to the system specification necessary for establishing a containment function through their engineering work. (See Chapter 3.1.2.6.2.3 for the progress status of installing covers on the side and top of the Unit 3 reactor building to improve its containment performance.)

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 (Fig. 21).

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[45]. 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[46].

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[47]. 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 liquid waste 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.

The issues involved in constructing system installations to maintain containment functions are outlined in section 3.1.2.6.2.3.

In establishing the containment function (liquid-phases), the technical issues to be addressed immediately for further expansion of fuel debris retrieval in scale are as follows:

---

[45] IRID, additional subsidies in FY 2018 for the Project of Decommissioning and Contaminated Water Management, “Technology development for further expansion of technologies to retrieve fuel debris/in-core structures”, actual results in FY 2019, August 2020.
https://irid.or.jp/wp-content/uploads/2020/09/2019008kibonosaranarukakudai.pdf

[46] IRID, additional subsidies in FY 2017 for the Project of Decommissioning and Contaminated Water Management, “Development of technology to establish primary containment vessel water circulation system (full-scale test), final report for FY 2019, August 2020.
https://irid.or.jp/wp-content/uploads/2020/09/2019006mizujyunkan.pdf
https://irid.or.jp/wp-content/uploads/2020/09/2019007mizujyunkanjitukibo.pdfhttps://irid.or.jp/wp-content/uploads/2020/09/2019007mizujyunkanjitukibo.pdf

[47] IRID, supplementary budget in FY 2016, “subsidies for the Project of Decommissioning and Contaminated Water Management”, sophistication of retrieval method and system of fuel debris and internal structures, final report in FY 2018, July 2019.
http://irid.or.jp/_pdf/20180000_13.pdf

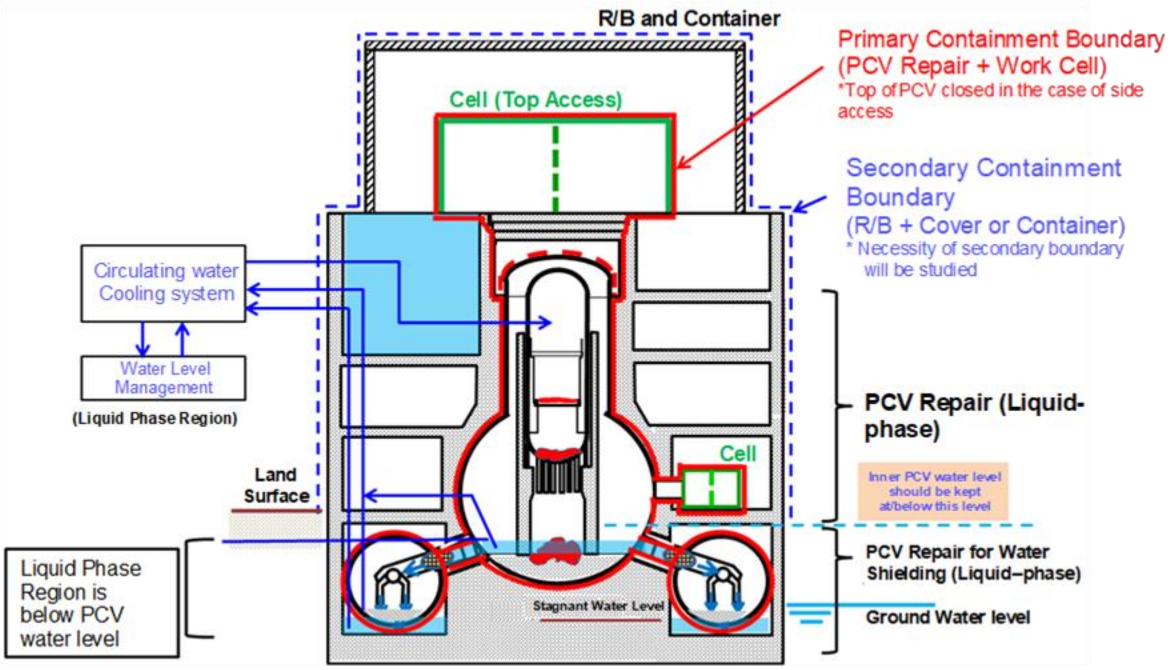


Fig. 21 An example of building containment function (liquid phase)

(1) Suppression of radioactive concentration increase in cooling water due to fuel debris retrieval work

As an approach to assess the radioactive concentration in the cooling water, it is necessary to plan to investigate the impact on liquid waste when gradually expanding the scale of retrieval.

To suppress an increase of radioactive concentration in cooling water in the PCV, cutting particles generated by fabrications such as cutting is planned to be collected through the PCV circulating cooling system to mitigate dispersion of dust. It is recommended that the results of monitoring by the water circulation system are taken into account and incorporate them into modifications of the PCV circulating cooling system as necessary in the stage of gradually expanding the scale of retrieval.

(2) Setting of water level in the PCV

Due to a low seismic margin of S/C support columns, it is recommended that the water level in the S/C is lowered, and thus, considerations are being given to lower the water level. In this instance, it is necessary to appropriately set and manage the water level in the PCV with consideration for the damaged condition of the PCV in each unit and prevention of the outleak of cooling water to groundwater (maintaining the water level in the reactor building below the groundwater level), etc., and to confirm that safety is ensured in terms of fuel debris cooling and control of dust dispersion.

As described above, regarding establishing a containment function (liquid-phase), based on the results of the Project of Decommissioning, Contaminated Water and Treated Water Management (technology for removing soluble nuclides that are considered to have leached from fuel debris into circulating cooling water, technology for treating solids collected by filters of the circulating cooling water system, etc.), construction of a PCV circulating cooling system has been under investigation through TEPCO's engineering. Going forward, based on the monitoring results obtained from trial retrieval and gradual expansion of the retrieval scale, consideration will be given to modifications required for the PCV circulating system while verifying the validity of the containment function to be established in the next phase.

3.1.2.6.1.3 Issues in cooling functions

Fuel debris generates heat due to the decay of radioactive materials. In Unit 2 after a lapse of 11 years or more since the accident, for example, the amount of heat generation has reduced to 1/1000 of the level at the accident. However, the maximum heat generation is still estimated to be several tens kW[48]. Therefore, unless cooling is continued, the surrounding materials gradually absorb the generated heat and there is concern that the following events may occur:

- Oxidation caused by increasing the temperature of the uranium oxide in fuel debris (increased O/U ratio) proceeds resulting in volume expansion, crack generation, and thereby progression of pulverization.
- Moisture in concrete structures is also dissipated and dried by heat, and then cracks occur to decrease the concrete strength.
- The inside of the PCV becomes dry, causing radioactive dust to be easily scattered and sent airborne.
- When water is injected after the PCV becomes dry, the water that contacts fuel debris turns into steam and raises the PCV internal pressure, which leaks from damaged areas with radioactive dust.

In order to prevent the above four events and excessive temperature rise of the fuel debris, the temperature is being maintained below 100°C (cold shutdown state) currently by conducting circulating cooling with water injection into the reactor. 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 m^3/h to 1.7 m^3/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 m^3/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.

[48] Kenji Nishihara et al., "Evaluation of fuel properties at the Fukushima Daiichi Nuclear Power Station", Japan Atomic Energy Agency (JAEA), JAEA-DATA/Code 2012-018(2012).

In the future, when accessing the vicinity of fuel debris during the fuel debris retrieval work, it is necessary to keep the temperature below the level at which the fuel debris retrieval device can continue to work without any problems for a long period of time.

However, the need for cooling water injection should also be considered now, assuming that the amount of decay heat decreases with a reduction in the remaining amount of fuel debris as fuel debris retrieval progresses in the future. The water injection shutdown test described above should be further promoted with the additional objective of identifying the scale (i.e., flow rate, diversity) of such a cooling system.

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.

As temperature monitoring in the PCV is also evaluated by the temperature of devices and water around the fuel debris, the fuel debris temperature is not directly measured. In preparation for reducing the amount of cooling water, a temperature measurement of fuel debris must be made or, if direct measurement is difficult, examining techniques to estimate it from the temperature of the devices and water used for the current assessment. Therefore, examinations are being made through research and development by the Project of Decommissioning, Contaminated Water and Treated Water Management.

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. Criticality assessment of equipment has been performed early, and criticality prevention measures that greatly affect the equipment specifications have been extracted in advance in order to avoid rework at a later stage.

For this criticality control, technical issues to be addressed for the time being are as follows.

(1) Establishment of criticality evaluation methods

Based on the information obtained from each stage of fuel debris retrieval, including internal investigations, evaluation methods have been developed to assess the likelihood of criticality and the degree of influence associated with the criticality of fuel debris. For evaluating these methods, a plan will be made so that information on the parameters with a high impact on the criticality evaluation can be obtained in the course of internal investigation and retrieval work. The information should also be updated as needed and appropriately reviewed by incorporating on-site information from prior operations into the safety assessment at a later stage.

(2) Local neutron measurement around retrieval points

There are various kinds of existing neutron detectors according to the application (fission chamber, B-10 proportional counter tube, semiconductor detector, etc.). Taking advantage of each feature, the selection of neutron detectors for each stage has been considered. The required specifications for the neutron detectors for criticality monitoring are; (1) the ability to survive the accumulated radiation dose (Gy) for the operation period and (2) installability of the assumed equipment, and (3) the guaranteed detection efficiency at the required level (time, accuracy). In the future, the optimal detector will be selected according to the information on PCV radiation dose rates obtained by internal investigations and the progress of the equipment development of each unit.

In addition to subcriticality measurement, a small neutron detector is used as a standalone detector for constant monitoring of local neutron measurement. Toward practical application of constant monitoring during fuel debris retrieval, development of specifications of neutron detectors and approach-to-criticality monitoring technologies has been discussed in the Project of Decommissioning, Contaminated Water and Treated Water Management. In FY 2021, the applicability of neutron detectors to the on-site environment was confirmed through tests[49]. Going forward, it will be necessary to consider detailed operations, including determination criteria on operation suspension/resuming if the fluctuation of the neutron flux is detected and on boron injection as a neutron absorber.

For the possibility of criticality at locations other than the retrieval worksite (i.e., outside the PCV bottom pedestal, in piping, water filters, wastewater receiving tanks, areas where cutting particles of fuel debris has accumulated, etc.), criticality detection by the PCV gas management system is required.

(3) Feasibility study of measuring the degree of subcriticality

When measuring the degree of subcriticality, in addition to the required specifications of (2), a neutron detector with high time resolution and high sensitivity is needed to capture neutron fluctuations in a short time. Considering the equipment mountability (size, weight, electromagnetic noise, etc.) and operation methods (measurement time and duration, installation location, etc.) are key issues due to the necessity of lead shielding in a high γ-ray environment (assuming 1000 Gy/h). In the future, optimization based on the fuel debris retrieval method and system constraints (balance of size, weight, measurement and fabrication time, etc.) and a combination of multiple detectors will be examined.

In addition, in order to verify the applicability to fuel debris, where various mixes of compositions and properties of the fuel debris are expected, it is necessary to assess the technical feasibility, including applicability, by planning and demonstration.

(4) Feasibility study of neutron absorber

For cases where the high possibility of criticality of the fuel debris cannot be denied by the information obtained at each phase of expanding the retrieval scale, the application of a neutron absorber (sodium pentaborate) during normal fuel debris retrieval work is also being considered

[49] IRID, Subsidies for the Project of Decommissioning and Contaminated Water Management, (2) Development of criticality control technologies of fuel debris, “Development of safety system (Liquid-phase system/gas-phase system, criticality control technique)”, Results for FY2021 implementation August 2022. https://irid.or.jp/wp-content/uploads/2022/09/2021011anzensystem.pdf

in TEPCO's engineering. As a result, environmental impact in the event of leakage and compatibility with concrete as structural materials have been evaluated[50].

Impacts on the PCV circulation cooling system and operations to maintain boron concentrations (e.g., impacts on systems and waste during segregation, collection, re-use, and processing) are also under consideration. It is necessary to verify the applicability on-site for the case of sodium pentaborate injection, together with the approach-to-criticality monitoring technologies described in (2) Local neutron measurement around retrieval points.

How to maintain and restore subcriticality in the event of criticality and emergency injection of sodium pentaborate should also be considered.

Non-soluble neutron absorbers are also under development to ensure maintenance of subcriticality when the margin for criticality is small. Non-soluble neutron absorbers have advantages such as a local impact on the PCV circulation cooling system. Methods and effects of spraying according to the fabrication operations have been verified for the candidate materials that underwent fundamental property testing and radiation resistance testing (B_4C metal sintered materials, glass containing B/Gd, Gd_2O_3 particles, and sodium silicate/Gd_2O_3 granulated powder). From FY 2021 onward, technology development is underway to materialize on-site operation methods suitable for fuel debris retrieval work conditions.

To introduce non-soluble neutron absorbers, it is necessary to study the impact on PCV corrosion and environmental impact in the event of an environmental release.

(5) Detection of criticality by PCV gas management system

The sophistication of detectors in the PCV gas management system is required to detect when approaching criticality and criticality in the vicinity of fuel debris retrieval points and to detect criticality due to the fall of fuel debris and/or accumulation of pulverized debris in other locations than retrieval points. In addition to subcriticality measurement, a small neutron detector is used as a standalone detector for constant monitoring of local neutron measurement.

3.1.2.6.1.5 Issues in the structural integrity of PCVs and buildings

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

[50] IRID, supplementary budget in FY 2017, subsidies for the Project of Decommissioning and Contaminated Water Management, Sophistication of retrieval method and system of fuel debris and internal structures (Technology development for establishing criticality control methods), final report, July 2019.http://irid.or.jp/_pdf/20180000_04.pdf

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. The following shows the key functional requirements as examples.

○ Existing equipment and buildings (including modified areas. The impact of aging is also considered as necessary)

- Control deterioration of containment functions of PCV, RPV and reactor buildings, etc., and control/prevent large release of radioactive materials (maintaining containment functions).
- Reactor buildings, etc., safely support equipment/systems to be newly installed in the reactor buildings for fuel debris retrieval in addition to the existing main equipment (maintaining support functions).

○ Equipment/systems and buildings to be newly installed for fuel debris retrieval (including connections to the existing equipment/systems)

- Have functions according to design requirements and control/prevent large release of radioactive materials (ensuring containment functions).
- Safely support equipment/systems to be installed for fuel debris retrieval (ensuring support functions).
- New buildings, etc., provide a safe work environment as required (ensuring shielding performance, etc.).

In FY 2020, TEPCO has formulated a long-term maintenance management plan for existing on-site systems/equipment and buildings in consideration of the progress of time-related deterioration, and started implementation of the plan. When new facts about the accident are revealed through further investigations and other activities, it is also necessary to clarify the impact of the accident, especially damage, by performing severe accident progression analysis evaluations, etc. and to secure functions throughout the decommissioning period in consideration of the progress of time-related deterioration. Moreover, regarding the existing equipment/systems and buildings, lowering of the water level in the PCVs of Units 1 and 3 was confirmed in the earthquakes[51,52] with their epicenter off the coast of Fukushima Prefecture that occurred on February 13, 2021, and March 16, 2022. Although cooling functions were maintained in both cases, in light of both earthquakes, in order to maintain and manage the equipment/systems and buildings

[51] The earthquake off the coast of Fukushima Prefecture, measured maximum upper 6 on the Japanese seismic intensity scale of 7 in Miyagi and Fukushima Prefectures. In Fukushima Daiichi NPS, 2nd basement floor (on the foundation plate) of the Unit 6 reactor building recorded the quake with its maximum acceleration of 235 gal. This is equivalent to the response level of about half of the seismic response analysis results of the buildings against the design basis earthquake ground motion (Ss) (600 gal) before the new seismic design policy determined by the NRA was applied.

[52] The earthquake off the coast of Fukushima Prefecture, measured maximum upper 6 on the Japanese seismic intensity scale of 7 in Miyagi and Fukushima Prefectures. In Fukushima Daiichi NPS, 2nd basement floor (on the foundation plate) of the Unit 6 reactor building recorded the quake with its maximum acceleration of 221gal.

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 and aging degradation risks.

(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.

In the specific designing of new equipment/systems and buildings, it is important to define seismic classes and perform seismic evaluation accordingly. However, it is still challenging to repair and reinforce buildings and main equipment damaged by the accident in a high radiation dose environment. Because of that, earthquake ground motion and design criteria used in the design will be appropriately defined in accordance with the new seismic design policy[53.54] determined by the NRA while considering the perspective of risk assessments. In doing so, although ensuring safety is with no doubt the top priority in the design policy of systems required for individual decommissioning operations, including planned fuel debris retrieval, we believe it is important to establish and implement a framework that allows TEPCO to exchange opinions on the earthquake ground motion to be applied and its interpretations with the NRA before the application while securing the independence of the review.

In addition, in the evaluation of existing systems, even for components that do not directly affect seismic resistance or are ignored in the seismic assessment, if parts or other components damaged by the accident collapse, they may have a significant social impact even if it does not cause structural and radiation safety hazards. To avoid such a situation, it is necessary to monitor the progress of deterioration daily and to implement comprehensive management from the viewpoint of personnel and system safety.

○New seismic design policy determined by the NRA (Reference)

The NRA stated, "Given the fact that the earthquake ground motion of the Great East Japan Earthquake in 2011 exceeded Ss 600, and that of the earthquake on February 13, 2021 exceeded Sd 300, the earthquake ground motion to be used in the future seismic design of 1F should take into account these seismic motions observed"[53], and "...For the time being, it is appropriate to reorganize 'the concept of earthquake ground motion and its application to the seismic design of 1F' based on the earthquake ground motion for review (Ss 900)"[53]. The NRA approved the application of the system based on the existing earthquake ground motion for review[55] (the Ss 900 system). In addition to the conventional seismic classes (Classes S, B, and C), B+ was newly adopted as a seismic class higher than Class B[53].

Based on the above, the following seismic policy[53] applies to newly installed systems.

- The earthquake ground motion for review (Ss 900) shall be established as the new design basis earthquake ground motion at the Fukushima Daiichi NPS (Ss 900).
- 1/2 Ss (maximum acceleration 450 gal (1/2 of Ss 900). Hereinafter referred to as "Sd 450") shall be applied as the new earthquake ground motion (Sd) for elastic design.

Then, the following shall be met, considering the situation at the Fukushima Daiichi NPS:

- When calculating seismic forces, two horizontal directions and a vertical direction shall be appropriately combined.

53 NRA, "The concept of earthquake ground motion and its application in the seismic design of TEPCO Fukushima Daiichi Nuclear Power Station in light of the earthquake on February 13, 2021," Nuclear Regulation Authority (19th meeting), Material 3, July 7, 2021.

54 NRA, "The concept of earthquake ground motion and its application in the seismic design of TEPCO Fukushima Daiichi Nuclear Power Station in light of the earthquake on February 13, 2021 (2nd)," Nuclear Regulation Authority (30th meeting), Material 2, September 8, 2021.

55 TEPCO, "Examination of protection against external events at the Fukushima Daiichi Nuclear Power Station," study group on monitoring and assessment of specified nuclear facilities meeting (27th), Material 2, October 3, 2014

- For Class B+, safety functions shall be maintained against Sd 450 in addition to the earthquake ground motion applicable to Class B.
- In principle, the same concept as above shall apply to already installed systems. However, among the facilities that require additional measures after evaluating the seismic resistance commensurate with the applicable seismic class, measures for early reduction of risk caused by the insufficient seismic resistance shall be separately examined for those that cannot be reinforced within a reasonable range in consideration of the impact on the decommissioning work and the risk of exposure due to the implementation of measures.

Regarding the concept of classification of seismic classes and the application of earthquake ground motion in the seismic design of the Fukushima Daiichi NPS, "In the seismic evaluation of facilities and systems at 1F, earthquake ground motion to be applied shall be established taking into consideration (1) Seismic class (S, B+, B, C), and (2) Impacts on decommissioning activities, consequent impacts on upper classes, service life, design progress, amount of radioactivity of contained liquid, etc., and measures shall be determined as needed."[54] The procedures for establishing earthquake ground motion and determining the necessary measures according to the seismic classes and characteristics of facilities are provided in Attachment[54].

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.

Specifically, it is important to prevent excessive exposure to workers through appropriate radiation protection schemes depending on the working environment and working style. Regarding protection from external radiation exposure, the radiation exposure dose is evaluated considering the radiation sources and the radiation dose rate in the work area. Then, based on the three principles, namely “time, distance, and shielding”, taking measures to reduce radiation exposure to as low as reasonably achievable will be needed.

Therefore, an appropriate combination of exposure reduction measures such as decontamination, shielding, remote technology etc. is to be selected, with the following ideas in mind.

- Priority should be given to reducing radiation exposure through a combination of remote technologies and decontamination. Then, plan on-site radiation exposure management for site workers by the “time, distance and shielding” approach.
- In the extremely high-radiation dose areas such as inside the PCV and torus rooms, work should be pursued by remotely controlled machines, etc. to avoid engaging personnel inside.
- With regard to the inside of the reactor buildings, except for the areas mentioned above, consideration should be given to the optimal combination of decontamination, shielding, removal of unnecessary objects, remote technology, and reduction of working time in order to keep the accumulative radiation dose for the entire project at a low level.
- Where remote technologies are employed, additional work will be required, such as the installation of systems, maintenance and technical troubleshooting, which must be taken into consideration in the above evaluation and planning.
- As for the decontamination tasks, the judgment between remote technologies and personnel employment must be made based on factors such as the radiation dose rate in the target areas, type of contamination, space for work, frequency of use, applicability and development situations of remote technologies, schedule and cost, etc.
- Priority must be placed upon areas where work requirements are clearly identified. Considerations must not be pursued if task requirements are unclear, or in a non-specific “betterment-oriented” manner such as to aim for an overall reduction of radiation dose.

Regarding protection from internal exposure, measures such as suppressing dispersion of radioactive dust and prevention of the spread of contamination are being taken and appropriate protective measures are to be selected depending on the target nuclides, airborne concentration and surface contamination density in the work area, to prevent inhalation ingestion and body contamination leading to internal exposure. In the event of intake, the effective radiation dose should be properly assessed using external counting (lung monitor) and bioassays. For this reason, it is important to select α-nuclides that are important for exposure assessment in advance, and to incorporate them into the control of airborne concentrations, standards for wearing protective equipment, and equipment calibration management. Controlling the surface contamination density in the work environment and the body of workers entering/leaving contaminated areas is also important to early detect the spread of contamination beyond the area division and to prevent an intake of re-suspended dust from loose contamination.

Based on the above, research and development for the protection of intake and radiation dose assessment for inhalation ingestion under the Project of Decommissioning, Contaminated Water and Treated Water Management have been in progress since FY 2021.

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 (50 mSv/year and 100 mSv/5 years) 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 other areas 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 taking into account the gas phase containment function described in 3.1.2.6.1.1.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 of Decommissioning, Contaminated Water and Treated Water Management 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.

Since the fuel debris retrieval policy stipulates that the optimum combination of retrieval methods should be selected depending on the location where fuel debris exists for each reactor Unit, it is important to proceed with research and development toward a planned scale expansion.

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. Since the stage of further expansion of fuel debris retrieval in scale is prolonged, and in order to ensure safe, efficient and continuous retrieval work, it is also important to develop integrated support technologies for decommissioning of the Fukushima Daiichi NPS, such as development of rational maintenance technologies for a wide variety of remote devices and equipment, and system development to continuously monitor environmental changes in the PCV along with work progress. These development activities have been promoted since FY 2021. 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.

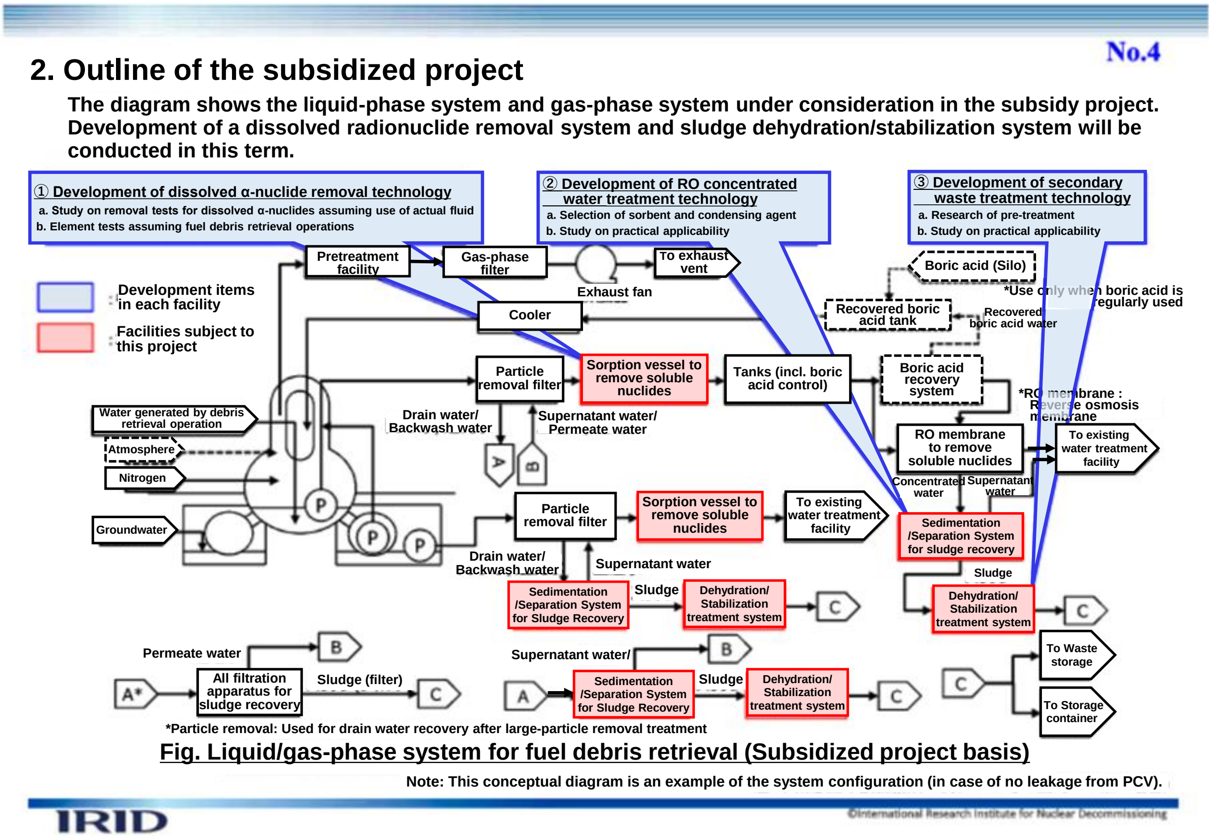
3.1.2.6.2.3 Issues in system installations and working areas

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. Fig. 22 shows an example study in research and development for the liquid-phase system by the Project[56]. In this project, technologies to remove soluble alpha-nuclides and treatment of secondary waste generated by water treatment are under development.

In engineering work by TEPCO, a basic plan for system configuration has been developed in reference to the results of the Project. A case study is also conducted on the feasibility of the system layout (installing devices in the reactor building or installing only some devices in the reactor building if there are restrictions on arrangement) under the reactor building environment (ease of securing equipment installation space, radiation dose in the subject area, etc.). Based on the result of this examination, further investigation will be given on feasibility as a safety system. As described above, in establishing safety systems, steady efforts are required to improve the quality of design by repeatedly adjusting system layout design, and reconsidering device specifications as the situation demands.



(Source : IRID)

Fig. 22 An example of examining the liquid-phase particle (particle collection/removal) in the Project of Decommissioning, Contaminated Water and Treated Water Management

[56] IRID, Subsidies for the Project of Decommissioning and Contaminated Water Management, "Development of safety systems (Liquid-phase system and gas-phase system, Development of criticality control technologies of fuel debris), FY2021 implementation result, August 2022.
https://irid.or.jp/wp-content/uploads/2022/09/2021011anzensystem.pdf

In order to improve the airtightness of the Unit 3 reactor building, constructing covers on the side and upper part of the building is under investigation. In this process, consideration is given to the surrounding environment in addition to securing the space necessary for cover construction. As the radiation dose on the upper floor of the reactor building is currently high, construction of the cover by the remote operation is under discussion. Sufficient verification that simulates the actual condition is required to achieve accurate construction of the cover. However, it is expected that there will be a limit to improvement of airtightness. Therefore, in parallel with the investigation of the structure and workability, the environment around the reactor building should be improved from a comprehensive viewpoint so that workers can be engaged in key operations and airtightness can be enhanced.

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[57],[58].

- 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

[57] IRID, supplementary budget start from FY 2018, "Subsidies for the Project of Decommissioning and Contaminated Water Management (Development of technology for collection, transfer, and storage of fuel debris (Dry technology of fuel debris))," FY 2021 Interim report, August 2022
https://irid.or.jp/wp-content/uploads/2022/08/20220825syunoukansou.pdf

[58] IRID, supplementary budget start from FY 2018, "Subsidies for the Project of Decommissioning and Contaminated Water Management (Development of technology for collection, transfer, and storage of fuel debris (Handling of pulverized fuel debris slurry/sludge))" FY2021 Final report, August 2022
https://irid.or.jp/wp-content/uploads/2022/08/20220825syunousurajji.pdf

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 retrieval scale.

Unit cans and containers in which fuel debris is stored should be handled and maneuvered by a remote device in a safe and reliable manner. Therefore, the assumed mockup operations need to be executed (e.g., handling of unit cans and containers as well as fuel debris sampling for analysis by using actual or similar remote device including a remote device) in the initial stage of detailed design. Moreover, in terms of preventing design change/modification, the approach through the mockup operations, which determines the specifications/sizes of these remote devices and the devices/equipment required for containing, transferring, and storing fuel debris, their layout, and the flow of fuel debris handling, is considered to be useful. In developing the specific installations and systems for handling and storing retrieved fuel debris, it is also necessary to give consideration to the installations to satisfy safeguards requirements (such as monitoring device).

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[59].

- 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 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 their strength by a number of numerical experiments by computer and to 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

[59] IRID, supplementary budget in FY 2018, subsidies for the Project of Decommissioning and Contaminated Water Management, “Technology development for further expansion of fuel debris /in-core structure retrieval,” results for FY 2019, August 2020.
https://irid.or.jp/wp-content/uploads/2020/09/2019008kibonosaranarukakudai.pdf

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.

3.1.2.7 Summary of key technical issues

The main technical issues and plans described in this section are summarized as shown in Fig. 23.

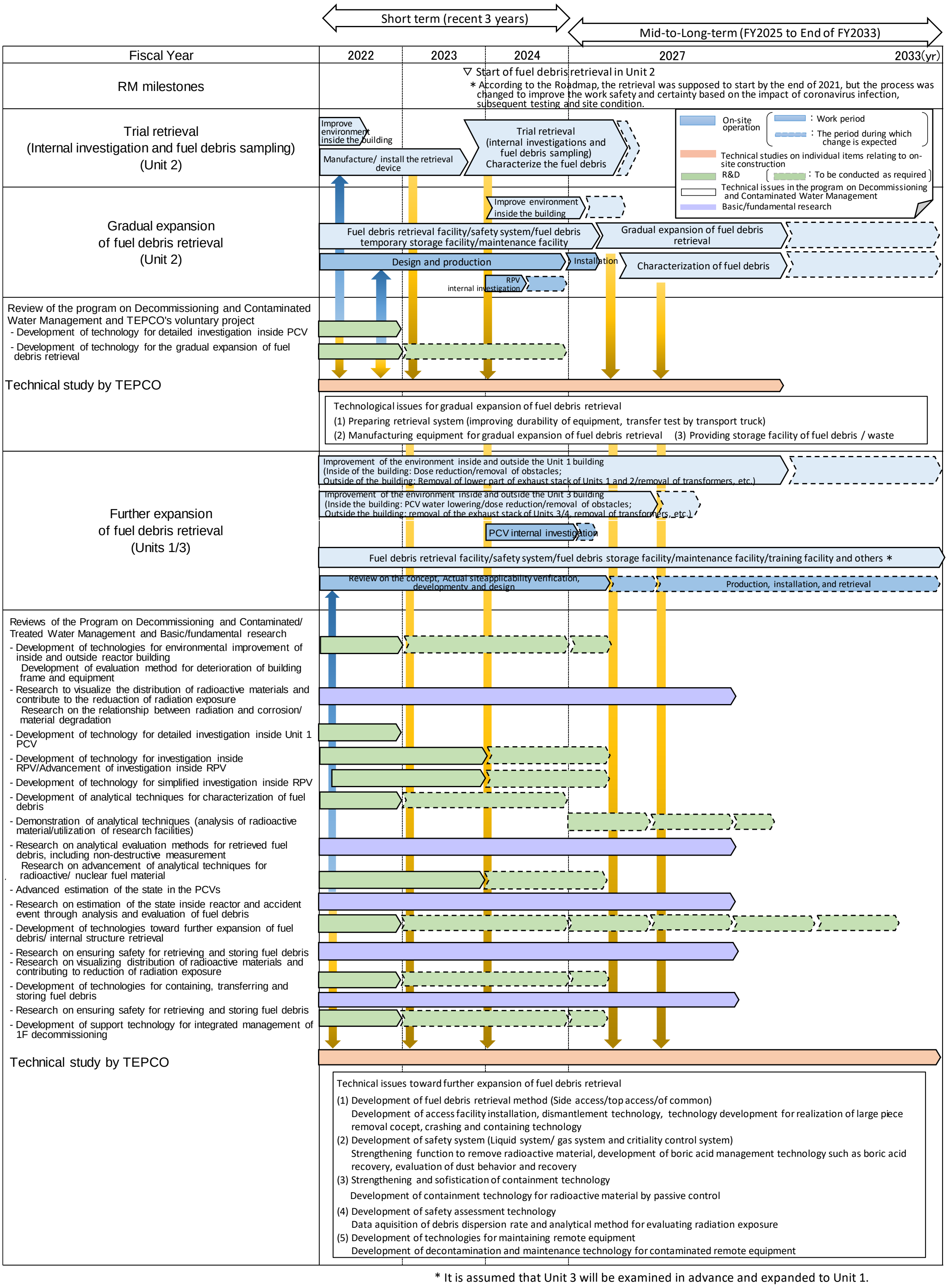


Fig. 23 Key technical issues and future plans on fuel debris retrieval (progress schedule)

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 method 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. Definitions of terms related to radioactive waste management in the IAEA Safety Glossary Terminology are shown in Attachment 8, and classification and disposal of radioactive waste in Japan and abroad are shown in Attachment 9.

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 the IRID. However, in preparation for the deadline for 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

Table 2 shows the current storage/management status for solid waste. To store these solid wastes 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 (Attachment 10).

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. In waste management, it is important to prioritize (1) as much as possible and consider (5) disposal as the last option (Fig. 24), 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/management, 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.

Table 2 Status of solid waste storage/management

(a) Management status of rubble, felled trees, used protective clothing, etc.

(As of July 31, 2022)

Classification	Stored volume (m^3) / Storage capacity (m^3) (Percentage)
Outdoor storage (surface radiation dose rate ≤ 0.1 mSv/h)	237,500 / 266,300 (89%)
Outdoor sheet covered storage (surface radiation dose rate 0.1 - 1 mSv/h)	47,700 / 50,700 (94%)
Soil-covered temporary storage facilities, outdoor container storage (surface radiation dose rate 1 - 30 mSv/h)	16,800 / 17,900 (94%)
Containers* (in solid waste storage building)	28,000/ 39,600 (71%)
Total	330,000 / 374,500 (88%)

Felled trees

Classification	Stored volume (m^3) / Storage capacity (m^3) (Percentage)
Outdoor storage (trunks, roots, branches, leaves)	92,000 / 134,000 (69%)
Temporary storage pool (branches, leaves)	37,300 / 41,600 (90%)
Total	129,300 / 175,600 (74%)

Used protective clothing, etc.

Classification	Stored volume (m^3) / Storage capacity (m^3) (Percentage)
Temporary storage	30,400/ 52,500 (58%)

* Including secondary waste generated by water treatment (e.g. small filter)
Note that the storage volume is rounded to the nearest $100m^3$, so the total and the breakdown may not be consistent.

(b) Management status of temporary storage (As of July 31, 2022)

Classification	Stored volume (m^3) / Storage capacity (m^3) (Percentage)
Outdoor storage	47,900/ 62,600 (77%)

(c) Management status of secondary waste generated by water treatment (As of August 4, 2022)

Sorption vessels, etc.

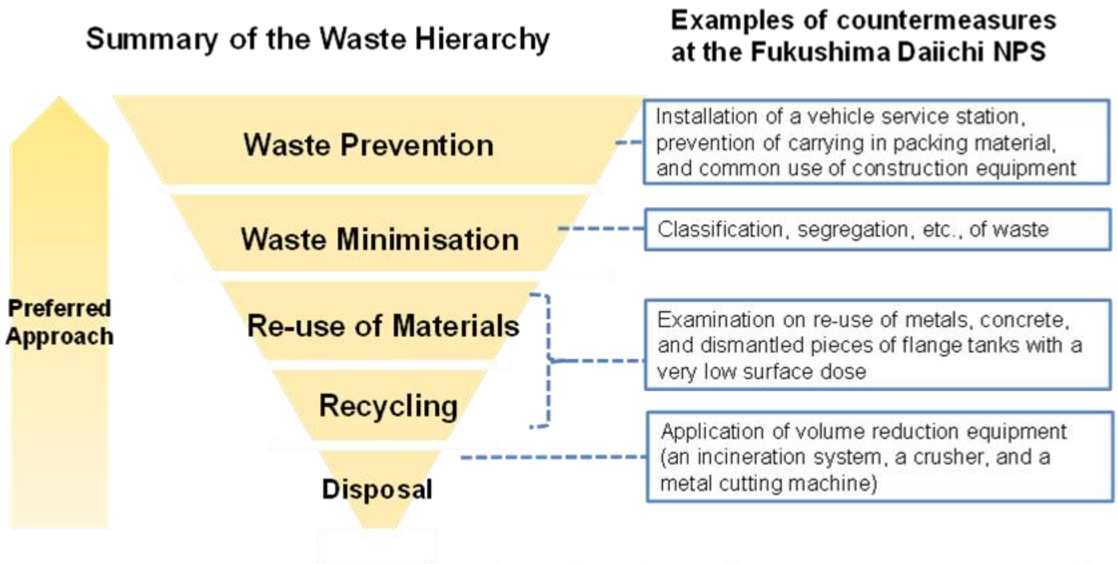
<table>
<tr><th colspan="3">Storage place</th><th colspan="2">Storage volume</th><th>Stored volume/capacity (Percentage)</th></tr>
<tr><td rowspan="8">Outdoor temporary storage area of used sorption vessels</td><td colspan="2">Cesium sorption apparatus</td><td>779</td><td>Number of vessels and filters</td><td rowspan="8">5,402 / 6,372 (85%)</td></tr>
<tr><td colspan="2">2nd Cesium sorption apparatus</td><td>254</td><td>Number of vessels and filters</td></tr>
<tr><td colspan="2">3rd Cesium sorption apparatus</td><td>13</td><td>Number of vessels and filters</td></tr>
<tr><td rowspan="2">HICs from multi-nuclide removal system</td><td>Existing</td><td>1,986</td><td>Number of containers</td></tr>
<tr><td>Expansion</td><td>2,041</td><td>Number of containers</td></tr>
<tr><td>Used vessels from high-performance multi-nuclide removal system</td><td>High performance</td><td>91</td><td>Number of vessels</td></tr>
<tr><td>Used columns from multi-nuclide removal system</td><td>Existing</td><td>17</td><td>Number of Columns</td></tr>
<tr><td colspan="2">Used vessels and filters from mobile type strontium system</td><td>221</td><td>Number of vessels</td></tr>
</table>

Waste sludge

Storage place	Stored volume (m^3) / storage capacity (m^3) (Percentage)
Sludge storage facility (indoor)	442 / 700 (63%)

Concentrated liquid waste

Storage method	Stored volume (m^3) / storage capacity (m^3) (Percentage)
Concentrated liquid waste storage tanks (outdoor)	9,380 / 10,300 (91%)



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

Fig. 24 Summary of waste hierarchy at the NDA, 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 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 waste, which review of the waste stream is progressed. Development of a storyboard[60] 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 Key issues and technical strategies to realize them

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 and 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.

To facilitate these efforts toward continued actions through an R&D organization with a high level of technology and human resources, it is essential for stakeholders to make constant efforts to develop human resources and improve technological capabilities in the area of waste and make efficient use of resources by strengthening collaboration within this area and making mutual use of the results of such efforts. It is also necessary to consider environmental arrangement that enables the maintenance and strengthening of the supply chain, including the elemental technologies necessary for each stage of waste management and peripheral technologies that are supporting them.

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 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

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

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 methods that combines the DQO process[61] 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 combine 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 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

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

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 (5,000 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 the 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. 25.

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 the characteristics of waste, changes in environmental conditions in and around disposal facilities into those 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.

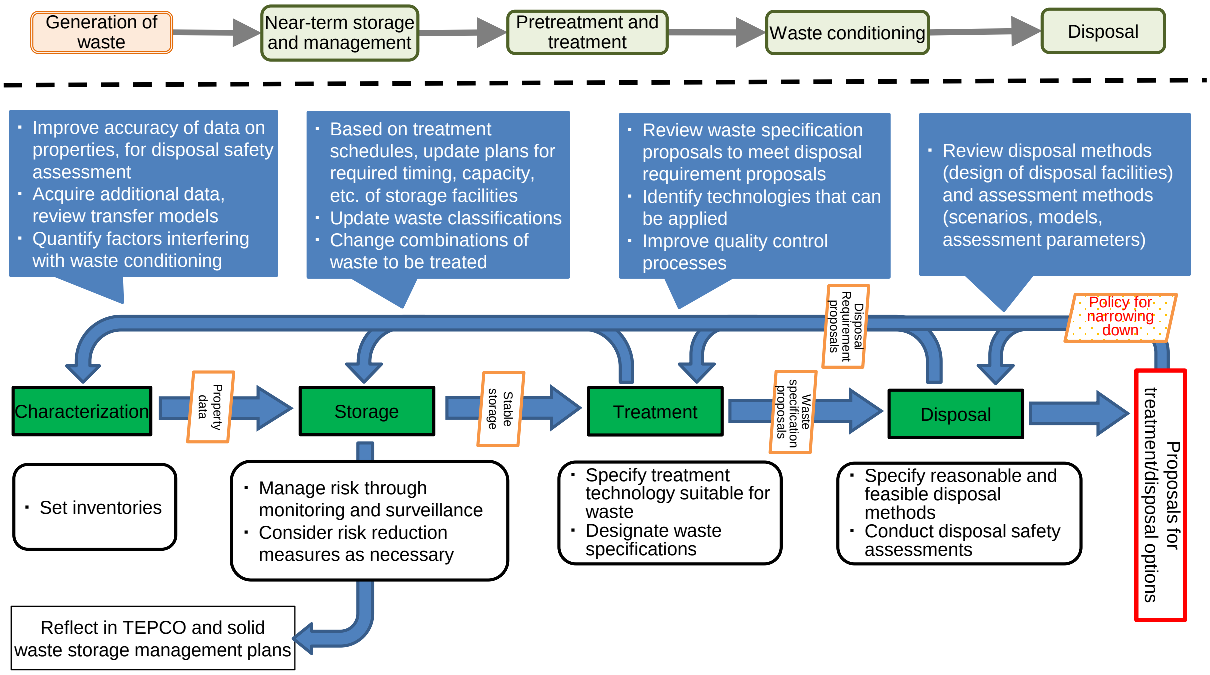


Fig. 25 Procedure to reasonably select safe processing/disposal methods of solid waste

3.2.2.4 Summary of key technical issues

The main technical issues and plans described in this section are summarized as shown in Fig. 26.

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, in Phase 3-[1], the study will be initiated to present appropriate overall measures for specific management approaches for solid waste. Specifically, based on the realistic inventory setting that incorporates property data evaluated by accumulating analysis data and applying statistical methods, the trial examples of optimization/rationalization of processing/disposal methods will be accumulated by waste stream under the assumption of ensuring safety to widely acquire findings on optimization by waste stream. Moreover, consideration will be given to specify strategies for optimization/rationalization of the overall picture covering the entire waste stream, allowing clarification of approaches toward such purposes.

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.

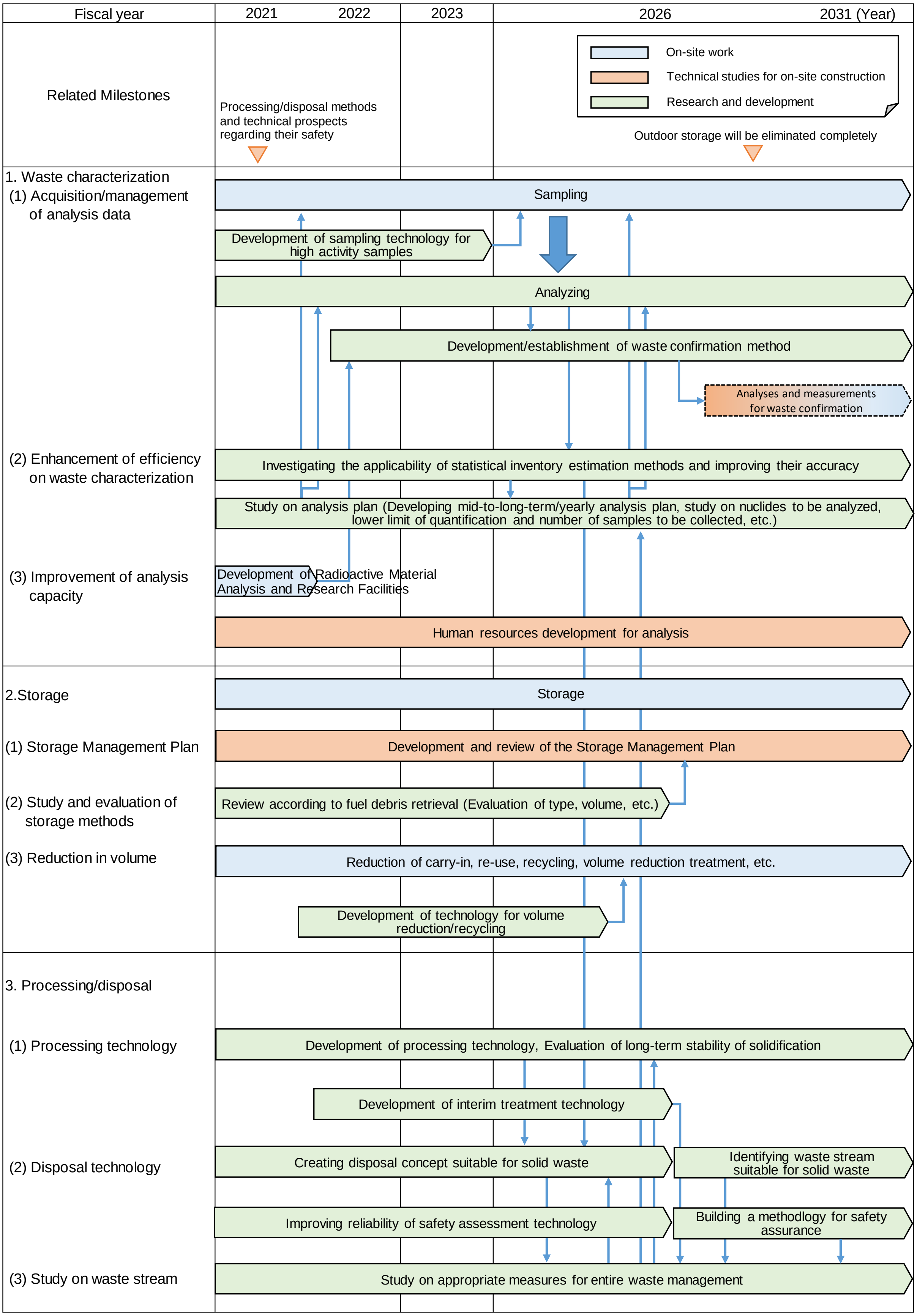


Fig. 26 Key technical issues and future plans on waste management (progress schedule)

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.

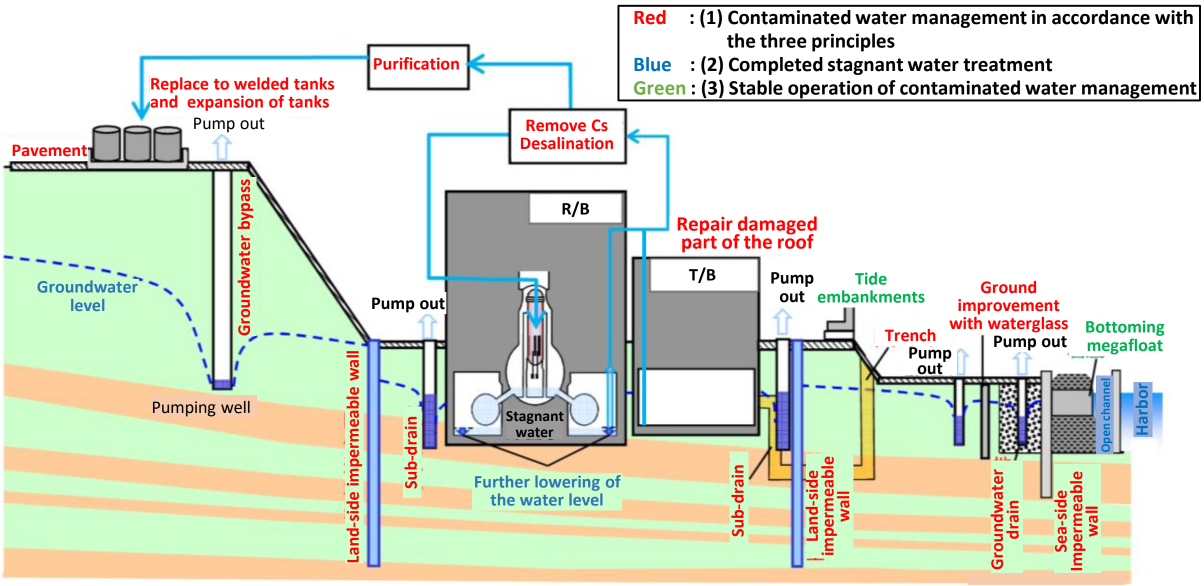
(2) To arrange the relationship with a decommissioning process including full-scale fuel debris retrieval beginning in the near future, and to promote examination of the measures of the contaminated water management for medium-and-long term prospects.

(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)

Fig. 27 shows the outline of the contaminated water management. 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 (refer to Section 2.2), 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:



(Source : TEPCO)

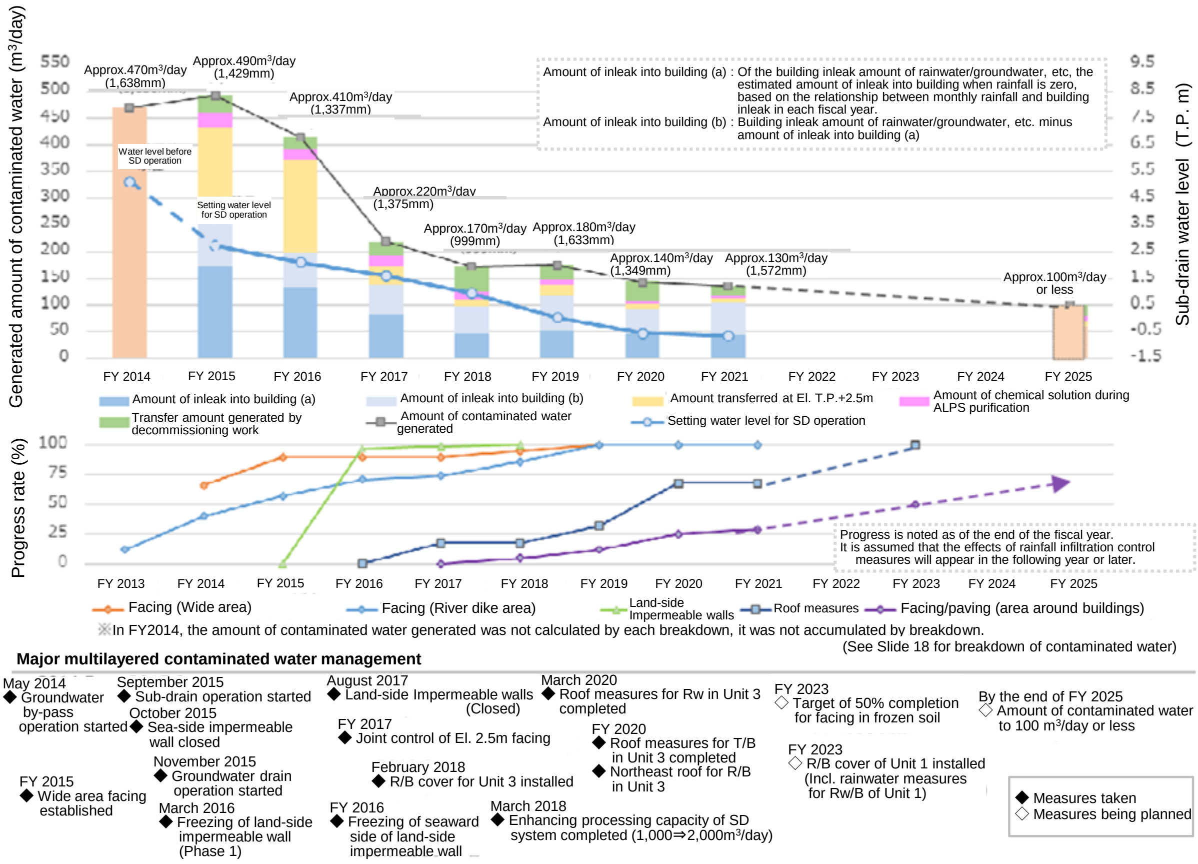
Fig. 27 Outline of contaminated water management [62]

(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. Fig. 28 shows the progress of contaminated water management and changes in the amount of contaminated water generated.[63]

[62] Secretariat Meeting of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water Treatment (100th), Material 2, “Outline of decommissioning, contaminated water and treated water”, March 31, 2022

[63] Committee on Countermeasures for Contaminated Water Treatment (24th meeting), Material 1, “Status of contaminated water management at the Fukushima Daiichi NPS”, June 15, 2022



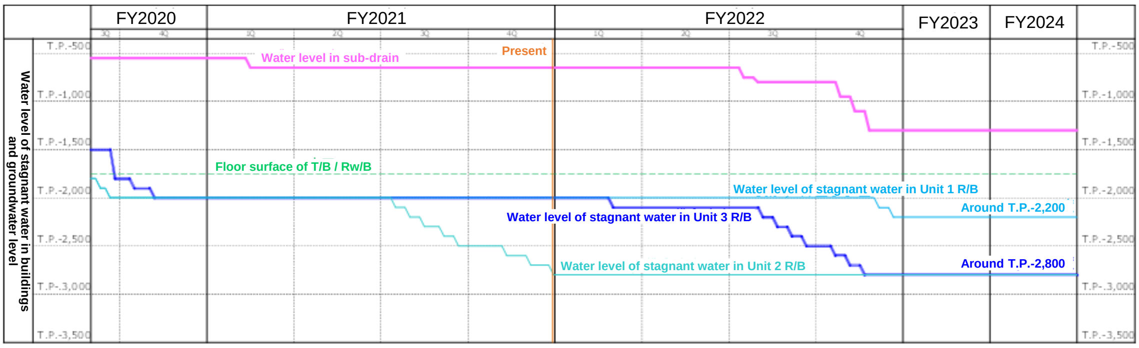
(Source : TEPCO)

Fig. 28 Progress of contaminated water management and changes in the amount of contaminated water generated

(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, moreover, the water level in 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 [64](Fig. 29).

[64] Meeting of the Secretariat of the Team for Decommissioning and Contaminated Water/Treated Water Management (100th), Material 3, “Progress status of treatment of stagnant water in buildings,” March 31, 2022



(Source : TEPCO)

Fig. 29 Lowering of sub-drain and building water levels[64]

The plan is 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 at the bottom of the reactor building (hereinafter referred to as “α-sludge”) 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.

Although the importance of multilayered measures such as land-side impermeable walls has not changed, damages to systems such as brine leakage have occurred. Considering that, in the future, it is important to strengthen monitoring, procures, and arrange spare parts and substitutes, and establish a framework for taking restoration measures as soon as possible. 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). Displacement exceeding the manufacturer’s recommended value[65] was observed in

[65] 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.

some connecting pipes. However, since the coupling valve is fully closed, there would be no leakage of water stored in tanks, even in the case of pipe rupture.

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

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 sea from the Fukushima Daiichi NPS after comprehensive discussions at expert meetings for more than six years.[66,67] 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 sea in about two years[68].

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[69], 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.

Table 3 shows major initiatives toward discharge of ALPS-treated water into the sea after the basic policy was announced. 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 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.

66 Tritiated Water Taskforce Report, June 3, 2016

67 Report by the subcommittee dealing with water treated with multi-nuclide removal equipment, February 10, 2020

68 Inter-Ministerial Council for Contaminated Water, Treated Water and Decommissioning Issues (5th meeting), Material 1, “Basic policy for disposing of treated water by multi-nuclide removal equipment at the TEPCO Fukushima Daiichi Nuclear Power Station (draft),” April 13, 2021

69 TEPCO: Attachment 1, “TEPCO Holdings’ Action in Response to the Government’s Policy on the Handling of ALPS Treated Water from the Fukushima Daiichi Nuclear Power Station,” press release, April 16, 2021

Table 3. Major initiatives for discharging ALPS-treated water into the sea

Schedule	FY 2021	FY 2022	First half of FY 2023
Government	▼Released "The Basic Policy on Disposal of ALPS-treated Water" The Cabinet Meeting for the Steady Implementation of the Basic Policy on Disposal of ALPS-treated Water ▼1st ▼2nd ▼3rd ▼Established the task force on monitoring and measuring the marine environment ▼Established the Expert Meeting for Marine Monitoring ▼Signed the Terms of Reference with IAEA (TOR) ▼Conducted third-party analyses for ALPS-treated water before the discharge	▼Started marine monitoring	
TEPCO	▼Released " TEPCO Holdings' Action in Response to the Government's Policy" ▼Announced "The status of the facilities study for ensuring safety" ▼Published "The Radiological Impact Assessment Regarding the Discharge of ALPS-Treated Water into the ocean (Design stage)" ▼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"	Installs facility, etc.	Pre-operation inspection ▽Will begin to discharge into the ocean
NRA	▼1st Review Meeting ▼2nd Review Meeting Review Meetings (3rd to 15th)	Public comments ▼ Approved	
IAEA	▼Signed the TOR with the Japanese government ▼Conducted a safety review on the handling of ALPS-treated water ▼Conducted a review of the regulations of ALPS-treated water	▼Published review results reports ▼Published review results reports	

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 sea 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 facilities for offshore discharge of ALPS-treated water, their operation methods, and safety during discharge into the sea, 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 Terms of Reference with the government. The IAEA published review results reports in April 2022 and June 2022, respectively.

The discharge of liquid waste generated in nuclear facilities into the sea, 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 sea. 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 sea 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 sea 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 NRA. Based on the selection results of the nuclides to be assessed, the radiation environmental impact will be verified.

・ Verify safety by experts from IAEA and other agencies

=> In February 2022, the IAEA conducted a safety review on the handling of ALPS-treated water, confirmed and announced in a report[70] 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. The next review mission is scheduled in November 2022, and a comprehensive report with final conclusions and findings will be published before the discharge of ALPS-treated water begins.

The IAEA also reviewed the NRA in March 2022 and announced that the NRA is functioning as an independent regulatory agency and is fulfilling its responsibility to develop an appropriate regulatory framework and evaluate safety[71].

The IAEA also plans to conduct analyses of ALPS-treated water at a laboratory of IAEA and research institutions in a third country as third-party analyses. In addition to its

[70] IAEA review of safety related aspects of handling ALPS-treated water at TEPCO’s Fukushima Daiichi Nuclear Power Station, Report 1: Review mission to TEPCO and METI (February 2022), April 29, 2022

[71] IAEA review of safety related aspects of handling ALPS-treated water at TEPCO’s Fukushima Daiichi Nuclear Power Station, Report 2: Review mission to NRA (March 2022), June 16, 2022

independent analysis, TEPCO plans to outsource analysis to external organizations with ISO/IEC 17025 certifications[72]. The Japanese government also intends to have the Japan Atomic Energy Agency (JAEA) conduct third-party analyses before the discharge. The results of these analyses will be disseminated domestically and internationally with high transparency.

- 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 sea 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

[72] International standards developed by the International Organization for Standardization for general requirements on the competence of testing and calibration laboratories.

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[73]. 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[73].

- 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[74]. 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[73].

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[75].

---

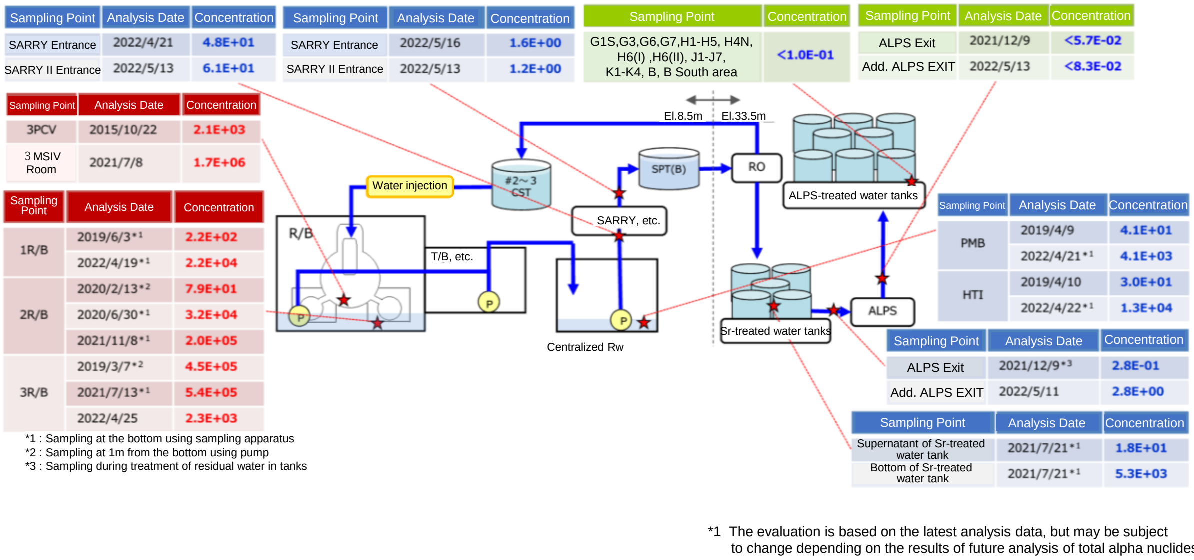
[73] Committee on Countermeasures for Contaminated Water Treatment (24th meeting), Material 1, “Status of contaminated water management at the Fukushima Daiichi NPS, References,” June 15, 2022

[74] Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment (91st), contaminated water management, Material 3-1-8, “Drilling holes on the first floor of the Unit 3 reactor building”, June 24, 2021

[75] Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment (94th), contaminated water management, Material 3-1-9, “Policy to respond to α-nuclide detected in remaining water in the Area E (flanged) tank,” September 30, 2021

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[76].



(Source : TEPCO)

Fig 30 Water treatment systems for stagnant water in buildings and measurement results of total α-nuclides[73]

(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

[76] From the viewpoint of removing α-nuclides, the filter system should be installed in the front stage of the cesium sorption apparatus. However, in this case, the filter will capture particulate radioactive cesium, resulting in a high radiation dose to the filter system and making replacement work difficult. Therefore, the filter system will be installed in the rear stage of the cesium sorption apparatus.

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[77].

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 recovery procedure of zeolite sandbags under consideration is shown in Fig. 31. The procedure 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[77]. 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.

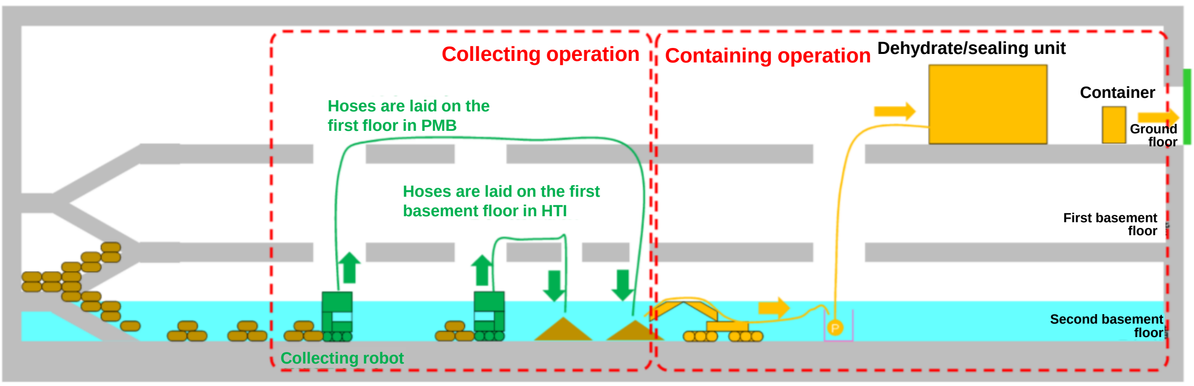
However, the basement floors of the process main building and the high-temperature incinerator building have been used as storage tanks for tens of thousands of cubic meters worth of stagnant water in buildings, where water with different chemical properties and radioactivity transferred from

[77] Committee on Countermeasures for Contaminated Water Treatment (24th meeting), Material 2, “Issues and countermeasures concerning contaminated water management at the Fukushima Daiichi NPS,” June 15, 2022

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[78].

- 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 inleak 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 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.



(Source : TEPCO)

Fig. 31 Zeolite sandbag recovery procedure [77]

[78] Committee on Countermeasures for Contaminated Water Treatment (24th meeting), Material 2, “Issues and countermeasures concerning contaminated water management at the Fukushima Daiichi NPS, References,” June 15, 2022

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.

In addition, although the current contaminated water management is shifting to a certain level of a stable state, it is difficult to immediately implement drastic water sealing against groundwater inleak in the entire building. As a medium-to-long-term issue, it is necessary to conduct a broad and comprehensive study on the most appropriate measures to further reduce the amount of inleak into the building, in coordination with the future decommissioning work and by comparing the current measures with those to be taken. In addition to measures to prevent rainwater inleak using facing around Units 1 to 4, TEPCO is considering water sealing (e.g., filling and ground improvement) at building penetrations (e.g., pipe) and gap ends between buildings in Unit 3 as local water sealing. It is important to accumulate knowledge obtained through a series of on-site applications of water sealing measures in order to consider drastic water sealing in the future while clarifying issues and studying countermeasures through construction tests and field tests.

However, 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. Partial submersion and submersion methods exemplified in 3.1 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 sea

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 sea. 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. 32, and the future plans for the water treatment system for fuel debris retrieval are shown in Fig.23.

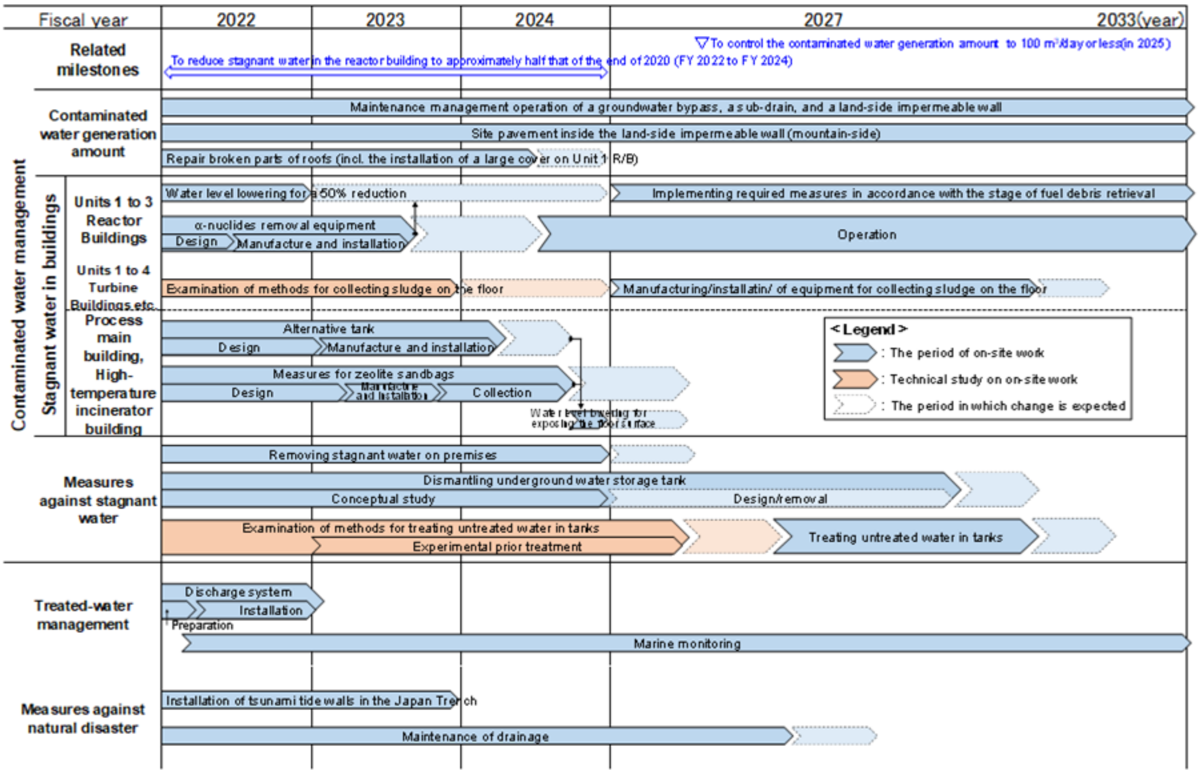


Fig. 32 Key technical issues and future plans on contaminated water/treated water management and natural disaster preparedness (progress schedule)

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.

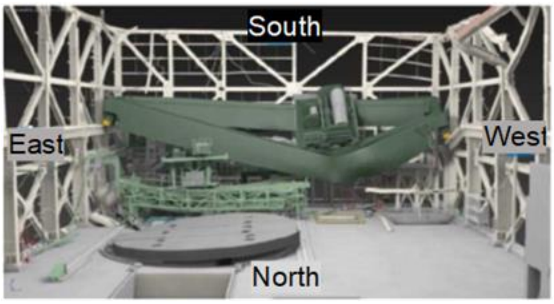
(4) To perform the evaluation of long-term integrity and the examination for treatment for the retrieved fuel and to decide the future treatment and storage method.

(Progress)

TEPCO is working on the work plan indicated in the Mid-and-Long-term Roadmap and the Mid-and-Long-term Decommissioning Action Plan.

In Unit 1, due to the hydrogen explosion, roof stabs, building materials, such as steel frames, which constituted the upper part of the building, an overhead crane, etc., have collapsed as rubble on the operating floor as shown in Fig. 33. While the residents were returning, from the perspective of further reduction of radioactive dust dispersion risk, the whole operating floor was covered with a large cover for fuel removal in Unit 1 SFP. In December 2019, the removal method was changed to one in which rubble removal and fuel removal from SFP are carried out inside the cover. Fig. 34 shows a conceptual drawing of this method.

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.

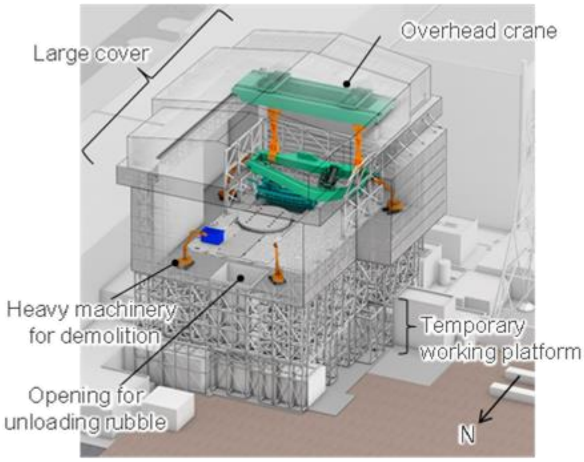


Condition of the existing installations under the collapsed roof (conceptual drawing)

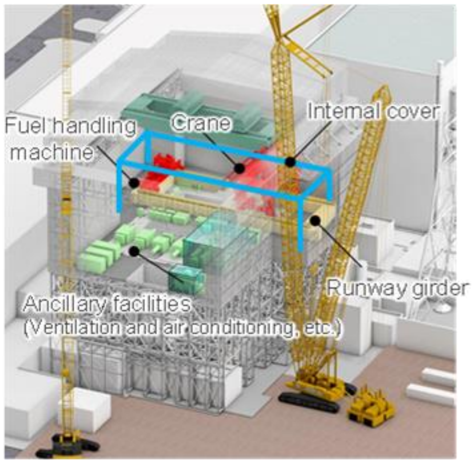
Condition of the collapsed south-side roof

(TEPCO material edited by NDF)

Fig. 33 State of the collapsed rubble on the Unit 1 operating floor



During rubble removal (Conceptual drawing)



During fuel removal (Conceptual drawing)

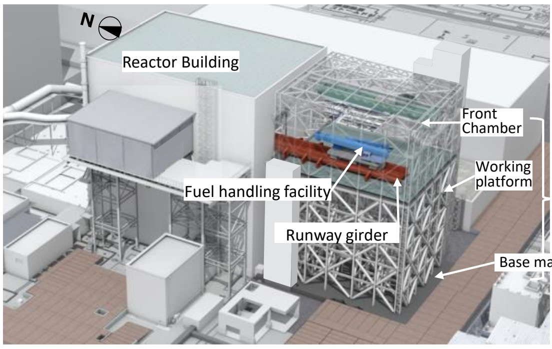
(TEPCO material edited by NDF)

Fig. 34 Fuel removal method from Unit 1 SFP

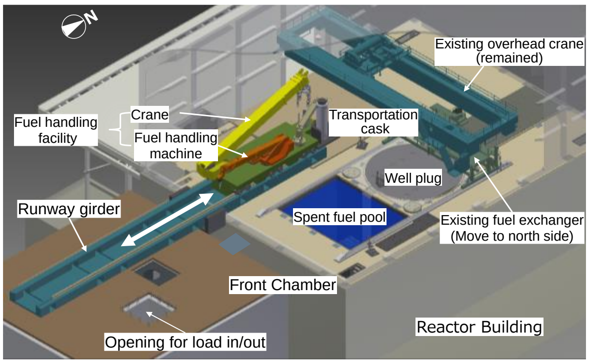
For Unit 2, a method in which the upper part of the operating floor will not be dismantled and with access from the working platform for fuel removal to be installed on the south side of the reactor building was adopted from the perspective of further reduction of radioactive dust dispersion risk similar to Unit 1. Fig. 35 shows a conceptual drawing of this method.

In associated with the changes in the implementation plan for the fuel handling system, etc., applied in December 2020, TEPCO submitted the amended application in March 2022, dividing the application into two parts: a working platform for fuel removal and a fuel handling system, based on the status of the review for the application of the new seismic design policy, etc., and the progress of the preparation work. Among those, the working platform for fuel removal was approved in April 2022. Ground improvement was completed in April 2022, and installation of the base mat for the 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.



Fuel removal method (conceptual drawing)



Fuel handling facility (conceptual drawing)

(TEPCO material edited by NDF)

Fig. 35 Fuel removal method from Unit 2 SFP

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 has commenced in August 2022.

Fig. 36 shows the available capacity of the Common Spent Fuel Storage Pool and Dry Cask Temporary Custody Facility. 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. Regarding the transfer of new fuel off-site, the plan is to start transferring new fuel from Unit 6 after FY 2022, and cleaning of new fuel in Unit 4 was completed in March 2022. Such efforts will be made to complete fuel removal in all units in 2031. Further, the earthquake off the coast of Fukushima Prefecture on March 16, 2022, disturbed the overhead crane operation in the cask carry-in area on the first floor of the Common Spent Fuel Storage Pool. Therefore, the transfer from the Common Spent Fuel Storage Pool to the Dry Cask Temporary Custody Facility scheduled for March 2022 was started in August 2022 after the crane was restored.

Fuel removal from Unit 3 was all completed in February 2021, but other high-radiation dose equipment such as control rods, channel boxes, and filters are also stored in the SFP. Although cooling is not necessary for them, shielding is required, and risk remains that the source in the pool will be exposed if the pool water leaks. Therefore, in terms of risk reduction, removal of such high-radiation dose equipment is needed following the fuel in SFP. In this case, it is efficient to utilize the device used for fuel removal and rubble removal. Therefore, as soon as preparations for removal are completed, including securing storage facility (Existing site banker is planned for Unit 3), removal work should be implemented immediately. Thereafter, pool water can be excluded from management by draining the pool. Prior to draining the pool, however, the radiation dose and dust dispersion from the pool after drainage should be evaluated to confirm safety. This leads to smooth fuel debris retrieval in the later stages because of the increased flexibility of use of the operating floor, etc.

As with Unit 3, for Units 1, 2 and 4, high radiation dose equipment is stored in each SFP. Giving priority to fuel removal from SFP (removal is completed in Unit 4), fuel removal and drainage of the pool should be performed in a planned manner. In designing fuel handling facility, it is necessary to consider not only the fuel in SFP but also the plan and process for removing the high-radiation dose equipment.

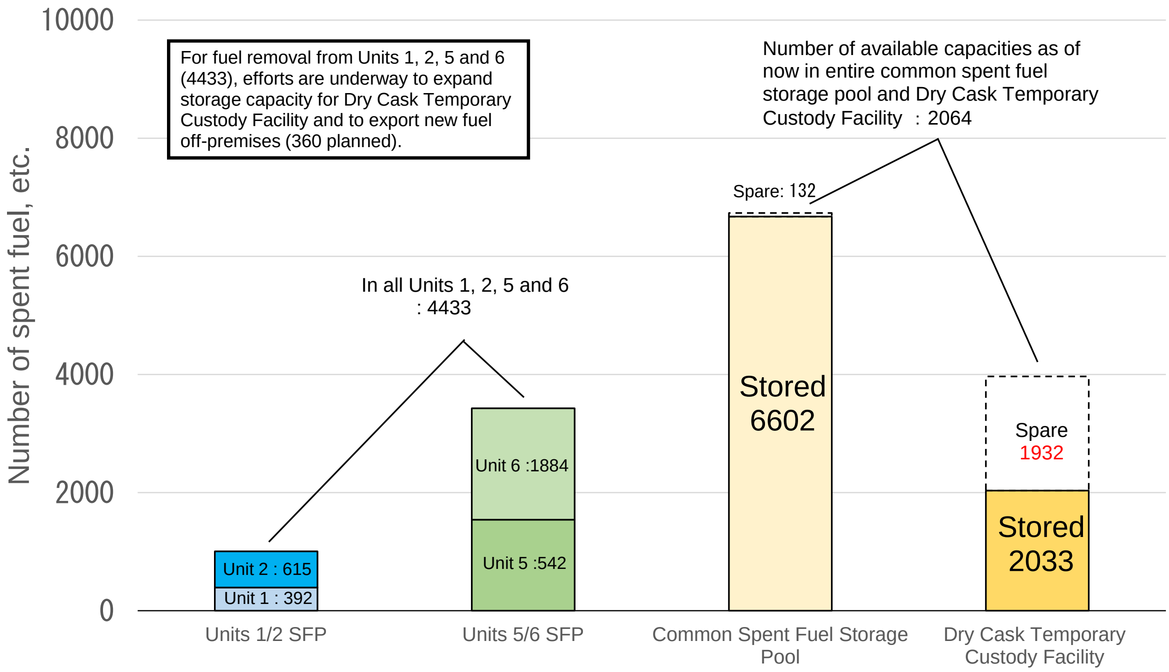


Fig. 36 Storage status of spent fuel (As of May 2022)

3.4.2 Key issues and technical strategies to realize them

3.4.2.1 Fuel removal from SFPs

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

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.

(1) Unit 1

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. Therefore, in ongoing examination of how to remove the overhead crane, it is necessary to perform all safety assessments as an assumption, and it is important to carry out a comprehensive examination based on the perspectives of (i) formulating specific work procedures and work plans enabling identification of risk items, (ii) the risk scenario assumed from (i) and the measures, (iii) identification of points to consider such as exposure of workers, from an operator's perspective, and (iv) rationality and impact on other work.[79] 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.

Regarding the contamination state of the well-plugs of Unit 1 to 3, the Study Committee on Accident Analysis of the Fukushima Daiichi NPS pointed out that the well- plugs have important implications in safety and decommissioning work due to the high level of their contamination[80]. Although the well-plugs of Unit 1 has been evaluated by the above mentioned Study Committee 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. It is necessary to make a comprehensive decision on how to handle these well-plugs based on the study results and by taking into consideration the impact on fuel removal from SFPs and fuel debris retrieval in the later stage and 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

[79] NDF, "Evaluation on the selection of fuel removal methods (plan) at the Fukushima Daiichi Nuclear Power Station Unit 1", Secretariat Meeting of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water (73rd), Material 3-2, December 19, 2019.

[80] NRA, "Draft revision of the interim report (draft) based on the results of public comments", The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station (19th meeting), Material 3 (pages 81 to 83), March 5, 2021

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.

(2) Unit 2

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.[81]

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, it is important to reduce the dose on the operating floor as much as possible and improve the environment in light of the fact that attended operation is also assumed partially for system installation or troubleshooting, and the study group meeting mentioned above pointed out[80] highly contaminated well-plugs. 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.

It is planned to transfer fuel in SFPs of all Units to the Common Spent Fuel Storage Pool by the end of 2031. Considering tsunami risk, however, it is recommended to transfer to higher ground, TEPCO is considering fuel storage on higher ground. In the case of storage on higher ground, it is recommended that dry storage is used, in which natural convection (ventilation) of the air is used for cooling, and system and maintenance/ management can be simplified. However, consideration

[81] NDF, "Evaluation on the selection of fuel removal methods (plan) at the Fukushima Daiichi Nuclear Power Station Unit 2," Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment (71st), Material 3-2, October 31, 2019

should be given in reference to overseas findings, including handling of fuel with damaged cladding tubes. It is necessary to prepare this storage facility from the perspective of safety and operator.

3.4.2.3 Summary of key technical issues

The main technical issues and plans described in this section are summarized as shown in Fig. 37.

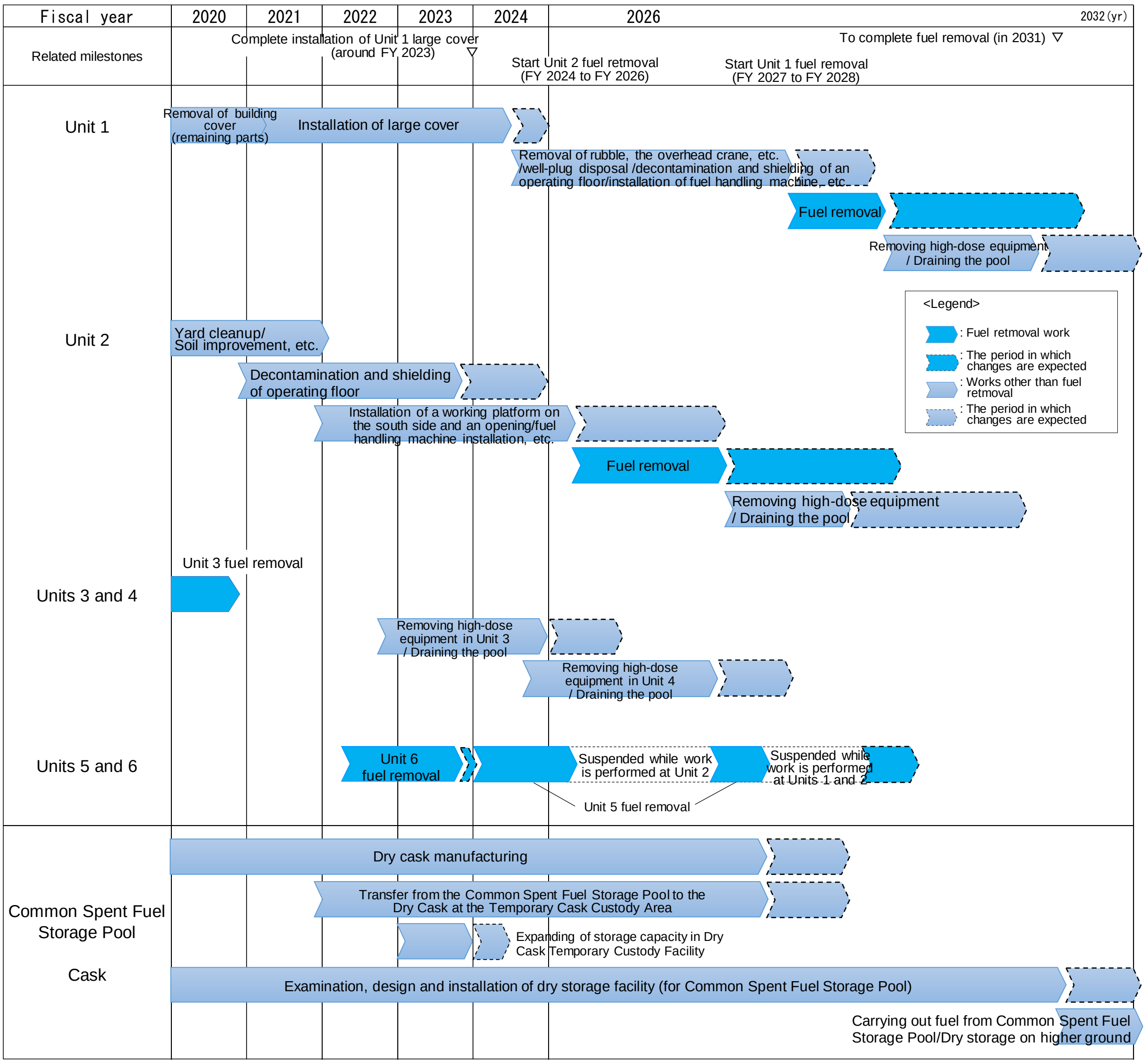


Fig. 37 Key technical issues and future plans for fuel removal from SFPs (Progress schedule)

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. Since there is uncertainty in the formation process of fuel debris and it is not under human control, it is considered that fuel debris would have heterogeneity in various physical properties such as chemical composition, microstructure, and density.

In cases where the uranium content is unknown, it is assumed to use the 97 to 98% uranium content of the fuel assembly before the accident to conservatively study safety assessment and safety measures for criticality control and off-site transport. According to the calculation results of the severe accident codes and the videos and photos of PCV internal investigations, it is highly likely that the uranium content decreases by melting and mixing with the surrounding structural materials. However, since there is no value to be used for the evaluation, an excessive margin is included in the safety measures. If the range of such uncertainty is reduced, there will be no need to include excessive margins in handling fuel debris, safety assessments, and safety measures. Thus, the promptness and rationality of decommissioning will be improved.

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, necessity of treatment, investigation to clarify the accident cause, and improvement of nuclear safety. As shown in Fig. 38, 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.

It has been reported that fuel debris at the Chernobyl NPP in Ukraine became powdered due to changes over time, making it a source of radioactive dust[82,83]. In contrast, fuel debris at the TMI-2 has not undergone significant changes over time, even 40 years after the accident. What causes aging in fuel debris over time is not clearly known. It is also unknown whether or not aging will also happen to fuel debris at the Fukushima Daiichi NPS. Therefore, the Project of Decommissioning,

[82] National Report of Ukraine, Ministry of Ukraine of Emergencies, "Twenty-five Years after Chernobyl Accident: Safety for the Future" (2011)

[83] B. Burakov, V. G. Khlopin Radium Institute, the 2nd International Forum on the Decommissioning of the Fukushima Daiichi NPS (2017)

Contaminated Water and Treated Water Management and the Nuclear Energy Science & Technology and Human Resource Development Project are studying aging in fuel debris and its stability evaluation[84,85,86,87], respectively. The occurrence of aging is considered to depend on the chemical stability of the fuel debris. If the chemical stability is low, it is assumed that the chemical form of the fuel debris gradually changes over time, resulting in volume changes, cracking, and leaching into the water. Therefore, in the process after retrieval, it is assumed that measures against the spread of contamination due to power generation and leaching into the water and the increase in the risk of internal and external exposure will become more important. The results of the sample analysis need to be compared with the findings obtained from the above studies, and it is necessary to confirm whether or not aging has occurred and to know the extent of aging which would be occurred. While accumulating them to reduce uncertainty in the properties of fuel debris, it is important to provide feedback to examination on the future retrieval methods and appropriate measures for storage. In addition to conventional sample analyses, studies on reducing uncertainty of fuel debris properties by other measurement methods have already started since FY 2020 in the Project of Decommissioning, Contaminated Water and Treated Water Management.

[84] TENEX and ROSATOM, "Development of Analysis and Estimation Technology for Characterization of Fuel Debris (Development of Estimation Technology of Aging Properties of Fuel Debris)", Final report for FY 2019 and 2020 (2021)

[85] Toshiba Energy Systems Corporation, Subsidy for the Government-led R&D program on Decommissioning and Contaminated Water Management “Development of analysis and estimation technology for characterization of fuel debris (developing estimation technology for aging characteristics of fuel debris)”, FY 2020 Final Report (2021)

[86] Akira Kirishima, “Fundamental research for stability evaluation of fuel debris, including alloy phase”, FY 2021 results report, meeting materials for the project to promote development of nuclear science, technology and human resources gathering wisdom and intelligence (2022).

[87] IMRAM of Tohoku University, JAEA and Kyoto University, ”Solid-solution phase determines “afterwards” of fuel debris – New chemical insights into the safe storage and processing/disposal of nuclear fuel debris”, June 13, 2022

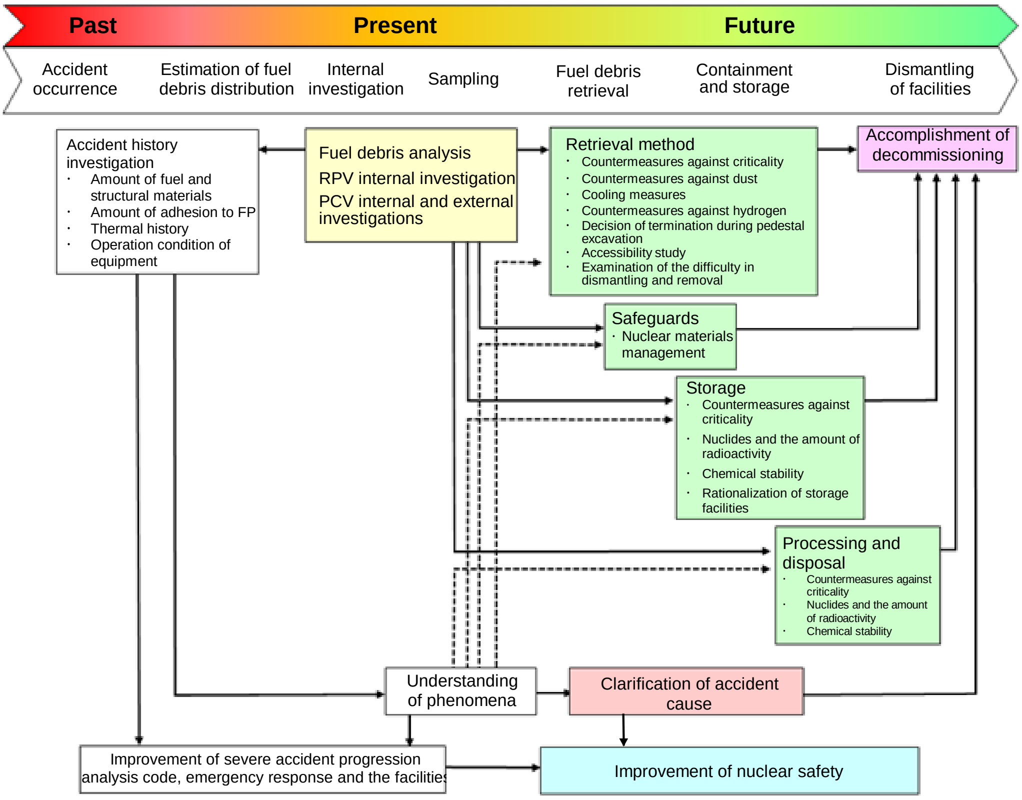


Fig. 38 Incorporation of analyses and investigation results, and their relationships

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, as shown in Fig. 39.

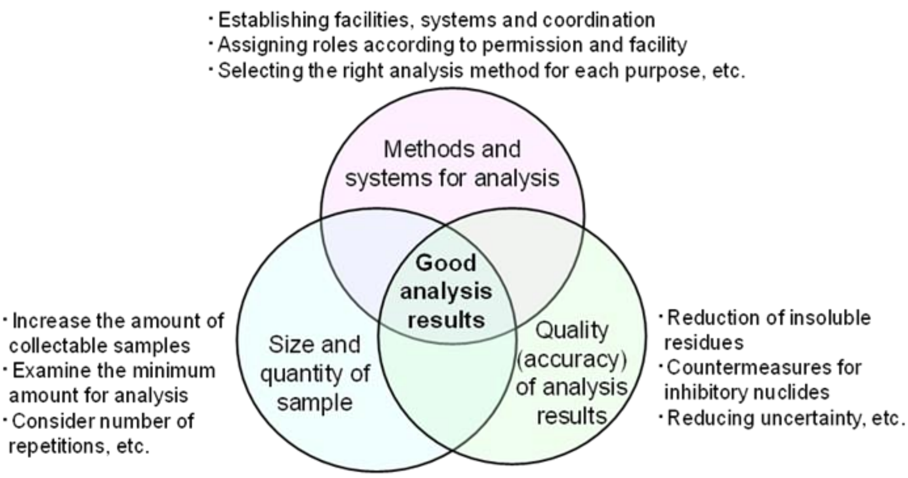


Fig. 39 Three elements of the fuel debris analysis strategy

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[88] under the supplementary budget of the Government (FY2012)[89]. 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 [90], 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[91,92], 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[93]. 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.40, 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

---

88 The 52nd Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment, “Material 3-4: Opening of the Okuma Analysis and Research Center facility management building”

89 The 24th meeting of the study group on monitoring and assessment of specified nuclear facilities, “Material 3-1: Development of R&D hub facilities for decommissioning”

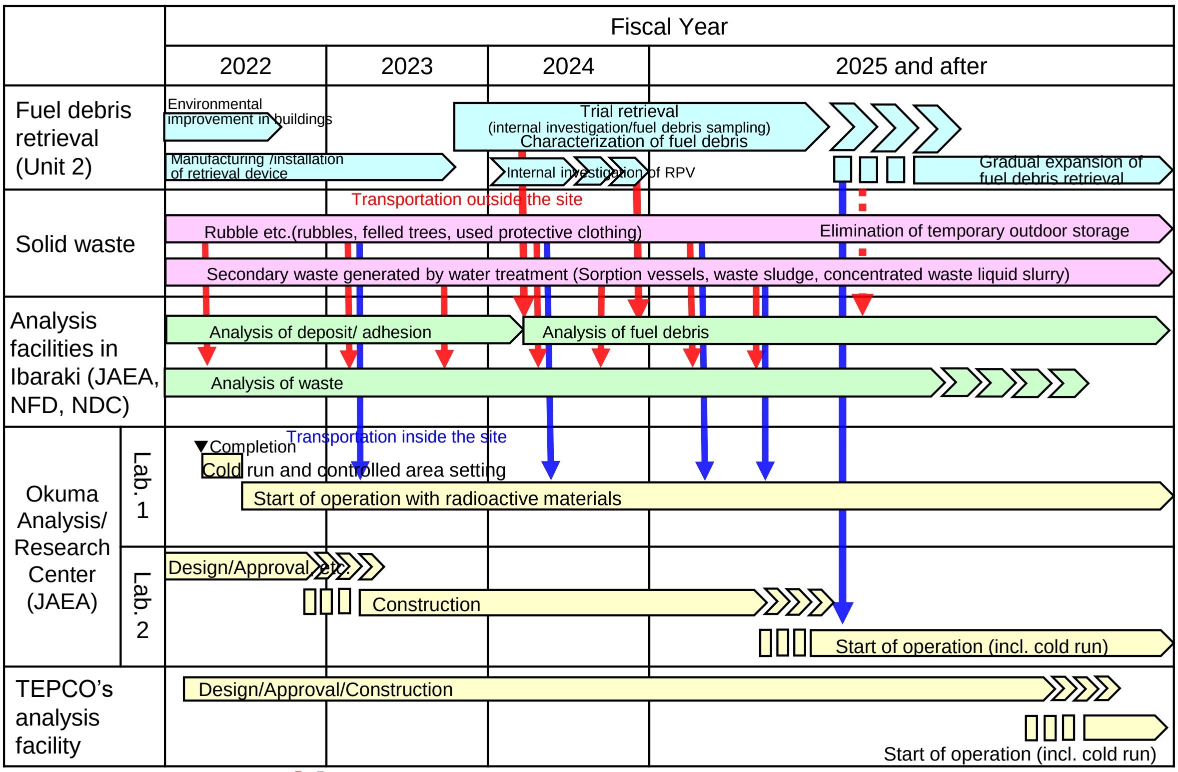
90 The 100th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water, “Material 4: Development status of Radioactive Material Analysis and Research Facility Laboratory-1”

91 Japan Atomic Energy Agency (JAEA), June 24, 2022 “Completion of the laboratory-1 of the Radioactive Materials Analysis and Research Facility (Okuma Analysis and Research Center) and future plans”

92 The 103rd Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water, “Material 4-1: Completion of the laboratory-1 of the Radioactive Materials Analysis and Research Facility (Okuma Analysis and Research Center) and future plans”

93 The 106th Meeting of the Secretariat of the Team for Decommissioning and Contaminated Water/Treated Water, “Material: Commencement of analysis work at the laboratory-1 of the Radioactive Materials Analysis and Research Facility”

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.41 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. 40 Construction and operation schedule for fuel debris retrieval and new analytical buildings

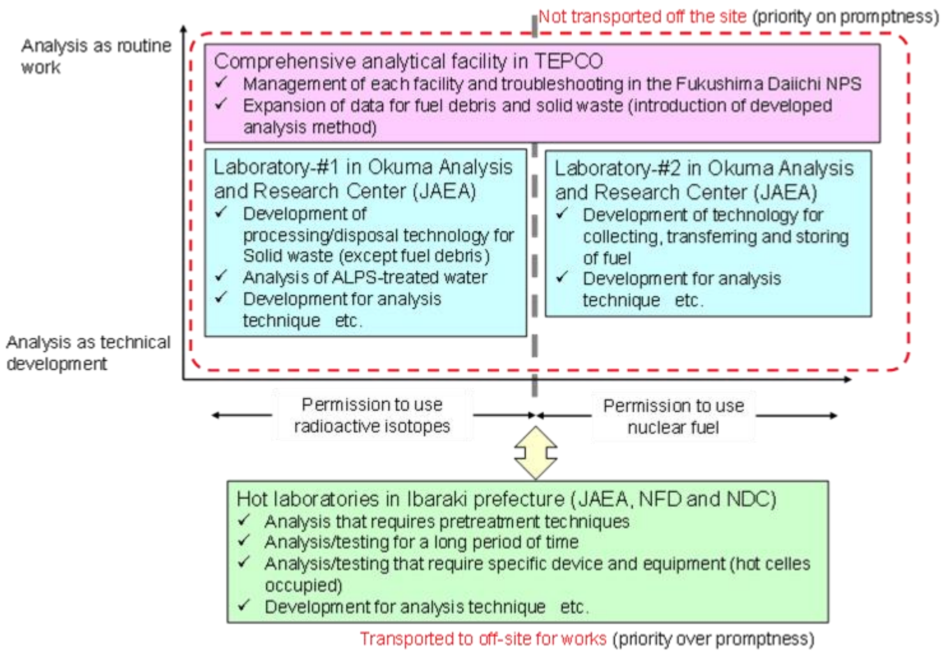


Fig. 41 Characteristics and roles of each facility for analysis

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. In normal nuclear power plants, fuel is sealed in fuel cladding, and before the accident, the unsealed alpha-nuclides were not directly handled in the Fukushima Daiichi NPS. The fuel debris generated by the accident contains unsealed fuel and FP, and there is a risk of internal/external exposure or spread of contamination in performing analyses. Therefore, in addition to knowledge on general chemical analysis and electronic equipment analysis, a wide range of knowledge is required, including radiation protection, laws and regulations related to nuclear power and radiation, chemical reactivity of fuel and materials, physical, chemical and biological properties of radioisotopes, properties of various types of radiation and measurement methods.

While such knowledge is acquired over time, 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 private-sector enterprise that have accumulated sufficient knowledge and experience on the handling of alpha-nuclides and fuel analysis techniques[94,95]. Personnel exchanges between TEPCO and the JAEA and personnel

[94] Tokyo Electric Power Company Holdings Inc., Japan Nuclear Fuel Limited., Conclusion of “Agreement on Technical Cooperation for the decommissioning of the Fukushima Daiichi Nuclear Power Station”, January 27, 2022

[95] Tokyo Electric Power Company Holdings Inc., Nippon Nuclear Fuel Development, “Memorandum of Understanding for cooperation in debris analysis for the Fukushima Daiichi Nuclear Power Station”, August 1, 2022”

acceptance from Nippon Nuclear Fuel Development Co., Ltd. (hereinafter referred to as "NFD") to TEPCO have been ongoing. Table 4 shows the state of personnel exchange. An agreement on technical cooperation between TEPCO and Japan Nuclear Fuel Limited. on the handling and analysis of alpha-nuclides was also signed in January 2022.[94]

Table 4 Personnel exchanges between TEPCO and JAEA and accepting personnel from NFD to TEPCO

		Fiscal year			
		2018	2019	2020	2021
From TEPCO to JAEA	Assigned, temporary, external researcher	1	1	3	3
	Transfer, reemployment	0	0	0	1
From JAEA to TEPCO	Assigned, temporary, cross-appointment	0	3	11	4
	Transfer, reemployment	0	0	1	0
From NFD to TEPCO	Assigned, temporary	0	0	1	0
	Transfer, reemployment	1	1	0	1

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[96]. 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[97]. Furthermore, as an international forum, the BSAF, BSAF-2, PreADES, and ARC-F, which have been implemented as projects of the

[96] IRID (2021), "Subsidized Project relate to grants for "Development of technologies for improving analytical accuracy and estimation of thermal behavior of fuel debris)", Final report of FY2020, August 2021
[97] IRID (2021), Supplementary budget in FY 2018, "Subsidies for the Project of Decommissioning and Contaminated Water Management" (Development of analytical and estimation techniques for characterization of fuel debris), implementation results for FY 2020

OECD/NEA, have come to an end, and the FACE project was launched in July 2022. The scope of the FACE project is (i) in-depth discussions for accident progression and associated FP behavior and H_2 combustion (ii) characterization of U--bearing particles and establishment of techniques for future fuel debris analysis for D&D; and (iii) collection and sharing of data and information. 23 organizations from 12 countries are participating in the project, with 6 organizations from Japan taking part in it: Nuclear Regulation Authority, Agency for Natural Resources and Energy, JAEA, Central Research Institute of Electric Power Industry, the Institute of Applied Energy, and NDF.

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 a manipulator 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 sample 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 complement 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 5 shows the relative comparison of the items for sample analyses to be performed inside analysis facility and for non-destructive assays to be performed outside the analysis facility and the sample amounts. Sample analysis can perform many analysis items, 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 5 Relative comparison of principal specifications between the sample analysis to be performed in the analysis facility and non-destructive assay to be performed outside 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.

If, in addition to the sample analysis in the facility for analysis, non-destructive assay focusing on specific items, for example, the quantification of nuclear fuel, is measured in the container of fuel debris, the small number of analyses can be supplemented, and the amount of nuclear fuel in the fuel debris can be promptly grasped (i.e., confirming that it is less than the minimum critical mass), making it possible to move to the next process while maintaining the subcriticality state. 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.

As an example of the application of non-destructive assay, Fig. 42 shows its use in the handling process from fuel debris retrieval to storage. Consideration is being given to performing the non-destructive assays ①, ②, and ③ shown in the figure. The amount of nuclear fuel in the retrieved fuel debris is quantified by non-destructive assay ②. The retrieved fuel debris is classified according to the amount of gained nuclear fuel, e.g. uranium quantity. Fuel debris with a large uranium quantity is stored in small-diameter containers, and fuel debris with a small uranium quantity is stored in large-diameter containers. In this case, the state of subcriticality can be maintained by applying dimension control for the small-diameter containers and mass control (total amount of nuclear fuel obtained by non-destructive assay ②) for the large-diameter containers. If the amount of nuclear fuel obtained by non-destructive assay ② is integrated, the amount of nuclear fuel for each container can be calculated. However, in non-destructive assay ②, it is expected that the amount of fuel debris used for one measurement will be small, and detected signal will be small as well. Therefore, it is desirable to perform non-destructive assay ③ after sealing to finally measure the value of nuclear fuel for transportation and storage. In non-destructive assays ② and ③, since the neutron absorber (B_4C), which is a control rod component, is contained in the fuel debris, the active neutron method may not be able to measure correctly. Other methods need to be examined to compensate for the inadequacies of the method using neutron.

However, it is expected that particles containing uranium and Cs -137 released at the accident have adhered to the surface of the upper internal structures. If the upper internal structures are cut and non-destructive assay ① can confirm no adhesion of particles containing uranium or Cs -137 after decontamination of the surface in consideration of necessity and feasibility, then the burden of solid waste storage and management levels can be lowered. Therefore, non-destructive assay ① requires a technique capable of measuring with high sensitivity and accuracy.

Technical development on non-destructive assay for fuel debris is in progress in the Project of Decommissioning, Contaminated Water and Treated Water Management. Since there is no precedent for non-destructive assay of fuel debris, and fuel debris has obstructive factors, it is necessary to verify the capability, applicability, and possibility of a combination of several non-destructive assay methods. Fig. 42 is an example and is subject to change depending on the status of future R&D and studies. However, considering the trial retrieval of fuel debris, characterization of fuel debris and gradual expansion of fuel debris retrieval, development of non-destructive assay methods ② and ③ is of high priority.

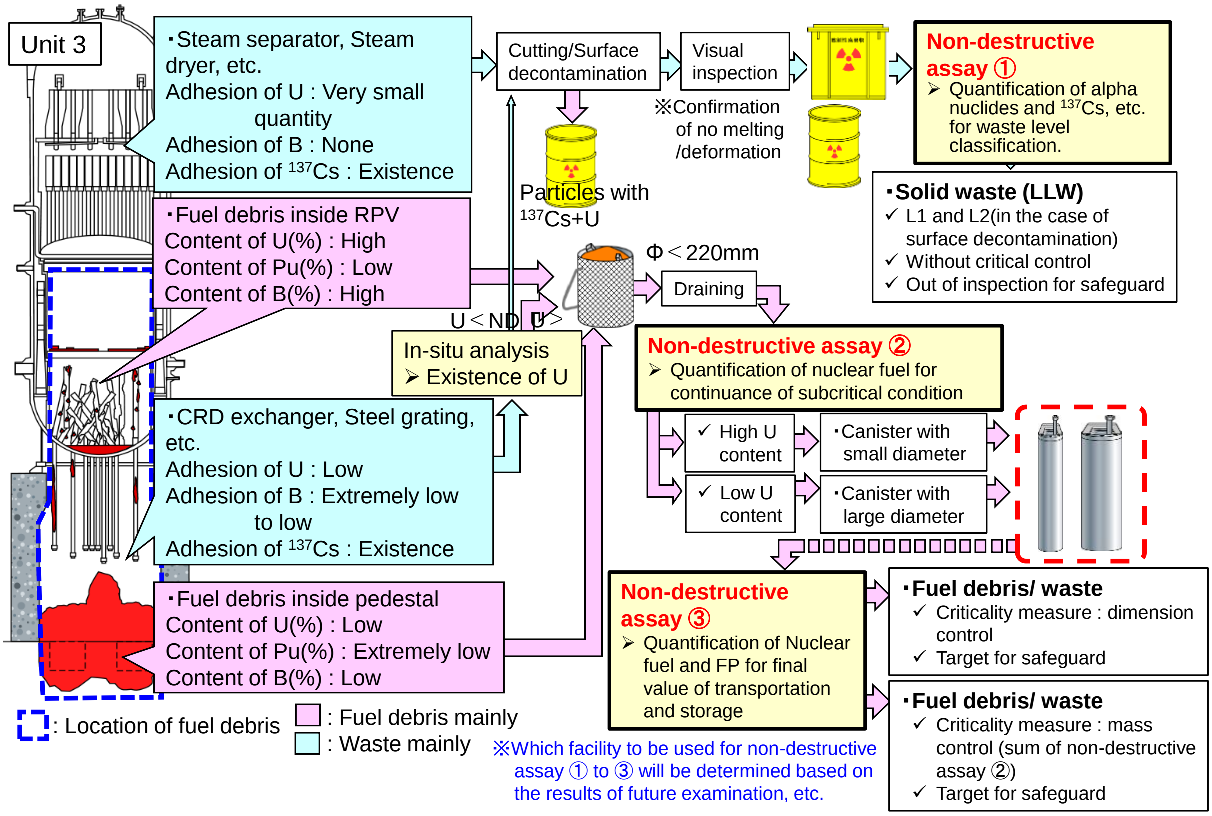


Fig. 42 Example flow of non-destructive assay in the handling process for retrieved fuel debris

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, it is necessary to accelerate research and development in consideration of the practical application for a gradual expansion of retrieval scale and further expansion of fuel debris retrieval in scale.

In order to solve these technical issues, basic/fundamental research and application research by universities in and outside of Japan and researching institutions such as JAEA, practical application research and field demonstrations by IRID, manufacturers, and TEPCO are being performed by various industrial-academic-governmental institutions, including overseas enterprises (Fig. 43).

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, Contaminated and 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 has been working on the technology development directly linked to site application, and established the Decommissioning Technology Development Center in August 2021 to strengthen the system for planning and management of technology development. The Center identifies research and technology development issues and examines solutions related to the Mid-and-Long-term Decommissioning Action Plan and manages the progress of technology development and reflects them in the development plan.

The NDF considers planning of the R&D medium -and-long-term plan and next-term R&D plans and supports the World Intelligence Project. NDF also has established the Decommissioning R&D Partnership Council with representatives of institutes involved and intellectuals from universities as its members, which considers information sharing on needs and seeds for R&D, adjustment of R&D based on the needs of decommissioning work, and issues on promoting cooperation related to the R&D and human resource development. Moreover, coordination between the Project of Decommissioning, Contaminated Water and Treated Water Management and the World Intelligence Project has been promoted through the Decommissioning R&D Partnership Council.

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. 44.

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[98] for the promotion of R&D[99].

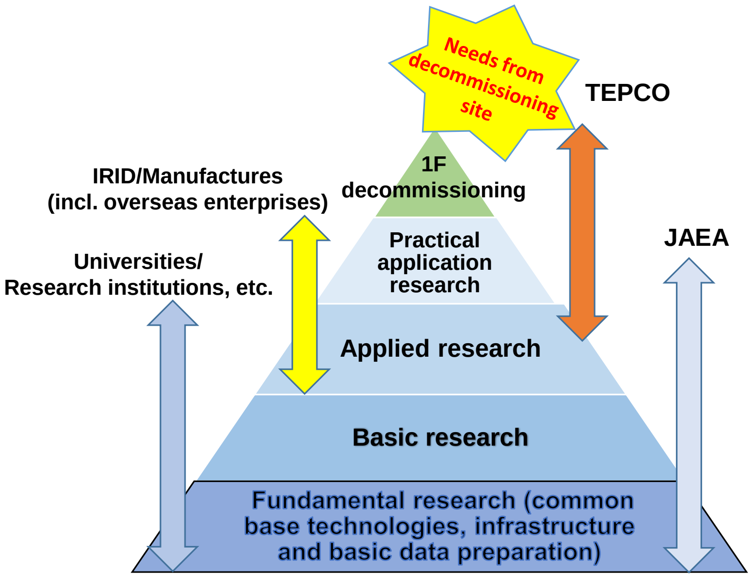
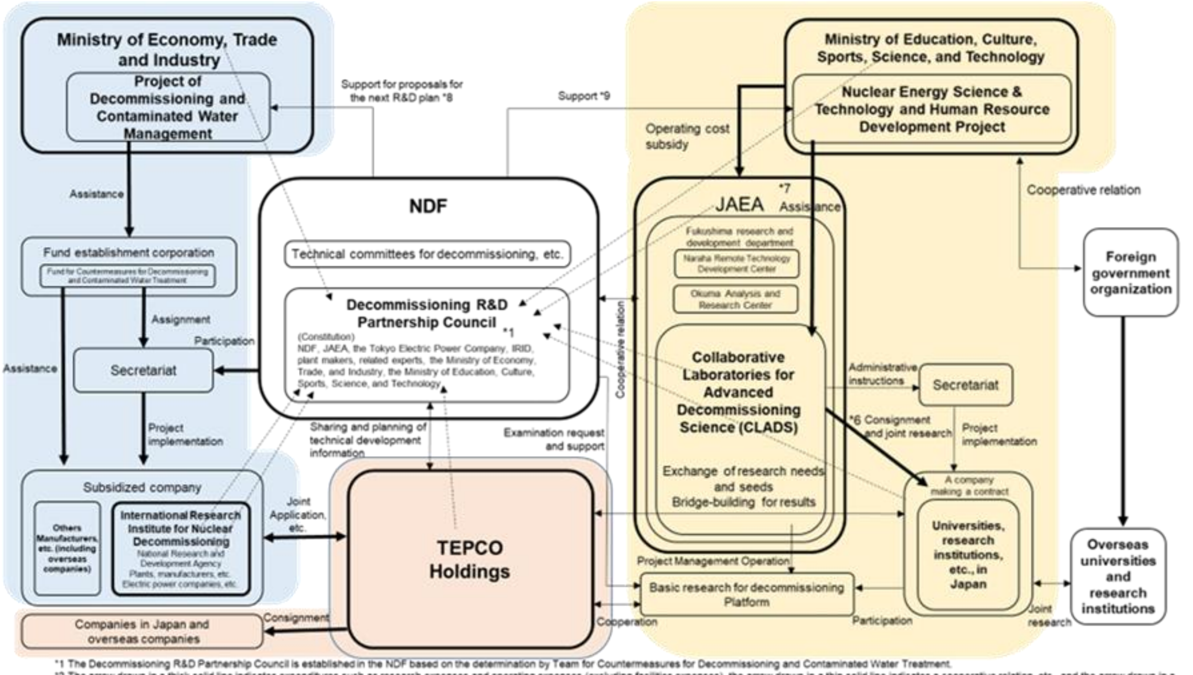


Fig. 43 Scope of studying decommissioning R&D and implementation entities

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

[99] 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 Research and development uniquely conducted by the Central Research Institute of Electric Power Industry, etc., are omitted in this figure.
*6 Although among the World Intelligence Project for Nuclear S&T and Human Resource Development the part adopted up to FY 2017 is the consignment from the Ministry of Education, Culture, Sports, Science, and Technology to a company making a contract, it is omitted in this figure.
*7 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.
*8 With regard to the Government-led Project of Decommissioning and Contaminated Water Management, based on the policy in the Mid-and-Long-term Roadmap or Strategic Plan and the progress situation of research and development, the NDF formulates a draft plan of the next research and development, and the Ministry of Economy, Trade, and Industry determines it.
*9 The NDF participates as a member in a steering committee of the World Intelligence Project for Nuclear S&T and Human Resource Development.

Fig. 44 Overview of the R&D structure of the decommissioning of Fukushima Daiichi NPS

5.2 Key issues and strategies

5.2.1 R&D medium-and-long term plan

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. Major revisions include updating the main decommissioning process and incorporating basic/fundamental research. The updated mid-and-long-term R&D plan is shown in Attachment 11. 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 and to discuss the required results, timing, implementation structure, etc. through the meetings. The plan will be updated and expanded continuously based on the information made clear by the progress of PCV internal investigation and fuel debris analyses as well as progress of R&D.

Moreover, in accordance with the discussion at the 10th Decommissioning R&D Partnership Council held in February 2022, TEPCO, Collaborative Laboratories for Advanced Decommissioning Science of JAEA (hereinafter referred to as “JAEA/CLADS”) and NDF jointly shared analysis of 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 in a comprehensive and exhaustive manner. The results will be incorporated into the R&D medium-and-long-term plan and the overall map of 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.

As shown in Fig. 44, the Project of Decommissioning, Contaminated Water and Treated Water Management selects project operators conducting R&D and provides necessary assistance through corporations with funds and the secretariat. Through the Project to date, significant results, such as internal PCV condition analysis by PCV investigations, have been obtained for promoting decommissioning work. Attachment 12 outlines the implementation of the Project up to now.

In the Project of Decommissioning, Contaminated Water and Treated Water Management, since 2020, NDF has been participating in the Secretariat of the Project to strengthen the functions of project planning and progress management. Also, in order to incorporate requirements in terms of actual site applicability into the R&D, TEPCO has been responsible for project management of the Project, jointly applying for issuance in cooperation with research leadership.

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 of Decommissioning, Contaminated Water and Treated Water Management, 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 of Decommissioning, Contaminated Water and Treated Water Management 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.[100] 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.

Starting this fiscal year, as a proposal for R&D planning, 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 the future, the system is planned to be improved based on the implementation results.

As an effort to ensure the quality of the Project, a Review System will be established for all Projects of Decommissioning and Contaminated Water/Treated Water Management. The objective

[100] The 102nd Team Meeting/Secretariat Meeting of the Decommissioning, Contaminated Water/Treated Water Management "Commencement of Request for Information (RFI) on Project of Decommissioning and Contaminated Water/Treated Water Management"

is to ensure the actual site applicability of the Project and to improve the quality of research and development. The details of the System will be discussed in the future.

On the other hand, for the projects that need to be succeeded to in the Project of Decommissioning, Contaminated Water and Treated Water Management, 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 of Decommissioning, Contaminated Water and Treated Water Management, 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 a 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

Universities/researching institutions tasked with basic/fundamental research are expected to maintain and develop human resources, knowledge and infrastructure to make a quick response when technical issues requiring scientific knowledge occur. It is important that universities/ researching institutions share awareness of issues in the field of decommissioning. In order to facilitate the long-term decommissioning project of the Fukushima Daiichi NPS, it is important to conduct scientific and technological investigations based on understanding of the principles and theories from the medium-and-long term perspectives.

In this background, MEXT has been promoting fundamental/basic research and human resource development activities, which contribute to problem-solving for the decommissioning of the Fukushima Daiichi NPS, by bringing together domestic and overseas intelligence from universities/researching institutions as the World Intelligence Project, 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.

Based on the discussions at this Decommissioning R&D Partnership Council, NDF set up “a task force on research collaboration”,[101] and identified six Essential R&D Themes mainly in the area of basic/fundamental research to be addressed with priority, in light of investigational issues and problem awareness on the side of the needs. Research and development on these Essential R&D Themes has been carried out in the World Intelligence Project and the Project of Decommissioning, Contaminated Water and Treated Water Management, and results have been obtained. In order to continue to position it as one of the Essential R&D Themes in basic fundamental research, it is compiled in the “overall map of basic/fundamental research” prepared by JAEA/CLADS.

In the World Intelligence Project public call, the “overall map of the basic/fundamental research” is used in soliciting applications, 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.

For the World Intelligence Projects in FY2022, public participation was called for in two cases: the “Problem-Solving Decommissioning Research Program,” which aims to solve issues by promoting needs-based R&D to steadily advance the decommissioning of the Fukushima Daiichi NPS, and the “International Collaborative Decommissioning Research Program (Japan-UK Joint Research),” which promotes R&D by integrating and collaborating research in various fields in Japan and the UK to gather broad knowledge and contribute to accelerating the decommissioning of the Fukushima Daiichi NPS. In Attachment 13, the selected issues of the World Intelligence Project adopted in the past are shown.

Further, 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

[101] It was established in NDF in 2016 and held 6 times in total. It consists of NDF, intellectuals from universities/researching institutions, and TEPCO. Six Essential R&D Themes were identified, which should strategically and preferentially ascertain the principle in promoting decommissioning at the Fukushima Daiichi NPS, and the interim report on the task force on research collaboration was developed (November 30, 2016).

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).

It is also important to build research and development infrastructures as hardware. The Naraha Center for Remote Control Technology Development of JAEA, which began full-scale operation in

Naraha Town, Fukushima Prefecture, in April 2016, is a facility where mock-up testing can be performed for the development and demonstration of remote-control devices and equipment. In particular, prior to the introduction of equipment into a severe environment that cannot be accessed by humans, it is essential to conduct full-scale mock-up tests for verifying the performance and for training and establishment of operating procedures, etc. In 2022, a mock-up test of the robot-arm was conducted for the trial retrieval of fuel debris (internal investigation and fuel debris sampling).

In Okuma Town, as described in 4.3, Fukushima Prefecture, the JAEA Okuma Analysis and Research Center (Radioactive Material Analysis and Research Facility) is under construction. The Laboratory-1 of Radioactive Material Analysis and Research Facility, where low-dose and medium-dose solid waste analysis as well as third-party analysis of ALPS-treated water are to be conducted, was completed in June 2022, and its controlled area was set in October, and its operation was started. The Laboratory-2, which analyzes high-dose samples such as fuel debris, is being designed in detail.

In this way, research facilities related to decommissioning projects are located in Fukushima Prefecture, where a global center for R&D for decommissioning has been established, and R&D infrastructures for medium-and-long-term prospects have been built.

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 project with a view to the medium and long term decommissioning work while coordinating and harmonizing, it is necessary for TEPCO 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 Nuclear Regulation Authority (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[102] 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. The leadership of 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 FY2022 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 and

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

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). Major initiatives are listed below.

① Strengthening the authority of project managers through reorganization, and improving safety and quality levels

In April 2020, the Fukushima Daiichi Decontamination and Decommissioning Engineering Company was reorganized to establish a program[103]/project structure and the Decommissioning Safety & Quality Office was set up directly under the Chief Decommissioning Officer (CDO). As a result, the authority of project managers has been strengthened by assigning full-time project managers and granting budget implementation authority. In terms of operation, efforts were made to improve the operational propelling force of the decommissioning project by establishing a system in which management and other related parties share information on the progress, issues and risks of each program and project every month. Moreover, the Decommissioning Safety and Quality Office was set up to ensure the safety of decommissioning work and to maintain and improve the level of work quality in the face of the extremely uncertain and technically challenging tasks such as fuel debris retrieval.

However, there are many issues for project-based operations to reach a mature level. For example, workforce and work content should be properly controlled so as not to ruin motivation of members due to fluctuations in workload between projects. Operations in the decommissioning safety/quality assurance office, a wide range of activities are needed, including establishing a system involved in engineering work by each lead group and developing members specializing in safety.

② Strengthening of risk management

A “risk” refers to “uncertain events” that may occur in the future, not an event that has already occurred. In “uncertain events”, some have negative effects (Threats) and the others have positive effects (Opportunities). Many of the “Uncertainty” [104]in the decommissioning of the Fukushima Daiichi NPS are “causes” that have a negative impact (threats) on the project. On the other hand, an event that has already occurred or an event that is surely to occur (probability of 100%) becomes an “*issue* (issues and problems)”.

Risk management involves using resources to address potential root causes and mitigate serious consequences. *Issue* management, on the other hand, uses the appropriate resources to deal with and solve issues and problems that have occurred. A risk becomes an i*ssue* if it is mishandled. Therefore, handling risks appropriately will reduce *issues*.

[103] Program is the upper level of project, and it is a project in which multiple projects are organically combined to realize the overall mission.

[104] As uncertainty that has a negative impact on the project include, for example: Uncertainty of design input conditions due to the inability to obtain 100% of site information, uncertainty due to the development of highly challenging technologies, and uncertainty in estimating cost schedules due to many tasks that have not been experienced in the past.

If risk management works out fine, “things that may be a problem will not occur”. However, if something happens as a result of a failure, “it will be seen as a problem, and accountability will be required “. With this, much of the project manager’s work is focused on eliminating, improving, and mitigating costs, schedules, and causes that affect performance. In other words, risk management is a core activity for project management.

Risk management is an activity to identify uncertain events before they materialize and to “take preventative measures” so as not to let events that negatively affect the project happen, or to “minimize the effects” even if they occur (the standard workflow of risk management is shown in Fig. 45).

TEPCO is fully aware of the importance of risk management, and has begun systematic efforts in line with the workflow in Fig. 45 from FY 2021 to further strengthen risk management.

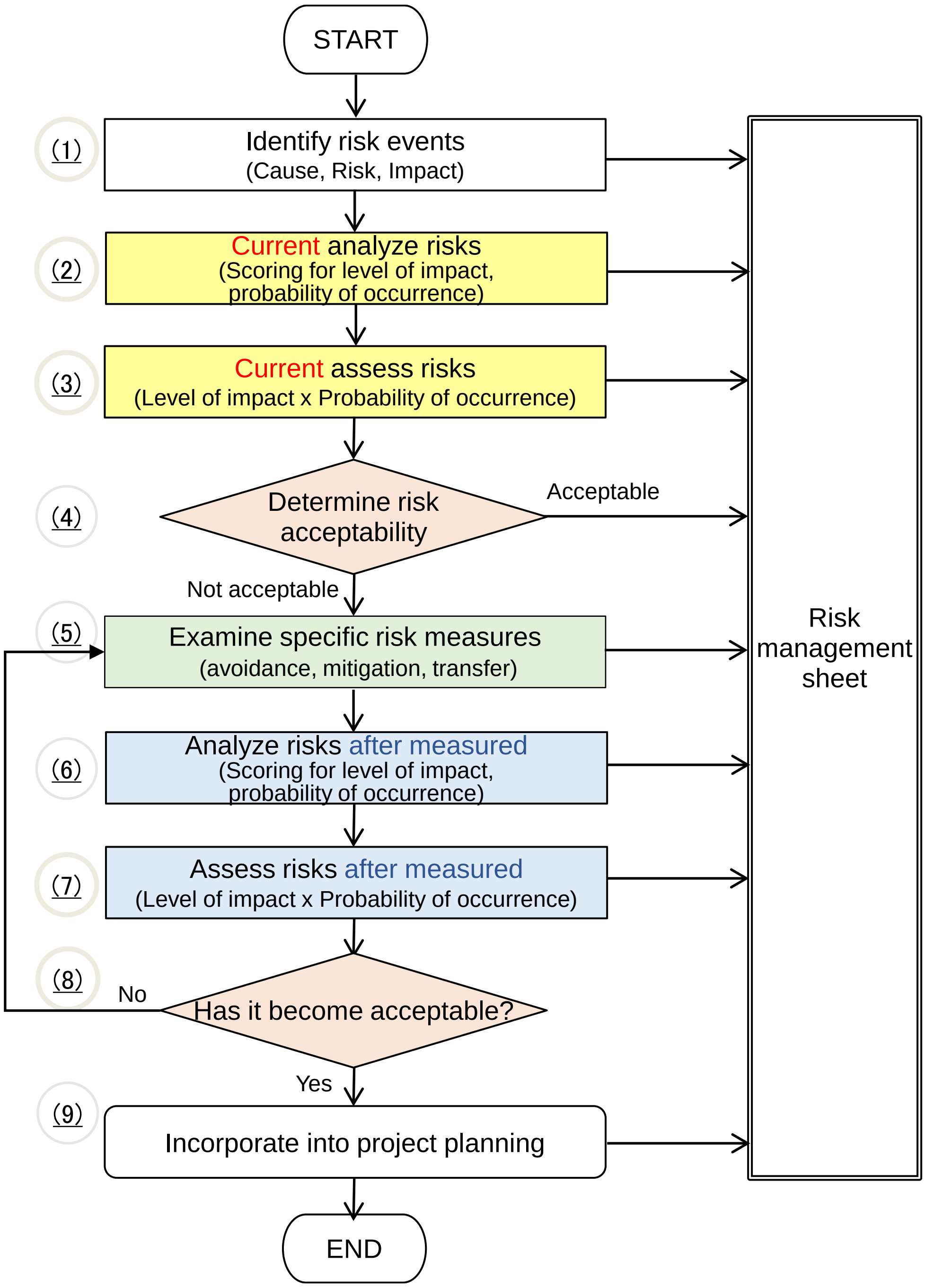


Fig. 45 Standard workflow of risk management

③ Preparation of a plan focusing on long term perspective (Mid-to-Long-term Decommissioning Action Plan)

Since the accident at the Fukushima Daiichi NPS, TEPCO has been implementing the decommissioning project, referring to the requirement based on the Act on Special Measures Concerning Nuclear Emergency Preparedness and the Nuclear Reactor Regulation Law[105], the Mid-and-Long-term Roadmap decided by the Ministerial Conference on Measures for

[105]Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors

Decommissioning, Contaminated Water, and Treated Water, and the target process (milestone) of the Target Map for Reducing Medium-term Risk prepared by the Nuclear Regulation Authority. In March 2020, TEPCO prepared and announced the Mid-and-Long-term Decommissioning Action Plan with the aim of presenting a concrete work plan to achieve the milestones of the Mid-and-Long-term Roadmap and the Target Map for Reducing Medium-term Risk. After this, in March 2022, TEPCO published the Mid-to-Long-Term Decommissioning Action Plan 2022, which was updated every year based on the progress of the work.

Mid-and-Long-term Decommissioning Action Plan is proof of the attitude of TEPCO to independently tackle the decommissioning as its responsible business. A certain level of transparency is given to the complex and long-term decommissioning project, and it is essential to maintain and improve transparency and the appropriateness of the content so that it can serve as effective communication tools with the local community and society.

Mid-and-Long-term Decommissioning Action Plan provides work plans for about the next 10 years for each major measure, and based on the plan for the next 3 years, a Withdrawal Plan for reserve fund for decommissioning has been prepared.

④ Formulation of R&D medium-to-long-term plan

The decommissioning of the Fukushima Daiichi NPS has entered a "strategic stage of foresight" and is entering a "phase of systematically tackling unexplored areas" such as the retrieval of fuel debris whose location and properties are unknown. For this reason, collaboration with R&D is becoming increasingly important, and TEPCO is preparing the R&D medium- to long-term plan jointly with NDF starting in FY2020. After that, with the aim of strengthening the planning and management functions of research and development to examine technology development issues and promote implementation plans, TEPCO established the D&D Research & Development Center in August 2021.

In order to work on the development in cooperation with each PG, the Center has launched a mission to identify technical development issues related to the Mid-and-Long-term Decommissioning Action Plan and to reflect important issues in the R&D mid-and-long-term plan. This mission is an important one for realizing the target process of the Mid-and-Long-term Roadmap, and it is necessary to plan mid-and-long-term R&D through early enhancement of resources.

In particular, regarding the research and development of fuel debris retrieval, it will be indispensable to carry out integrated promotion in close cooperation with a new engineering company that is to be established in October this year, and therefore, the Center's structure needs to be further improved. It will also be an important role for the Center to monitor the R&D progress of each PG at all times, evaluate the effectiveness of R&D on a regular basis, and appropriately feed the evaluation results back to each PG.

⑤ Enhanced budget planning

Each fiscal year, budget plans for program/project work, non-program work (maintenance and utility facilities), and operating costs necessary for decommissioning are formulated, and efforts were made to improve budget accuracy through the appropriation of subjects based on the Mid-and-Long-term Decommissioning Action Plan, determination of designs at an early stage, preparation and analysis of monthly report budget difference reasons. As a result of these efforts, there has been a downward trend in the budgetary variance caused by problems with work procedures (insufficient consideration, poor coordination, lack of confirmation, etc.). On the other hand, the following issues need to be addressed continuously.

Fukushima Daiichi Decontamination and Decommissioning Engineering Company concludes hundreds of construction contracts every year. At the planning stage, the completion date of the construction contract (hereinafter referred to as “acceptance inspection period”.) is set not to be at the end of the fiscal year (March), but the subsequent engineering does not proceed as planned, and at the contracting stage the acceptance inspection period has to be set to March. As a result, there is no buffer to absorb the process changes caused by the actual construction within the fiscal year, and there are many cases in which the acceptance inspection is carried over to the next fiscal year.

In the future, it is important to examine appropriate processes at the planning stage, set the acceptance inspection period with a certain level of margin relative to the end of the fiscal year, and establish an acceptance inspection plan that is as uniform as possible throughout the year to diversify resources.

⑥ Addressing issues across projects

TEPCO constantly identifies and shares risks and issues, and each project deals with them, but for issues that do not fit into individual programs/projects, a cross-divisional system is established to deal with them. Examples are shown below.

- In the decommissioning of the Fukushima Daiichi NPS, the prevention of the spread of alpha-nuclides to the environment and the prevention of internal exposure of workers have been identified as future issues, and a cross-program/project working group has been established to deal with these issues.
- Work on multiple projects is congested around the west side of the reactor buildings of Units 1 and 2. In response to this, a cross-program/cross-project working team has been set up to study the issues.
- In October 2021, a person in charge of seismic design and evaluation was established, and cross-organizational adjustments are being carried out to prevent delays due to variations in seismic design and rework.

6.1.2 Key issues and strategies to be strengthened in the future

As shown in 6.1.1, various measures are being implemented to ensure the safe and reliable implementation of the decommissioning project, and it is necessary to continuously upgrade and improve the operation of each of these measures. The following is the important items 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 2021, 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 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. Because 11 years have passed since the accident and the systems are aging, as measures against aging degradation, the attempts are being made to improve the process of long-term maintenance planning, to prevent human errors (HEs), and to analyze factors and take actions from the on-site perspectives according to each department's structure and tasks in the prevention of occupational accidents.

Frequent occupational accidents, human errors, 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.

Ultimately, it is the people and organizations (operators) who handle all aspects of the "Fukushima Daiichi NPS site" (operation, maintenance, radiation control, instrumentation, analysis, etc.) that will realize safety. At Fukushima Daiichi NPS, the effectiveness and sufficiency of radiation exposure reduction and personal safety measures are confirmed at "ALARA Meeting[106]" and "Safety pre-evaluation Meeting[107]". However, it is important that operators (including not only TEPCO employees but also employees of subcontractors) who are familiar with the work site participate in these meetings, and that the work process is designed so that safety can be comprehensively checked from the "on-site perspective" (experience) of the various operators. In other words, it is important to establish the business process as a mechanism, such as incorporating into the gate process the business process of "systematizing and manualizing experience and related information from the field about procedures, rules, and precautions to ensure safety at work, and having the personnel and operators in charge of managing and operating the field work familiarize themselves with them. It is important to establish such a system.

6.1.2.2 Owner's engineering capability

In the case of large scale projects, where the technology is mature and the performance requirements are clear, such as the construction of nuclear power plants, waterfall-type[108] engineering is generally used. In this type of waterfall engineering, it is effective to clearly communicate the requirements of the client (TEPCO) to the potential contractors (manufacturers, general contractors, etc.) in the supply chain as far as possible upstream of the project to proceed with the project smoothly.

However, since the fuel debris retrieval is an inexperienced approach, the target setting and required specifications from TEPCO, the executor of the decommissioning project, are not always clear at the time of engineering, and the degree of performance requirement setting, physical feasibility of the method and equipment, and performance assurance must be 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

[106] The purpose of this meeting is to reduce the radiation exposure of workers and to discuss the effectiveness and sufficiency of engineering measures (physical measures) such as removal of radiation sources and installation of shielding.

[107] The purpose of this meeting is to prevent the occupational accidents and to deliberate on the effectiveness and sufficiency of personal safety measures using risk management methods (risk identification, risk analysis and risk assessment).

[108] 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.

be iteration approach-based, to some extent[109]. In this regard, it would be effective to proceed by referring to case examples in other industries that are also implementing the same iteration-type engineering. For iteration-type engineering, the contract between a project executor and a supply chain is not conventional[110]. Therefore, TEPCO, as a project executor, is strongly required to “make a judgment on engineering and is responsible for the results.” To do so, TEPCO needs to improve, specifically the engineering ability that TEPCO, the project executor, proactively performs as the owner[111] (owner's engineering capability).

The owner's engineering capability here refers to the capability required of TEPCO itself as a site owner 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. The fact that the project executor bears the business and technical risk also means that the project executor itself must have the technical ability to assess the reliability of the functional settings and engineering design, as well as project management capability. Here, the most important point is to incorporate “safety and operator's perspectives” as upstream as possible in engineering. (Fig.46)

For example, in the evaluation of fuel debris retrieval method selection, it is necessary to evaluate from the viewpoints of quality (fuel debris retrieval status, safety, etc.), project (cost, time and other visions), and technical feasibility. Alternatively, a project that would previously have been ordered by a single company can be divided among multiple companies, and TEPCO can oversee and manage the entire construction. It is also important for the enhancement of owner's engineering abilities to accumulate and feedback various field experiences, such as by these activities and the promotion of insourcing to be described later.

---

[109] 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.

[110] In the conventional construction of nuclear power stations, a supply chain has delivered completed products to a project executor after guaranteeing the performance (Full turnkey contract).

[111] 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)

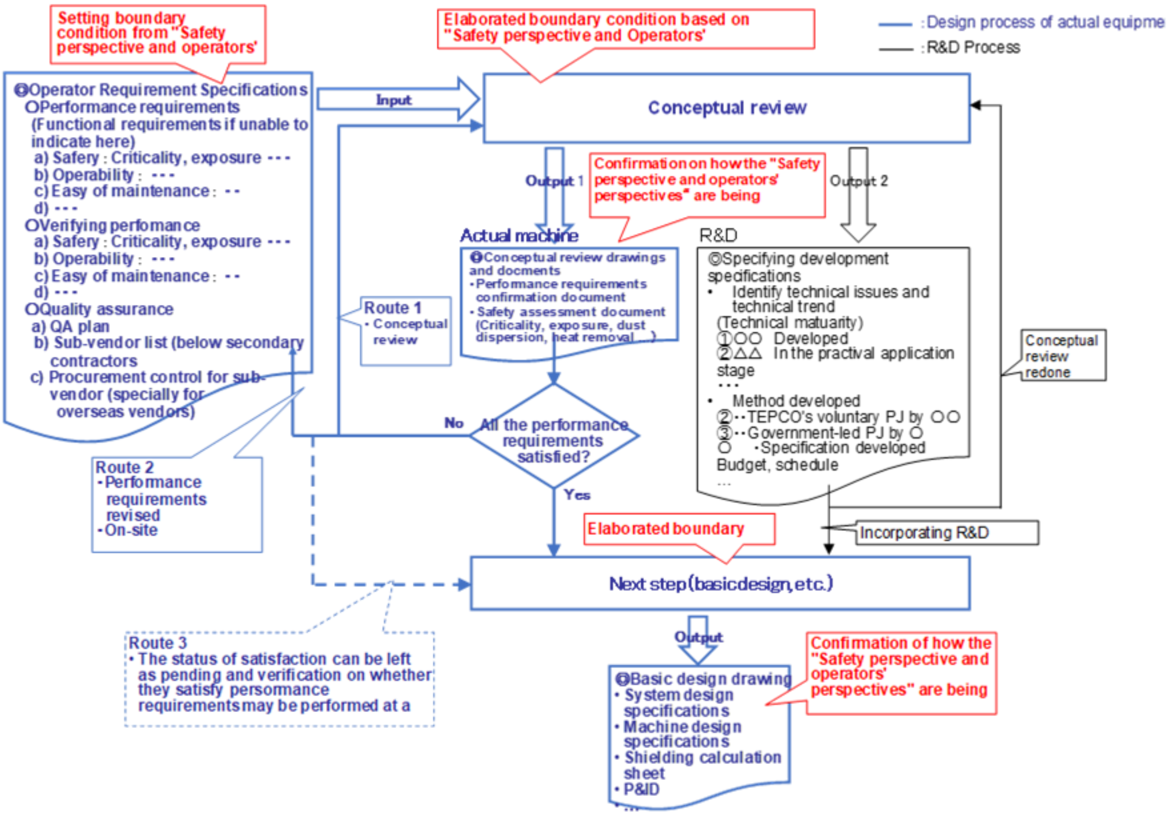


Fig. 46 Design flow of fuel debris retrieval (conceptual)

6.1.2.2.1 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 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 (Table 6).

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[112,113] 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.

This approach will be tested in a pilot project. After determining its effectiveness and scope, it will be gradually rolled out to other projects. (Table 7)

Table 6 Difference between “Making” and “Buying”

	Making	Buying
	Acquisition of the outcome of the project (Acquisition)	Purchase products (things) that meet the specifications
What to call the order receiving parties and their roles	Contractor, a partner who is responsible for obtaining the outcome of the project	Vender, who supplies equipment that conforms to specifications
How to decide who will receive the order	Select based on proposal content and feasibility	Select by price
Contract method	Contracts in line with risk allocation	Fixed price contract
	Data-based cost estimation (analogy: analogy, integration, parametric : sensitivity, analysis, etc.)	Quotation/price list, etc.
	“Do the Right Things” ※ * When doing things, always think about what the right purpose, the right goal, and the right means.	“Do Things Right” ※ * Do things right, by the rules, by the procedures.

112 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.

113 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).

Table. 7 Future project management (To Be)

		Present project management ⇨	Future project management (To Be)
Definition of Purpose and "Success"		◻ Purposes are set but **"Success" (achievement evaluation criteria) is not clarified in advance.**	◻ **Define the evaluation criteria to be achieved** as well as purposes at the time the project is launched
Feature (Structure of WBS*1)		◻ Break down "Works" into the **work-elements** to be performed	◻ Decompose "Works" into **outcome elements (product, structure, deliverable)** to be acquired
Control Parameter	Cost	◻ Budget phase : In the phase cost cannot be estimated, infer from similar works, get **a quote from vendors** ◻ Execution phase : **Actual costs are not collected** at the breakdown level	◻ Budget phase : In the phase cost cannot be estimated, cost estimated based on **reliable data** ◻ Execution phase : **Collect actual costs** by WBS unit
	Schedule	◻ Planning phase : **Best Effort** process ◻ Execution phase :**Subjectively** assess progress **against milestone**	◻ Planning phase : Process with **risk factored in** ◻ Execution phase : **Quantitatively** assess the status of results acquisition using **objective and scientific methods** (EVM*2, etc.)
	Technical Performance	◻ **Assumed that it will be achieved** (performance is guaranteed as an obligation of the ordering party and is not subject to control)	◻ **Set a baseline of technical performance** to control technical performance at the WBS level as well
Contract		◻ **Fixed**-price contracts	◻ **Risk-based** contract **(type, scale, etc.)**

※1 : Work Breakdown Structure
※2 : Earned Value Management

6.1.2.2.2 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.

"Insourcing" means to develop an ability that enables TEPCO to implement planning, design, maintenance, and operation on its own. It aims at reducing unreasonableness and waste, further deepening the level of productivity improvement, and improving the operation quality of TEPCO employees including the quality of design and procurement. The improvement of these qualities will ultimately contribute to the improvement of safety. While insourcing is effective for a wide range of issues, it is advisable to proceed with an awareness of the issues that are expected in the future to gain more benefits. Examples of future issues are listed below.

・Improvement of operation and facility quality through internal integration of operation and maintenance know-how

In terms of operation and maintenance of facilities, it is expected that the number of operation tasks will increase due to the installation of new facilities and that maintenance costs will increase due to the aging and deterioration of facilities. It is necessary to devise more "Smart Maintenance" methods to keep maintenance costs low while not degrading reliability. For example, in the case of a new system to be used for a long period of time, sensors (vibration, heat, sound, etc.) for online monitoring of the operating status can be mounted in advance, a large amount of accumulated maintenance data be processed by computer to be used for prediction maintenance, and maintenance data obtained from existing systems be utilized. In this way, systematization and sophistication of maintenance knowledge management facilitate accumulation of maintenance knowhow internally. Accordingly, a databased system for the equipment to be maintained will go live. It is important to expand the information on maintenance in the future and to establish it while improving its operation.

Furthermore, for long-term operations such as fuel debris retrieval, where highly radioactive materials (and nuclear fuel materials) are handled, TEPCO employees, who are the license holders, should perform the operations themselves, and the operator should ensure radiation safety and strive to internally accumulate operational know-how.

・Enhanced capability to make an engineering judgment

For a task like fuel debris retrieval, which is inherently subject to great uncertainty and for which TEPCO has no previous experience, TEPCO needs to make engineering judgments on its own, and to do so, it must have a firm grasp of the details of design, construction, maintenance, and operation. Therefore, to take design as an example, TEPCO should improve its competence by working on system design and determining the required specifications of equipment from the current stage.

・Strengthening site capabilities

The on-site situation at the Fukushima Daiichi NPS has changed significantly from before the accident. As described in *2.3.1 Basic policy for ensuring safety based on the characteristics of Fukushima Daiichi NPS*, a large amount of radioactive materials exist in unconventional and unsealed conditions without complete barriers to contain the radioactive materials, such as reactor buildings and PCVs. Furthermore, the environment is subject to constant changes in situations due to natural events such as weather and earthquakes, as well as aging degradation of equipment and buildings, and has uncertainties in the conditions of radioactive materials and containment barriers. In addition, the accessibility of personnel and systems is limited due to high radiation doses and damage to equipment and buildings, making it difficult to obtain complete on-site information.

Although radioactive materials such as fuel debris and contaminated water are now controlled in a stable state, the decommissioning of the Fukushima Daiichi NPS involves a series of tasks that have never been experienced in the past in terms of construction, operation, and maintenance. Therefore, TEPCO must always keep in mind that unpredictable situations may occur and observe the site, and it will be particularly important to have the ability to think about things from the perspective of the site by detecting changes on site as soon as possible ("on-site capability").

Specifically, the following capabilities should be developed based on a thorough knowledge of the functions and performance of the equipment to be acquired.

- 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. With such awareness, TEPCO is expected to take the following actions.

(1) Error prevention and improvement of two-way communication with society

TEPCO has established a system to prevent mistakes and errors and improve two-way communication with the public in order to eliminate mistakes and errors on-site, which cause a loss of trust in the eyes of society, including nonconformance in nuclear material protection in Kashiwazaki-Kariwa NPS and failure to share information on the failure of seismometers installed on a trial basis at the Fukushima Daiichi NPS, and other incidents such as delays in reporting or confusing reporting. In addition to continuing efforts, it is necessary to further promote creation of an open workplace, including with contractors. In creating an open workplace, for example, management constantly disseminating information is effective and, although it takes time, so is providing education and training for the middle management, including group managers, to ensure psychological safety[114].

(2) Efforts to improve operational efficiency and effective use of resources

Now that operations are becoming more project-based, this is an excellent opportunity to continue to explore how to improve the way of working and optimize and enhance the allocation of resources. It is important to constantly review operations, improve operational efficiency, and use resources effectively, so as not to be hindered by prior ways of working. While efforts have already been made through Kaizen activities, it is desirable to promote these efforts further. In addition, as mentioned above, TEPCO is aiming for project management that focuses primarily on obtaining results, which will further improve the quality of operations in terms of costs, schedules, etc. Furthermore, this initiative is expected to contribute to efficient operation management by improving the time planning of work and enabling members to check the performance of members.

(3) Securing and developing human resources

In decommissioning projects, it cannot be denied that the installation of new systems and facilities will continue, and the workload will increase to ensure the safe and reliable operation of the installed systems, etc. To cope with increasing workloads with limited human resources, it is necessary to develop staffing and development plans with a mid-to-long-term perspective, increase headcount and reallocate personnel accordingly, promote human resource development systematically and steadily even if it takes time, and establish a system to implement these plans flexibly and smoothly. 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 (e.g., actinide chemistry, analytical evaluation, seismic resistance, environmental impact, etc.) in addition to those in each job category (project management, design, operation, maintenance, chemistry, analysis, safety assessment, radiation control, etc.) that will be needed in the future.

For securing human resources, in addition to extracting available human resources by improving operational efficiency as mentioned above, it would also be effective to introduce a system that is conscious of the local community, such as employing from local high schools, technical colleges, and universities, or employing local people who have entered higher education in different areas, in anticipation of the decommissioning project to be carried out in cooperation with the local community over the long term. In addition, more efficient use of human resources becomes possible by reviewing personnel allocation and job assignment flexibly and smoothly in response to changes in workload and required skills as the work progresses.

---

[114] Psychological safety: The belief that your opinion won’t be rejected, or other members won’t punish you. Such a state of mind allows you to speak without fear.

Moreover, training and securing analyzers are urgent for human resource development. TEPCO has started human resource development through OJT training[115] at JAEA and other organizations with expertise in analysis. At present, the training of analysis managers is a priority, but from now on, it is also necessary to concentrate on training analytical engineers (management) who can determine applicable analytical techniques according to the situation and formulate analysis plans. It is also desirable to train analytical evaluators who understand the process of each decommissioning work, what analysis is necessary for it, and who can plan the scope and items of analysis in anticipation of how to utilize the analysis results.

<<Example idea of human resource development: Development of technical leaders for decommissioning under the unique environment of 1F>>

Under the unique conditions of Fukushima Daiichi NPS described in *2.3.1 Basic policy for ensuring safety based on the characteristics of Fukushima Daiichi NPS*, the technical leadership at the program manager level must possess a wide range of capabilities to safely and steadily promote decommissioning. This requires basic knowledge and technical experience to gain a comprehensive understanding of handling nuclear fuel materials and associated requirements and develop it. In developing such knowledgeable and experienced leaders, the issues are how to help them acquire these skills (training), how to check that each person has these skills (check), and how to raise each person's awareness (motivation) to acquiring these skills. To solve these issues, as mentioned above, it is necessary to prepare a human resource development plan and implement it systematically and steadily. An example of the implementation structure is described below.

a) Personnel development planning

For each skill item required of technical leaders, an organizational human resource development plan should be prepared, which defines [1] the target, required knowledge and technical level, etc., [2] OJT and training items, etc. as a means and needed for the acquisition, and [3] standards to determine whether the skills have been acquired. Based on the plan, group managers as superiors prepare individual development plans for the personnel to be trained, with a vision of their future as a career path.

b) Development and skill check

The basis of human resource development lies in OJT training. By assigning tasks that exceed or are outside the scope of the target's abilities and having them perform, they can acquire new skills. Under the coaching of an instructor appointed as necessary, the target personnel develop and fulfill the procedures and implementation schedule for the assigned

[115] It stands for "On the Job Training", a method of training employees to acquire knowledge, skills, etc., by providing instruction through actual work.

tasks. The schedule should include acquiring basic technologies as needed, utilizing the Core Decommissioning Technology Course, etc. that have already been provided. It is difficult to set skill standards to judge whether or not a person has acquired the skill and to judge it. Therefore, assigning one person, who is most proficient in the skill, is effective, leaving it to that person to make a judgment. If the skill level required matches the official qualification (e.g., Nuclear Fuel Protection Supervisor), acquisition of the qualification could be used as a skill check.

c) Motivation improvement

Since decommissioning itself is a national challenge that requires the collective wisdom of humankind, and the skills to be acquired and personalities to be demonstrated for the challenge are diverse, activities to increase motivation leading employees in various directions will be diverse in themselves. Common and important to all of these activities is to visualize outstanding employee performance that embodies the future beyond the efforts of individual employees. It is important for TEPCO as an organization to develop a more robust culture that nurtures and values employees who can serve as role models.

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 inheritance of technological skills. As the entire industrial-academic-governmental institutions, it is important to make steady advancement of efforts according to each level of secondary and higher education stages.

Primarily, the assumption is that TEPCO will establish the decommissioning of the Fukushima Daiichi NPS as a planned and sustainable project, under which activities of human resource development and acquisition, including their employees and contractors, will be promoted independently and continuously. Human resources involved in decommissioning of the Fukushima Daiichi NPS are required not only to specialize in nuclear energy but also to possess science and technical knowledge in fields other than nuclear energy, and ensuring and nurturing human resources with such diverse technical backgrounds are being required.

For this reason, in addition to the importance of strongly encouraging human resource development and recruitment directly within TEPCO and contractors, it is most important that excellent human resources who have graduated from universities, graduate schools, technical colleges, high schools, etc., and have specialized in science and technology are continuously sourced to these companies. In order to achieve this in a stable manner, it is necessary for higher and secondary educational institutions to create an opportunity for learning and acquiring peripheral knowledge in addition to professional knowledge, and to maintain associated systems and structures so that they can function as a whole, including teachers.

For students in higher education such as universities, graduate schools, and technical colleges, it is important for the industry and higher education institutions to cooperate and continuously implement activities to promote understanding of the nuclear industry. In recent years, due to the reorganization of faculties and departments related to nuclear energy, it has been pointed out that the human resource development function in higher education institutions in the nuclear field is weakening. Therefore, attention must be paid to maintaining and enhancing the human resource development function in the nuclear field nationwide. In particular, it is necessary to communicate the idea that the decommissioning of the Fukushima Daiichi NPS is an extremely advanced technical challenge, which is unprecedented in the world, and to establish various career paths for young researchers and engineers to thrive in the nuclear industry including decommissioning, and to specifically demonstrate and make them feel a career view. For the development of next-generation human resources, it is fundamentally important that young researchers/engineers are constantly produced 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. From the perspective of human resource development, support has been provided for young researchers and teachers in preparing and implementing lecture curriculums related to decommissioning. After more than five years since the launch of the World Intelligence Project, it has produced great results in terms of both research and human resource development. At “the Conference for R&D Initiative on Nuclear Decommissioning Technology by the Next Generation (NDEC)”, a conference for students to present their research findings as part of the World Intelligence Project, and the Creative Robot Contest for Decommissioning for technical college students, students present their research results, exchange views with researchers and engineers involved in the decommissioning of the Fukushima Daiichi NPS, and are given awards for excellent performance on a constant basis. As for an initiative for young researchers in the World Intelligence Project, in addition to the existing program represented by young researchers under the age of 39, a new program was launched in FY 2021 that requires young researchers to assume commensurate research responsibilities within R&D projects as a requirement for application. In order to encourage autonomous research activities, an initiative has been taken since April 2021 where young researchers engaged in the World Intelligence Project are allowed to be involved in independent research activities up to 20% of the efforts devoted to the project with the consent of the research representatives (relaxation of the obligation of full-time commitment).

The World Intelligence Project’s mechanism and implementation have produced some results for researchers and students belonging to the higher education organizations, 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 junior and high school students in the stage of secondary education, it is important to introduce appealing points of engaging in the nuclear energy 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 the Fukushima Daiichi NPS, and in a broad sense, of the career path in science and technology fields. The secondary education stage is a stage in which, as a preparatory stage for participating in and contributing to society, students can develop their individuality and competence while being influenced by researchers, engineers, and science teachers who are active in society, and can make independent choices and decide their career paths. From this perspective, NDF holds the “International Mentoring Workshop Joshikai in Fukushima” for middle and high school female students mainly in Fukushima Prefecture in cooperation with the OECD/NEA as an effort to increase interest in science and engineering, especially in decommissioning, etc., through exchanges with female researchers and engineers in order to enhance understanding among women and help increase their motivation to participate in development studies. In 2020, the "International Mentoring Workshop Virtual Joshikai in Fukushima 2020" was held using the online system, even in the midst of the global outbreak of the new coronavirus infection, and it was held using the online system in 2021 in succession. In addition, “student sessions” for high school students, etc., were held 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, etc., 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. These sessions and forums will continue to be held in 2021 by utilizing an online system.

For the development of such technical personnel associated with decommissioning of the Fukushima Daiichi NPS, it is also necessary to expand into wider fields including fundamental research and related research. In the course of raising the level of the entire fundamental technological base in Japan, it is expected that initiatives to deal with the nuclear legacy and nuclear safety will take deeper root.

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, 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), the government is promoting the continuation and expansion of on-site classes and the promotion of the use of radiological supplementary readers. The NDF also holds workshops for local students to consider 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. Among the reactors that have experienced severe accidents are the Windscale Pile-1 reactor in the UK, the Three Mile Island Unit 2 reactor (TMI-2) in the US, and the Chernobyl Unit 4 reactor (ChNPP-4) in Ukraine. These facilities have been undergoing stabilization work and safety measures for many years. In addition, there are large uncertainties in the management of a wide variety of radioactive materials at legacy sites overseas, and decommissioning and environmental remediation efforts are expected to take a long time. 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.

In addition, the decommissioning of the Fukushima Daiichi NPS is a process to solve unexplored engineering problems by combining knowledge from various fields, not limited to the nuclear field, and it can be interpreted that the decommissioning of the Fukushima Daiichi NPS can be an important place to create innovation. Consolidating diverse knowledge and experience from around the world in Fukushima is, in the first instance, an important effort to steadily advance the decommissioning of the Fukushima Daiichi NPS itself. This is also an important initiative from the perspective of leading innovation through the decommissioning process to the restoration of local industry and building a symbiotic relationship with the local community which is essential for the long-term progress of decommissioning.

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 the OECD/NEA. These international organizations have an important role in establishing international standards for decommissioning. It is important to participate in formulating international standards based on Japan’s experience in decommissioning to promote the decommissioning of the Fukushima Daiichi NPS in an open manner to the international community. It is also expected to fulfill part of Japan’s responsibility to the international community by sharing Japan’s experience with other countries. From this perspective, 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 participation in their side events of the IAEA General Conference and speaking at major international conferences such as the OECD/NEA Steering Committee. By securing the confidence 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. (Attachment 14)

In addition, in the course of the above-mentioned international cooperation, due to the global outbreak of the 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. Meanwhile, IAEA, OECD/NEA and other overseas organizations concerned are holding face-to-face meetings as in the past, and there are increasing opportunities to participate in, and speaking at conference venues. As the number of cases of COVID-19 infection has been increasing and decreasing repeatedly, NDF is considering and holding face-to-face meetings, online meetings, and meetings combining face-to-face and online meetings, taking into account the movements of overseas organizations and the prevalence of the COVID-19 at home and abroad. (Fig. 47)

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.

Fig. 47 Exchanging opinions with experts overseas through face-to-face meeting and online (Held in June 2022)

6.2.2 Key issues and strategies

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

The decommissioning of the Fukushima Daiichi NPS is expected to be a long-term project with challenging engineering issues. To solve these issues, it is important to utilize the world's highest level of technology and human resources and incorporate the experience and knowledge gained from decommissioning the legacy sites that have preceded this project.

The decommissioning of legacy sites has many points of reference in terms of technology and management as a leading model. From a technical aspect, in each country with a legacy site, public organizations related to decommissioning are playing a central role in promoting decommissioning to cope with issues such as the necessity of new technologies and expertise that differ from the operation and maintenance of nuclear reactors. From an managemental aspect, public decommissioning-related organizations also play a central role in developing systems, policies, and strategies, project planning and management, safety assurance, and local communication.

Therefore, it is important for Japan to conclude cooperative agreements and arrangements among domestic and overseas organizations under the intergovernmental framework, continue to implement regular information exchange, and accumulate and learn the world's intelligence on technical and managemental aspects.

NDF needs to continue to maintain and develop long-term partnerships with public decommissioning organizations that play a central role in each country, such as NDA in the UK, CEA (French Alternative Energies and Atomic Energy Commission) in France, and DOE (Department of Energy) in the US, and integrate wisdom and knowledge including learning obtained from decommissioning of overseas legacy sites through information exchanges and leverage them for decommissioning in Japan.

In moving forward with decommissioning Japan has received support from the international community and 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 such as the DAROD project by the IAEA and the joint project by the OECD/NEA.

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 results 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 the COVID-19 are 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 secure opportunities for face-to-face communication.

Currently, the decommissioning of the Fukushima Daiichi NPS, is being carried out under contracts between many companies and decommissioning executors both in Japan and abroad to steadily proceed with decommissioning, and the global market for decommissioning is expanding greatly. 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[116]. 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

[116] Brought up in the Decommissioning Strategy Committee in June 2021
https://www.dd.ndf.go.jp/files/user/pdf/committee/pdf/summary/20210618dscsum.pdf

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.

≪An example and issue that revealed the importance of ensuring transparency of information and disseminating information≫

〜Discharging of ALPS-treated water into the sea〜

As one example that revealed the importance of ensuring transparency and information dissemination, the reaction from countries can be given, following the announcement of the policy on the discharge of ALPS-treated water into the sea.

In April 2021, the Japanese government announced the discharge of ALPS-treated water into the sea on the premise that safety would be ensured and that measures against reputational damage would be thoroughly taken.

In response to this announcement by the Japanese government, foreign governments, related organizations, and international organizations that understand the status of Japan’s decommissioning and appreciate the transparency of the national efforts, based on the information that has been disseminated so far, provided comments in support of Japan’s decision, with the expectation of ensuring transparency continuously. In addition, the IAEA announced that it would actively cooperate with the discharge of ALPS-treated water into the sea from a third-party standpoint by dispatching a review mission and supporting environmental monitoring. These actions are pushing to gain international understanding of offshore release, the importance of ensuring transparency, accurate information dissemination, and building cooperative relationships with the international community were recognized again.

On the other hand, some countries issued comments expressing concern about the impact on the environment and questioning the transparency in discharge. The follow-up review mission [117] by IAEA made in April 2020 held the view that to support the implementation of the chosen disposition path, supported by a local, national and international communication plan ensuring a proactive and timely dissemination of information to all stakeholders and general public are necessary. In order to gain the understanding of the international community on the safety of ALPS-treated water, it is necessary to fully cooperate with IAEA and continue to disseminate information carefully by ensuring the transparency of information.

It is important to continue to obtain the understanding and cooperation of these countries for the steady implementation of decommissioning, including the future discharge of ALPS-treated water into the sea. On the premise of ensuring transparency of information, TEPCO needs to ensure that the government and other relevant domestic organizations disseminate accurate and easy-to-understand information based on the interests and in the amount of knowledge and information of the recipient at international conferences, international joint activities, and on websites.

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

[117] The follow-up review mission (April 2, 2020)
https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/iaea_review.html

regions and industries. In light of this, TEPCO will contribute to job creation, human resource development, and the creation of industrial and economic infrastructure in the region through decommissioning, while collaborating with efforts to realize the "Fukushima Innovation Coast Framework Promotion Organization", which sets the accumulation of decommissioning-related industries in the Hamadori region as a priority field, and aims to achieve "Balancing between reconstruction and decommissioning".

6.3.1.2 Specific measures under the current situation

(1) Communication initiatives

The government has been exchanging opinions with local related organizations at the "Fukushima Advisory Board on Decommissioning, Contaminated Water and Treated Water" and other meetings held by the government, disseminating information on the current status of decommissioning through videos, websites, brochures, etc., and holding briefings and roundtable discussions for local residents and related local governments.

NDF is holding the International Forums for the purpose of frank exchange of opinions on decommissioning with participants including local communities and organizations concerned, and for sharing of the latest knowledge, technical achievements, and issues on decommissioning with experts in Japan and overseas. They also hold briefings on the progress of decommissioning at meetings hosted by the national and local governments. In order to promote the exchange of opinions at the International Forums, a “hearing activity” is held every year to hold a conversation with local communities including high school and technical college students before the International Forum is held. Then, their real voice is collected, summarized and edited as a booklet, and distributed as the “Voice from Fukushima” at the International Forums.

TEPCO has been making efforts to provide explanations and dialogue to regional representatives at conferences hosted by the government and Fukushima Prefecture, as well as to hold regular press conferences and lectures for the media, and to disseminate information through its website and brochures. In addition, the company is actively accepting visitors to the Fukushima Daiichi NPS and holding roundtable discussions, as it is very effective in forming a common understanding to have people see the current status of decommissioning as it is (number of visitors: 18,238 in FY2019, 4,322 in FY2020, and 6,138 in FY2021). On the other hand, in the current situation where direct observation of Fukushima Daiichi NPS is limited and because of the fact that some people are not able to make direct inspections due to the new coronavirus infection, a virtual tour of the decommissioning site of the Fukushima Daiichi NPS has been available on TEPCO's website since 2018. It is also important to proactively disseminate information utilizing such simulated experience programs are more useful than ever.

In addition, the "TEPCO Decommissioning Archive Center" established in Tomioka Town as a place where people can learn about the process of the nuclear power plant accident and the progress of decommissioning has about 80,000 visitors as of the end of April 2022, and since fiscal year 2020, the center has been collaborating with the "The Great East Japan Earthquake and Nuclear Disaster Memorial Museum" opened by Fukushima Prefecture in Futaba Town.

(2) Approach to create regional industrial and economic infrastructure through decommissioning

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. At the same time, in order to steadily promote initiatives for local community engagement, TEPCO has reformed their organization as needed. The local partnership promotion group was established in the Fukushima Daiichi Decontamination & Decommissioning Engineering Company in April 2020, TEPCO set up the specialized department working to engage with local community at the Fukushima Daiichi NPS in October 2020, and the Hama-dori decommissioning industry project office that directly reports to the president was also established. Based on the division of roles, they are engaged in internal/external coordination, field response to local communities and consideration of medium-and-long-term direction.

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 is 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, as well as holding a matching business meetings between prime contractors and local companies, making individual visits to local companies, and organizing inspection tours of Fukushima Daiichi NPS for 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 are expected to continue for the foreseeable future, TEPCO will make active use of rapidly developing 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, 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), the government is implementing the measures to overcome rumors by communicating safety based on scientific evidence, providing support for capital investment and expansion of sales channels for fishermen, and enhancing safety nets such as funds and compensation. TEPCO has been making efforts to suppress reputational damage through information dissemination via its "Treated-water portal site" and safety confirmation by related organizations, etc. based on 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

As described in 6.3.1.2 (2), 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 April 27, 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. It is 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. As mentioned in 6.3.1.2 (2), 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.

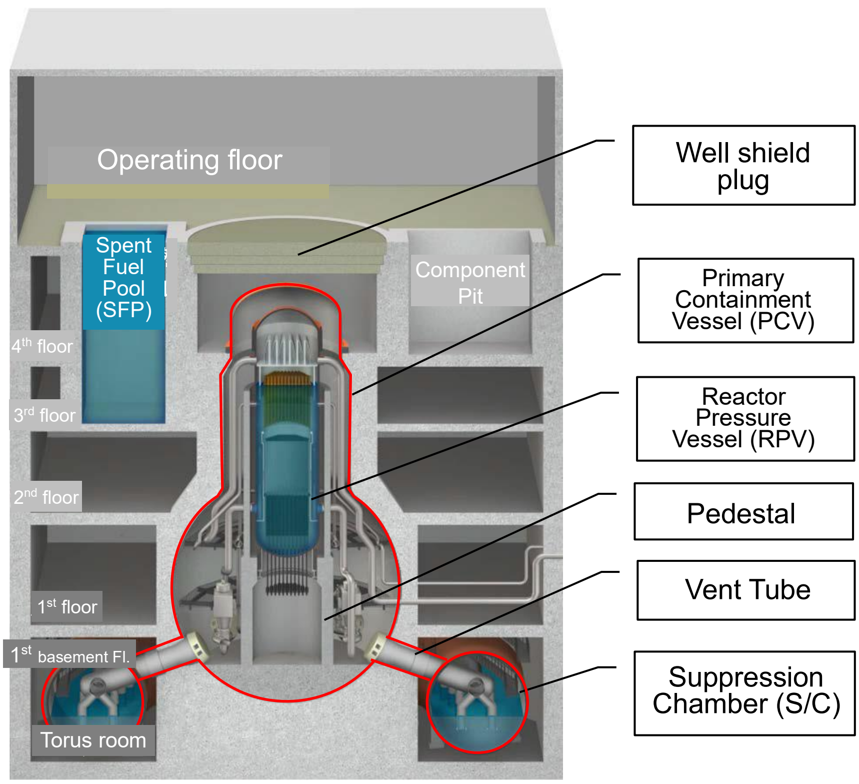
Moreover, it is necessary to further strengthen cooperation and collaboration with local governments, including Fukushima Prefecture, and local related organizations, including the Fukushima Innovation Coast Framework Promotion Organization and the Fukushima Soso Recovery Promotion Organization, which 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.

List of Acronyms/Glossaries

ALARP	As Low As Reasonably Practicable：Risk should be reduced as far as reasonably practicable including risk/benefit criteria or cost while taking feasibility of risk reduction measures into account.
ALARA	As Low As Reasonably Achievable：The principle of radiological protection in which it advocates that all radiation exposure must be maintained as low as reasonably achievable in consideration of social and economic factors.
AWJ	Abrasive Water Jet
DOE	United States Department of Energy
FP	Fission Products
HIC	High Integrity Container
IAEA	International Atomic Energy Agency
IRID	International Research Institute for Nuclear Decommissioning
JAEA	Japan Atomic Energy Agency
JAEA/CLADS	JAEA Collaborative Laboratories for Advanced Decommissioning Science
MADA evaluation	Multi-attribute decision analysis
NDA	Nuclear Decommissioning Authority
NDC	Nuclear Development Corporation
NDF	Nuclear Damage Compensation and Decommissioning Facilitation Corporation
NFD	Nippon Nuclear Fuel Development Co., Ltd, MHI
OECD/NEA	OECD Nuclear Energy Agency
PCV	Primary Containment Vessel
RPV	Reactor Pressure Vessel
S/C	Suppression Chamber
SED	Safety and Environmental Detriment
SGTS	Standby Gas Treatment System
TMI-2	Three Mile Island Nuclear Power Plant Unit 2
Penetration X-2	Penetration X-2 of PCV
Penetration X-6	Penetration X-6 of PCV
Center of the World Intelligence project	The project that promotes nuclear science and technology and human resource development gathering wisdom and knowledge
Operating Floor	Operating Floor of the buildings
Commitment	The commitment to the people of Fukushima for achieving both reconstruction and decommissioning
Kashiwazaki-Kariwa	Kashiwazaki-Kariwa Nuclear Power Station

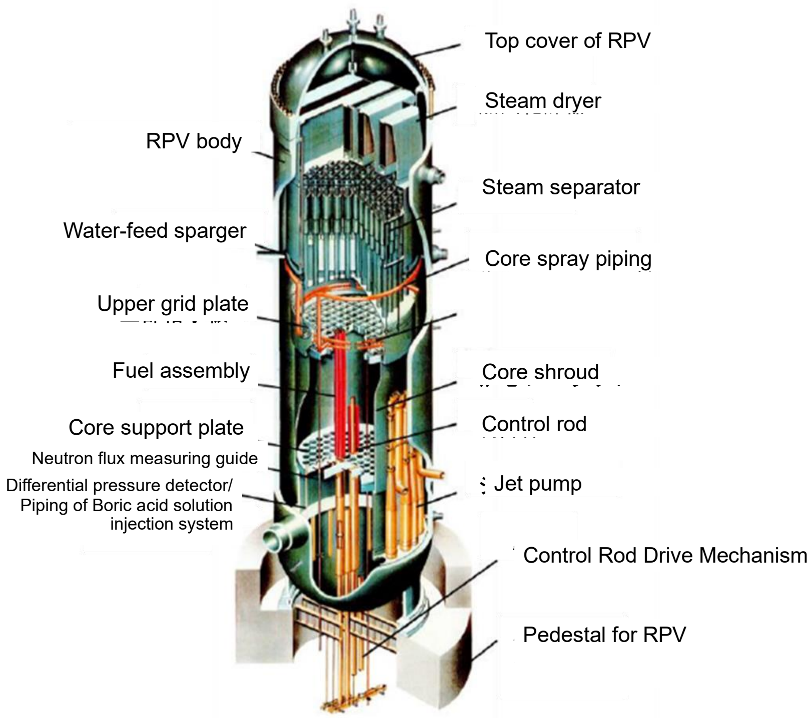
Technical Strategic Plan	Technical Strategic Plan for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.
Technical Prospects	Prospects of processing/disposal method and technology related to its safety
International Forum	International Forum on the Decommissioning of the Fukushima Daiichi Nuclear Power Station
Submersible ROV	A remotely operated submersible survey vehicle (Remotely Operated Vehicle)
Mid-and-Long-term Roadmap	Government-developed “Mid-and-long-term Roadmap” toward the decommissioning of TEPCO’s Fukushima Daiichi Nuclear Power Station Units 1 to 4
TEPCO	Tokyo Electric Company Holdings, Inc.
Non-destructive assay	A method to evaluate the amount of nuclear fuel without destroying the sample by using radiation, quantum, etc. emitted, scattered, or transmitted from the sample
Fukushima Daiichi NPS	Fukushima Daiichi Nuclear Power Station of Tokyo Electric Company Holdings, Inc.
Measurement by muon (fuel debris detection technology with muon)	A technology to grasp location or shape of fuel in using the characteristics by change of number or track of particle depending on the difference of density, when muons atoms (muon) arrive from the cosmos and atmospheric air and pass through a substance
Target Map for Reducing Medium-term Risk	Measures for Mid-term Risk Reduction at TEPCO’s Fukushima Daiichi NPS (Risk Map)

Inventory	Amount of radioactive material contained in the risk source (radioactivity, concentration of radioactive material, or toxicity possessed by the radioactive material)
Well plug (Shield plug)	A top cover to screen upper part of Primary Containment Vessel made of concrete (It is the floor face of the top floor of reactor building in operation)
Engineering	Design and other work to apply technical elements to the site
Cask	Special container used for transporting and storing spent fuel
Subdrain	Wells near the building
Sludge generated at decontamination device (waste sludge)	Sludge containing high level of radioactive material generated at the decontamination device (AREVA), which was operated for contaminated water treatment from June to September 2011
Spray curtain	Watering to contain dust and allow it to settle
Sludge	Muddy substance, dirty mud
Slurry	A mix of dirty mud and mineral, etc. in water
Zeolite	Sorbent used to recover radioactive materials such as cesium
Shell structure	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
Torus room	A room that houses a large donut-shaped suppression chamber that holds water for emergency core cooling system.
Fuel debris	Nuclear fuel material molten and mixed with a part of structure inside reactor and re-solidified due to loss of reactor coolant accident condition
Bioassay	A method for evaluating the types and amounts of radionuclides ingested into body by analyzing samples from the human body, such as excrement
Facing (paving)	Covering the ground surface in the power station with asphalt, etc.
Platform	Footing for work installed under RPV inside pedestal
Flanged tank	Bolted assembly tanks
Pedestal	A cylindrical basement that supports a body of reactor
Manipulator	Robot arm to support fuel debris retrieval
Mock-up	A model which is designed and created as close to real thing to possible
Boric acid, sodium chloride	Soluble neutron absorber (boric-acid solution)



(Courtesy of IRID)

Fig. 48 Structural drawing inside Reactor building



(Courtesy of IRID)

Fig. 49 Structural drawing inside Reactor Pressure Vessel (RPV)

List of Attachment

Contents

Attachment 1 Revision of the Mid-and-Long-term Roadmap and the earlier published Technical Strategic Plan

[1st Edition of the Mid-and-Long-term Roadmap (December 21, 2011)]

- In response to completion of Step 2 described in “the Roadmap towards Restoration from the Accident at the Fukushima Daiichi NPS” compiled by the government and Tokyo Electric Power Company (TEPCO) after the accident, the necessary measures to be progressed over the mid-and-long-term, including efforts to maintain securely stable conditions, fuel removal from spent fuel pools (SFPs), fuel debris retrieval, etc. were compiled by three parties of TEPCO, Agency for Natural Resources and Energy, and Nuclear and Industrial Safety Agency and conclude at The Government and TEPCO’s Mid-to-Long-Term Countermeasure Meeting.
- Basic principles towards implementation of mid-to-long efforts were proposed and targets with time schedules were established by dividing the period up to completion of decommissioning into three parts; the period up to spent fuel removal start (1st period), the period up to fuel debris retrieval start from completion of the 1st period (2nd period) and the period up to completion of decommissioning from completion of the 2nd period (3rd period).

[Mid-and-Long-term Roadmap Revised 1st Edition (July 30, 2012)]

- “Specific plan on the matters to be addressed with priority to enhance mid-and-long-term reliability” developed by TEPCO after completion of Step 2 was reflected and revised targets based on the state of work progress were clearly defined.

[Mid-and-Long-term Roadmap Revised 2nd Edition (June 27, 2013)]

- Revised schedule was studied (multiple plans were proposed) based on the situation of each Unit concerning fuel removal from SFP and fuel debris retrieval, and R&D Plan was reviewed based on the above.

[Technical Strategic Plan 2015 (April 30, 2015)]

- The 1st edition of the Technical Strategic Plan was published to provide a verified technological basis to the Mid-and-Long-term Roadmap from the viewpoint of proper and steady implementation of decommissioning of the Fukushima Daiichi Nuclear Power Station.
  (NDF was inaugurated on August 18, 2014 in response to reorganization of existing Nuclear Damage Compensation Facilitation Corporation)
- Decommissioning of the Fukushima Daiichi Nuclear Power Station was regarded as “Continuous risk reduction activities to protect human beings and environment from risks caused by radioactive materials generated by the severe accident”, and Five Guiding Principles (Safe, Reliable, Efficient, Prompt, Field-oriented) for risk reduction were proposed.
- Concerning the field of fuel debris retrieval, feasible scenarios were studied by regarding the following methods as the ones to be studied selectively; the submersion-top entry method, the partial submersion-top entry method, and the partial submersion-side entry method.
- Concerning the field of waste management, policies for storage, control, etc. were studied from a mid-and-long-term viewpoint based on the basic concept for ensure safety during disposal or for a proper processing method.

[Mid-and-Long-term Roadmap Revised 3rd Edition (June 12, 2015)]

- While much importance was placed on risk reduction, priority-setting for actions was performed so that risks could definitely be reduced in the long term.
- Targets for several years from now were concretely established including policy decision on fuel debris retrieval (two years later from now was targeted), volume reduction of radioactive materials contained in the stagnant water in the buildings by half (FY2018), etc.

[Technical Strategic Plan 2016 (July 13, 2016)]

- In response to the progress state of decommissioning after publication of the Technical Strategic Plan

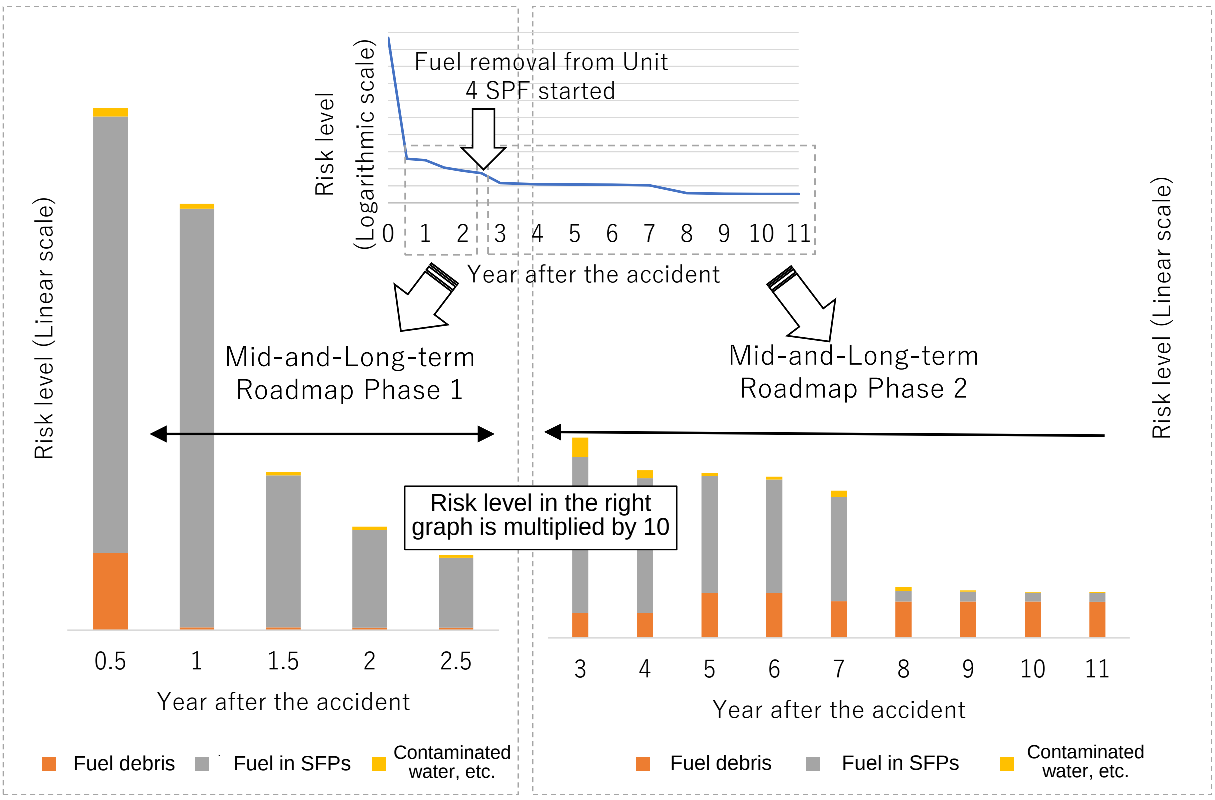
2015, concrete concepts and methods were developed based on the concept and direction of the efforts of the Technical Strategic Plan 2015 to achieve the target schedule specified in “Policy decision on fuel debris retrieval for each unit” which is expected to be completed by about summer 2017 defined in the Mid-and-Long-term Roadmap, “Compiling of the basic concept concerning processing/disposal of radioactive waste” which is expected to be complete in FY2017, etc.
[Technical Strategic Plan 2017 (August 31, 2017)] • Feasibility study was conducted on the three priority methods for fuel debris retrieval. Recommendations for determining fuel debris retrieval policy were made and efforts after policy decision including preliminary engineering were recommended as strategic recommendations. • Recommendations were made for compiling the basic concept concerning solid waste processing/disposal.
[Mid-and-Long-term Roadmap Revised 4th Edition (September 26, 2017)] • Policy on fuel debris retrieval and immediate efforts were decided based on NDF technical recommendations. • Basic concepts concerning solid waste processing/disposal were compiled. • Individual work was defined based on the viewpoint of “Optimization of total decommissioning work”.
[Technical Strategic Plan 2018 (October 2, 2018)] • The Plan added contaminated water management and fuel removal from SFP, and presented the direction from mid-to-long-term perspective that overlooks entire efforts of decommissioning of Fukushima Daiichi NPS.
[Technical Strategic Plan 2019 (September 9, 2019)] • The plan presented the strategic recommendation for determining fuel debris retrieval methods for the first implementing unit as well as the direction from mid-to long-term perspective that overlooks entire efforts of decommissioning of Fukushima Daiichi NPS including waste management, etc.
[Mid-and-Long-term Roadmap Revised 5th Edition (December 27, 2019)] • The first implementing unit and the method of fuel debris retrieval were determined. • The methods of fuel removal from SFP in Units 1 and 2 were changed. • TEPCO maintains the current target to suppress the amount of contaminated water generation to about 150m3/day within 2020, in addition, set the new target to less than 100m3/day within 2025.
[Technical Strategic Plan 2020 (October 6, 2020)] • The plan characteristically included providing of the Mid-and-Long-Term Decommissioning Action Plan, identifying of requirements for the study of fuel debris retrieval methods toward further expansion of the scale, clarifying of the concept for ensuring safety in decommissioning operations, and strengthening of management system in response to the growing importance of R&D.
[Technical Strategic Plan 2021 (October 29, 2021)】 • The plan presented the issues to be addressed for the trial retrieval of fuel debris to minimize the impact of the new coronavirus infection, the issues to be discussed for the selection of methods for further expansion of retrieval scale, and the efforts for the ALPS-treated water, while offering the prospects of processing/disposal method and technology related to its safety,

Attachment 2　Major risk reduction measures performed to date and future course of action

Change in the risk level over time assessed and expressed by SED for the entire Fukushima Daiichi NPS is shown in Fig. A 2-1. The vertical axis in the top graph in the figure shows the risk level in common logarithmic scale and the horizontal axis shows number of years after the accident.

Although the risk level at the time of zero year after the accident was at high level caused by the fuel in SFP which lost its cooling function and the molten nuclear fuel, over the time of 0.5 years after the accident the risk level has been reduced with a significant decrease in both Hazard Potential and Safety Management, because of implementation of safety measures including cooling function restoration of SFPs, cooling of fuel debris with water injection by core spray system, nitrogen injection, etc. (in 2011) as well as the contribution of inventory and decay heat decrease due to decay of radioactive materials.

The risk level in 0.5 to 2.5 years after the accident is shown in the enlarged graph (the vertical axis is in linear scale) with the breakdown of major risk source (fuel debris, fuel in SFP and contaminated water, and the others) at the bottom left in the figure and the similar graph since 3 years after the accident is given in the bottom right with the risk level multiplied by 10. These graphs demonstrate that a continuous risk reduction has been achieved.



Evaluation of fuel in SFP 8 years after the accident occurred reflects the results of water temperature rise in the testing on SFP cooling shutdown. (For detail, see Fig. 3 in Chapter 2 of main part.)

Fig. A2- 1 Reduction of risks contained in the Fukushima Daiichi NPS

Change in the risk level with further breakdown of major risk sources over time since 0.5 years after the accident is shown in Fig. A2-2. With a logarithmic scale, risk sources can be indicated that are too small to be displayed in the linear scale of Fig. A2- 1. Fuel in the Common Spent Fuel Storage Pool and the Dry Cask Temporary Custody Facility are not shown which stay in the region of sufficiently stable management. The “stagnant water in buildings + zeolite sandbags” shown in Fig. A2- 2 was assessed based on the information on the stagnant water in buildings for the period of 0-8 years after the accident. However, since 9 years after the accident, the condition of zeolite-containing sandbags placed in the basement of the process main building and the high-temperature incinerator building has become clear, and this information was incorporated into the assessment.

Among the major risk sources, fuel debris, fuel in SFPs, stagnant water in buildings, zeolite-containing sandbags, and secondly waste generated by water treatment have relatively high risk levels. Although, in recent years, the treatment of the stagnant water in buildings has progressed and the risk level of the “stagnant water in buildings + zeolite sandbags” has been on a declining trend, attention should be paid to zeolite sandbags laid with a high dose because they may hinder future decommissioning work. In regard to secondly waste generated by water treatment, the risk level is higher than the assessment of the Technical Strategic Plan 2021 (10 years after the accident), because some ALPS slurry stored in HICs affected by beta irradiation need to be transferred. In addition, as for the water stored in tanks (flanged tank and welded tank), the risk level is higher than 10 years after the accident by reflecting the high radioactivity levels of strontium detected in the remaining concentrated saltwater in the flanged tanks during 2021. However, since the treatment of stored water in flanged tanks itself was in progress, the actual risk level was considered to be higher (broken line: Stored water in tanks (estimated)) than the level shown in the Fig. A2-2 (solid line : stored water in tanks).

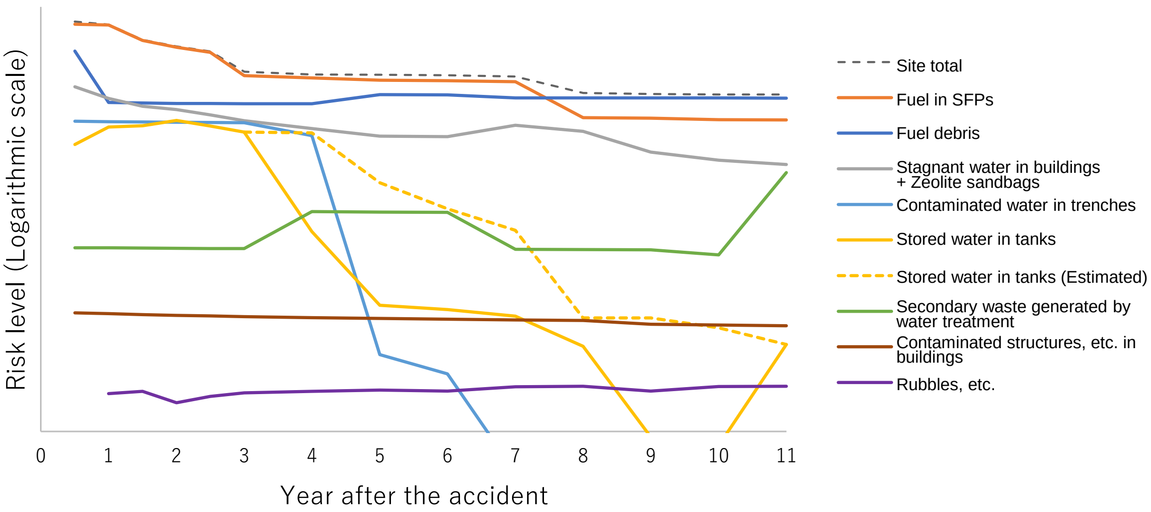


Fig. A2- 2 Change in the risk level for each major risk source

(1) Fuel in SFPs

From one year after the accident, rubble was removed and a cover for fuel removal was installed at Unit 4 in preparation for fuel removal, thereby enhancing the functions of reducing the risk of fuel damage by rubble in SFP and controlling the dispersion of damaged fuel. Further, 2.5 years after the accident, fuel removal was started and the fuel was transferred into the Common Spent Fuel Storage Pool with low Safety Management, and the risk level was lowered (completed in 2014)[118].

Although the effect of risk level reduction was observed due to the decrease in Safety Management through the diffusion control function of the building cover at Unit 1 (installed in 2011), this effect has been currently lost because the building cover was removed (in 2015) in preparation for removal of fuel in SFP[119]. In order to prevent dust scattering during rubble removal, a large cover will be installed by FY2023, and fuel removal from SFP is planned to start in FY2027 to FY2028.[120].

For Unit 2, a gantry for fuel removal will be installed on the south side of the reactor building, and the removal of the fuel in SFP is scheduled to start in FY2024 to FY2026[120].

In Unit 3, a cover for fuel removal was installed in 2018 after rubble removal was performed in preparation for fuel removal from SFP, then fuel removal from SFP was started from April 2019. After that, transfer to the Common Spent Fuel Storage Pool was completed in February 2021[121].

In case cooling fuel in SFPs is stopped, the pool water temperature may rise and the pool water level may lower due to decay heat. In and after the 8th year after the accident, as a result of incorporating the observation that the rise in water temperature after cooling shutdown of SFPs was slower than expected, the risk level of fuel in SFPs is lower than previously estimated, because the time margin before the risk of water level lowering becomes apparent increases.

(2) Fuel debris

Although fuel debris was at a high-risk level just after the accident because it was at molten state, and in addition, radioactive materials were released, the risk level was reduced, not only by decay of the radioactive materials, but also by reduction of Hazard Potential and Safety Management because of restoration and strengthening of cooling function.

As described in (1), the diffusion control function of the building cover of Unit 1 reduced the risk associated with the dispersion of fuel debris, and lowered the risk level due to the decrease in Safety Management; however, this effect is currently lost.

---

[118] Decommissioning project, Status of the decommissioning work, Fuel removal work of Unit 4, (Website), Tokyo Electric Power Company Holdings, Inc.

[119] The 57th Study Group on Monitoring and Assessment of Specified Nuclear Facilities, Reference 7 “State of progress of Unit 1 of Fukushima Daiichi NPS and rubble removal on the north side of the operating floor”, Tokyo Electric Power Company Holdings, Inc.

[120] Mid-and-Long-term Decommissioning Action Plan (March 31, 2022), Tokyo Electric Power Company Holdings, Inc.

[121] Decommissioning project, Status of the decommissioning work, Fuel removal from spent fuel pool in Unit 3, (Website), Tokyo Electric Power Company Holdings, Inc.

(3) Stagnant water in buildings + Zeolite sandbags

Although stagnant water in buildings is generated by cooling of fuel debris and immersion of groundwater into the buildings, etc., the risk level has been lowered due to the start of operation of cesium sorption apparatus (KURION) and Second cesium sorption apparatus (SARRY), the effect of subdrains and land-side impermeable walls, water drainage in condensers, and the start of the operation of Third cesium sorption apparatus (SARRY-II). This stagnant water treatment in the buildings so far significantly contributes to risk level reduction of the total site following contribution by fuel removal in SFP.

(4) Contaminated water in trenches

Although the contaminated water of high concentration has been stagnated in the seawater pipe trenches in Units 2 to 4 since immediately after the accident, the trenches were blocked and the treatment of the stagnant water has been completed (in 2015)[122]. With regard to the seawater pipe trench of Unit 1, the concentration of which is lower than that of Units 2 to 4, purification of the stagnant water is under consideration [123].

(5) Stored water in tanks

There are several types of stored water in the tank with different radioactive material concentrations depending on the stage of purification treatment. First of all, the strontium treated water generated from the purification process of the water in the buildings by KURION, SARRY and SARRY Ⅱ is stored as welded tank water. After that, the risk level is further reduced by multi-radionuclide removal equipment (ALPS), etc., and the water is stored in welded tanks as ALPS-treated water, etc. (ALPS-treated water and water under treatment). For the concentrated liquid waste generated from the evaporation-enrichment system, which operated only for a short period immediately after the accident, the precipitated slurry with a high concentration of radioactive materials (concentrated liquid waste slurry) was separated, and the remaining liquid (concentrated liquid waste) is transferred to welded tanks, to reduce the leakage risk and lower the risk level.

The treatment of the concentrated salt water generated from the treatment with KURION before ALPS came into operation was completed in 2015 through the operation of ALPS and the advanced multi-nuclide removal equipment (Advanced ALPS)[124].

Risk level of these stored water in the tanks are also lowered by raising and duplexing the weir (for the existing tanks completed in 2014), transferring from flanged tanks to welded tanks, and treating the Sr-treated water remaining at the bottom of the flanged tanks (in 2019), and treating ALPS-treated water (in 2020). The remaining concentrated saltwater at the bottom of flanged

[122] Decommissioning project, Status of the decommissioning work, Removal of contaminated water in seawater pipe trenches, (Website), Tokyo Electric Power Company Holdings, Inc.

[123] The 98th Study Group on Monitoring and Assessment of Specified Nuclear Facilities “Reference 1 ”Work Schedule for Instruction Items to be Considered Based on the Measures for Mid-and-long-term Risk Reduction at TEPCO’s Fukushima Daiichi NPS (Risk Map), (March 2021 Edition)”, Tokyo Electric Power Company Holdings, Inc.

[124] Decommissioning project, Status of the decommissioning work, Purification of contaminated water, (Website), Tokyo Electric Power Company Holdings, Inc.

tanks is being collected for dismantling the tanks, then the remaining water, after sludge removal by filtering, is planned to be transferred to the process main building.

(6) Secondary waste generated by water treatment

Many radioactive materials have moved from contaminated water to secondary waste through water treatment. What has been generated includes the sludge from decontamination device, the waste sorption vessels by operation of KURION and SARRY (in 2011) and by the SARRY-II (in 2019), ALPS slurry by operation of ALPS (in 2013), the waste sorption vessels by the advanced ALPS (in 2014), waste sorption vessels by the mobile-type treatment system that treated seawater pipe trenches, etc. The risk level is higher than the assessment of Technical Strategic Plan 2021 due to the ALPS slurry stored in the HIC to be transferred and is the dominant factor among the secondary waste generated by water treatment. HICs that are evaluated to have exceeded or are close to exceeding the standard value for cumulative absorbed dose are planned to be transferred during FY2023. Although the number of HICs whose cumulative absorbed dose approached the standard value will gradually increase over time, ensuring that the cumulative absorbed dose can be managed so as not to exceed the standard value will reduce the risk level by systematically implementing the transfer operation. For other risk sources, the sludge from decontamination device greatly contributes to the risk level though, sludge is not newly generated at present, and thus, the risk level of the total secondary waste generated by water treatment is not on an increasing trend. As a tsunami countermeasure, the decontamination sludge stored in the main process building (T.P. 8.5m) will be extracted (planned for FY2023), placed in a storage container, and transferred to the elevated area (T.P. 33.5m) [125].

Although the concentrated liquid waste slurry separated from the concentrated liquid waste was stored in horizontal welded tanks without the weir and placed on the ground without the base, its risk level has been lowered due to the approach to safety taken by installing the reinforced-concrete base and the weir.

(7) Contaminated structures, etc., in the buildings

There is no significant change at the present moment in the risk level of contaminated structures, etc. in the buildings comprised of structures, piping, components, etc. (shield plug, piping of emergency gas processing system and the like) in the reactor buildings, PCVs or RPVs that are contaminated by dispersed radioactive materials caused by the accident.

(8) Rubble, etc.

Rubbles, etc. as solid waste are stored under a variety of conditions such as in solid waste storage, in temporary waste storage and by outdoor accumulation. Each has different Safety Management, and the rubbles stored in outdoor sheet covered storage and outdoor accumulation are of the highest risk level. In the past, the facilities with better management condition have been enhanced by soil covered temporary storage facilities (in 2012), felled tree temporary storage pool (in 2013), expansion of solid waste storage facilities (in 2018), etc. In addition, the rubble from

[125] Safety Monitoring Council for the decommissioning of Fukushima Daiichi NPS (March 8, 2021), Reference 5-1

temporary storage facilities was transferred to the better-controlled solid waste storage facility (in 2020). With the start of operation of the additional solid waste incineration facility (May 2022), combustible rubbles and other materials stored outdoors can be transferred to the solid waste storage facility after incineration to reduce their volume. Furthermore, outdoor temporary storage is planned to be discontinued by the end of FY 2028 by further increasing volume reduction installations and solid waste storages, etc., in accordance with the Solid Waste Storage Management Plan[126].

[126] The Solid Waste Storage Management Plan at the Fukushima Daiichi NPS (July 2022 Edition), Tokyo Electric Power Company Holdings, Inc.

Attachment 3 Overview of SED indicator

Risk analysis targeting various risk sources, which have diverse characteristics and exist all over the site, was conducted in reference to the SED indicator[127] developed by the NDA. The SED indicator is an important factor to decide priority to implement risk reduction measures. It was partially modified (refer to the following pages) so that unique characteristics of the Fukushima Daiichi NPS could be easily reflected when it was applied to the Fukushima Daiichi NPS. Overview of the SED indicator and the modified part to be applied to the Fukushima Daiichi NPS are described below.

The SED indicator is expressed by the following formula. The first formula is the one widely used for waste assessment and the second is for contaminated soil assessment. In each formula, the first term is referred as to "Hazard Potential" and the second as "Safety Management" of risk sources.

$$SED = (RHP + CHP) \times (FD \times WUD)^4$$

or

$$SED = (RHP + CHP) \times (SSR \times BER \times CU)^4$$

Each indicator is explained below. Although CHP stands for "Hazard Potential" of the chemical substance, details are not given here as it is not used in this section.

(1) Hazard Potential

Radiological Hazard Potential (RHP) is an indicator representing the potential impact of radioactive materials and represents the impact to the public by the following formula when the total amount of radioactive materials is released.

$$RHP = Inventory \times \frac{Form\ Factor}{Control\ Factor}$$

Inventory is defined as shown below by Radioactivity of risk sources and the Specific Toxic Potential (STP) and corresponds to the effective radiation dose[128]. The STP is defined as the volume of water required to dilute 1TBq of radioactive materials and corresponds to the radiation dose coefficient. Ingestion of a certain amount of such diluted water throughout the year will result in a radiation exposure dose of 1mSv. The SED indicator conservatively uses the larger radiation dose coefficient between ingestion and inhalation.

$$Inventory(m^3) = Radioactivity(TBq) \times STP(m^3/TBq)$$

[127] NDA Prioritization – Calculation of Safety and Environmental Detriment score, EPGR02 Rev.6, April 2011.
[128] Instruction for the calculation of the Radiological Hazard Potential, EGPR02-WI01 Rev.3, March 2010.

Form Factor (FF), as shown in Table A3-1, is an indicator representing how much radioactive material is actually released depending on material form, such as gas, liquid, solid, etc. The indicator is set assuming that 100% of radioactive material is released in the case of gas and liquid when containment function is totally lost and that 10% of radioactive material is released in the case of powder based on the measurement data. Because of no clear basis, the indicator in case of solid is set to a sufficiently small value assuming that the solid materials are less easily released.

In Table A3-1, several expected forms, especially for fuel debris, are added to the definition used by the NDA. The scores for the form of No.4 and No.5 are newly established.

Control Factor (CF), as shown in Table A3-2, is an indicator representing time allowance available before restoration when safety functions maintaining current stable state are lost. CF is taking into account exothermicity, corrosivity, flammability, hydrogen generation, reactivity with air or water, criticality, etc. which are typical characteristics of risk sources. CF is the same as the one defined by the NDA.

(2) Safety Management – FD and WUD

Facility Descriptor (FD) is an indicator representing whether containment function of the facility is sufficient or not. Risk sources are ranked by score based on a combination of the factors including integrity of the facility, redundancy of containment function, safety measure condition, etc.

Waste Uncertainty Descriptor (WUD) is an indicator representing whether any impact is generated or not when the risk source removal is delayed. Risk sources are ranked by score based on a combination of the factors including degradation or activity of the risk source, packaging state, monitoring condition, etc.

As these indicators are difficult to be applied to the Fukushima Daiichi NPS if they are used as defined by the NDA, they are re-defined as shown in Table A3-3 and Table A3-4 respectively.

(3) Safety Management - SSR, BER and CU

The definition of SSR, BER and CU used for Safety Management assessment for contaminated soil is the same as the one defined by the NDA and each score is shown in Table A3-5.

Speed to Significant Risk (SSR) is an indicator concerning the time until the public is affected through such as distance to the site boundary, groundwater flow conditions, etc. and to assess urgency of taking measures.

Benefit of Early Remediation (BER) is an indicator to assess benefits obtained from early implementation of measures against risks.

Characterization Uncertainty (CU) is an indicator to assess reliability or uncertainty in the risk assessment model.

Table A3-1 Definition and score of FF

No.	Form	FF
1	Gas, liquid, watery sludge* and aggregated particles*	1
2	Other sludge	1/10 = 0.1
3	Powder and removable contaminants (surface contamination, etc.)*	1/10 = 0.1
4	Adhesive* or penetrating contaminants (surface penetrating contamination)*	1/100 = 0.01
5	Fragile and easily decomposable solid (porous MCCI (Molten Core Concrete Interaction), etc.)*	1/10,000 = 1E-4
6	Discrete solid (transportable size and weight by human power such as pellets, etc.)	1/100,000 = 1E-5
7	Large monolithic solid, activated component	1/1,000,000 = 1E-6

* : Form which is added to the NDA definition to enhance applicability to the case of the Fukushima Daiichi NPS

Table A3-2 Definition and score of CF

No.	Time allowance available before any risk is realized	CF
1	Hours	1
2	Days	10
3	Weeks	100
4	Months	1,000
5	Years	10,000
6	Decades	100,000

Table A3-3 Criteria and score of FD

Category	Criteria (NDA definition is modified to enhance applicability to the case of the Fukushima Daiichi NPS)	NDF Score
1	No component for diffusion control function exists. Therefore, no assessment for containment function is available.	100
2	"Safety assessment criteria*2" are not satisfied at "the time of assessment*1" caused by the accident effects, etc. The component for diffusion control function is single.	91
3	"Safety assessment criteria" are not satisfied at "the time of assessment" caused by the accident effects, etc. The component for diffusion control function is multiple.	74
4	"Safety assessment criteria" are not satisfied until "the time of work (such as transfer, treatment, recovery, etc.) *3" for the risk source contained in the component for diffusion control function. The component or diffusion control function satisfying "safety assessment criteria" exists at "the time of assessment".	52

5	Integrity of diffusion control function has been assessed and “safety assessment criteria” are satisfied until “the time of work (such as transfer, treatment, recovery, etc.)” for the risk source. Frequency of occurrence of “contingency*4” is high, and when contingency occurs countermeasures preventing diffusion of the risk source contained in the component are not sufficient. The component for diffusion control function is single.	29
6	“Safety assessment criteria” is satisfied until “the time of work (such as transfer, treatment, recovery, etc.)” for the risk source. Frequency of occurrence of “contingency” is high, and countermeasures preventing diffusion of the risk source contained in the component are not sufficient. The component for diffusion control function is multiple.	15
7	“Safety assessment criteria” are satisfied until “the time of work (such as transfer, treatment, recovery, etc.)” for the risk source. Facilities dissatisfying “safety assessment criteria” exist in the surrounding area, and the potentiality is high to make (receive) the diffusion impact*5 of the risk source to (from) these adjacent facilities. The component for diffusion control function is single.	8
8	“Safety assessment criteria” are satisfied until “the time of work (such as transfer, treatment, recovery, etc.)” for the risk source. The potentiality is high to make (receive) the diffusion impact of the risk source to (from) these adjacent facilities. The component for diffusion control function is multiple.	5
9	“Safety assessment criteria” are satisfied until “the time of work (such as transfer, treatment, recovery, etc.)” for the risk source. The potentiality is low to make (receive) the diffusion impact of the risk source to (from) these adjacent facilities. The component for diffusion control function is single.	3
10	“Safety assessment criteria” are satisfied until “the time of work (such as transfer, treatment, collection, etc.)” for the risk source. The potentiality is low to make (receive) the diffusion impact of the risk source to (from) these adjacent facilities. The component for diffusion control function is multiple.	2
*1. This refers to “at the time” of study on SED score, i.e., “at the present time” of assessment. *2. “Safety assessment criteria” described in this sentence refer to “the matters for which measures should be taken” or “securing of diffusion control function within the scope of design basis event”. *3. This refers to the time of “recovery” of the risk source for disposition and carrying out for which SED score shall be studied. *4. External events (natural disasters, etc.) are postulated as contingencies. *5. The potentiality of diffusion of the risk source exists to (from) adjacent facilities when facilities receive external impact caused by contingencies or impact caused by any events (fire, etc.), etc.		

Table A3-4 Criteria and score of WUD

Category	Criteria (NDA definition is modified to enhance applicability to the case of the Fukushima Daiichi NPS)	NDF Score
1	The material is fuel (which contains fissile material) and active*1. Necessary information (existent amount, existent location, radioactivity, etc.) for work including treatment, recovery, etc. is insufficient (cannot be confirmed or estimated), and control and surveillance with monitoring, etc. are unavailable. Handling is impracticable for the current form or condition because of reasons where the form is not proper for handling, or that it is not stored in a special container.	100
2	The material is fuel and active (which has fissile properties). Necessary information for work including treatment, recovery, etc. is insufficient, and control and surveillance are unavailable. Handling is practicable for the current form or condition because of reasons where the form is proper for handling or that it is stored in a special container.	90
3	Although the material is active, it is not fuel (but waste). Necessary information for work including treatment, recovery, etc. is insufficient.	74
4	The material is fuel and active (which has fissile properties). Necessary information for work including treatment, recovery, etc. is obtained (can be confirmed or estimated), and control and surveillance with monitoring, etc. are available. Handling is impracticable for the current form or condition.	50
5	The material is fuel and active (which has fissile properties). Necessary information for work including treatment, recovery, etc. is obtained, and control and surveillance are available. Handling is practicable for the current form or condition.	30
6	Although the material is active, it is not fuel (but waste). Necessary information for work including treatment, recovery, etc.	17
7	Although the material is inactive*2, it has physical or geometrical instability. Handling is impracticable for the current form or condition.	9
8	Although the material is inactive, it has physical or geometrical instability. Handling is practicable for the current form or condition.	5
9	The material is inactive and has no physical or geometrical instability or has sufficiently low level of instability. Handling is impracticable for the current form or condition.	3
10	The material is inactive and has no physical or geometrical instability or has sufficiently low level of instability. Handling is practicable for the current form or condition.	2
*1 "Active" refers to possession of activity defined by CF at such a significant level as that activity affects control and work. *2 "Inactive" refers to non-possession of activity or possession of sufficiently low level of activity.		

Table A3-5 Definition and score of SSR, BER and CU

<table>
<tr><th>Indicator</th><th>Score</th><th colspan="2">Criteria</th></tr>
<tr><td rowspan="3">SSR</td><td>25</td><td colspan="2">Risks may be realized within 5 years.</td></tr>
<tr><td>5</td><td colspan="2">Risks may be realized within 40 years.</td></tr>
<tr><td>1</td><td colspan="2">40 years or over (There is very little possibility that risks are realized.)</td></tr>
<tr><td rowspan="3">BER</td><td>20</td><td colspan="2">Implementation of measures can reduce risks by 2 or more orders of magnitude or can facilitate control stepwise.</td></tr>
<tr><td>4</td><td colspan="2">Implementation of measures can reduce risks by 1 or more order of magnitude, but cannot facilitate control.</td></tr>
<tr><td>1</td><td colspan="2">Implementation of measures can only bring negligible risk reduction effects, and cannot facilitate control, either.</td></tr>
<tr><td rowspan="3">CU</td><td>20</td><td>(1)+(2)=
5 to 6
points</td><td rowspan="3">(1) Assessment for the present state
1 point: Major nuclear types and diffusion pathways are monitored.
2 points: Monitored, but insufficient data for construction of assessment model
3 points: Not monitored
(2) Assessment on future prediction
1 point: Sufficient site characteristics are obtained for construction of assessment model.
2 points: Major characteristics representing the site are obtained.
3 points: There is no model usable for future prediction</td></tr>
<tr><td>4</td><td>(1)+(2)=
3 to 4
points</td></tr>
<tr><td>1</td><td>(1)+(2)=
2 points</td></tr>
</table>

Attachment 4 Risk sources that are not explicitly addressed in the major risk sources

Major risk sources are listed in the Table 1 in Chapter 2 of the body part. Looking ahead to the decommissioning of the entire Fukushima Daiichi NPS, it is necessary to focus on risk sources that are not explicitly addressed in the major risk sources. Table A4-1 focuses on waste existed before the accident and radioactive materials with low concentration diffused by the accident, and is summarized with reference to Measures for Mid-term Risk Reduction at TEPCO's Fukushima Daiichi NPS (Risk Map)" provided by the NRA.[129].

Table A4- 1 Risk sources that are not explicitly addressed in the major risk sources (1/3)

Issue	Risk source	Descriptions
Liquid radioactive materials	Sludge on the floor in the buildings	The floor surface of turbine buildings and radioactive waste disposal buildings of Units 1 to 4, waste process building and Unit 4 reactor building remain exposed, and radioactivity of sludge after the exposure was 1.9×10^{13}Bq[130]. For reactor buildings of Units 1 to 3, process main building and high temperature incinerator building, stagnant water processing is underway.
	Underground water tank	The residual water in all the underground water tanks were completely recovered [131]. Dismantling and removal policies are under consideration.
	Accumulated water on site	Extracted by the comprehensive risk inspection performed in 2015[132]. Since then, the concentration of radioactive materials and volume of water are being checked accordingly [133].
Spent fuel	Fuel in Units 5/6 SFP	Unit 5 : 1,374, Unit 6 : 1,456[134]
	Spent control rods, etc.	Spent control rods, etc.: 23,547. Shroud fragments, etc.: 193 m^3[135]. The major nuclide is Co-60.
	In-pool water	Salt removal in Units 2 to 4 was completed in 2013.

129 NRA, Measures for Mid-term Risk Reduction at TEPCO's Fukushima Daiichi NPS (Risk Map)", (March 2021 Edition)

130 The 87th Study Group on Monitoring and Assessment of Specified Nuclear Facilities "Reference 3-5: Progress of the treatment of stagnant water in buildings, etc."

131 The 44th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment "Reference 3-6: On-site Monitoring Status (Conditions of Water Discharge Channels in Units 1 to 3 and Underground Water Storage Tanks)"

132 Comprehensive Risk Inspection of Fukushima Daiichi NPS that impacts outside the Site Boundary - Review Results - (April 28, 2015) Tokyo Electric Power Co., Inc.

133 The 100th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment "Reference 1: Status of contaminated water and other accumulated water on the premises (as of March 24, 2022)"

134 The 100th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment "Reference 3-2 : Storage status of spent fuel , etc."

135 NRA, Material of interview with the licensee "Solid Waste at Fukushima Daiichi NPS" June 18, 2021, Tokyo Electric Power Company Holdings, Inc.

Table A4- 1 Risk sources that are not explicitly addressed in the major risk sources (2/3)

Issue	Risk source	Descriptions
Solid radioactive materials	Rubbles around buildings	Dismantling of rubbles scattered on the roof floor of the buildings due to hydrogen explosions is now in operation and planned. The amount of rubbles has not been confirmed.
	Waste before the earthquake	185,816 drums are stored[136]. The major nuclide is Co-60.
Counter-measures to external events, etc.	Rainwater inleak into buildings	Rubble on the roof was removed and waterproofing was newly provided. Purification materials were installed in the gutters. Check valves were installed in the drain pipes. The roof drain was repaired and closed[137]. Facing of the Elevation T.P.2m, T.P.6m and T.P.8.5m was completed[138].
	Megafloat	The work of bottoming and internal filling was completed[139]. Revetment maintenance and embankment work are underway.
Important issues to progress decommissioning	Dust in operating floor	Below the target value of release control (1×10^7 Bq/h). Gradually declining[140].
	Radiation source on the 3rd and 4th floors of Unit 3 R/B	On the 3rd floor, beams at several locations were damaged. A maximum of 45 mSv/h was measured. On the 4th floor, 104 mSv/h was observed[141].
	Drainage	In drainage A, Cs-137: lowered to ND ~ 23 Bq/L [142]. In drainage K, the contamination source on the roof of the Unit 2 Reactor building was removed, and the contamination level fell to 67 Bq/L. In addition, purification materials were installed[143], and measures such as operation of discriminating-type PSF monitors were taken[144].

136 NRA, Material of Interview with Licensee "Restoration Status of Exhaust Radiation Monitor at Auxiliary Common Facilities for Common Spent Fuel Storage Pool and Ventilation & Air Conditioning System at Fuel Storage Area of Fukushima Daiichi NPS" September 21, 2018, Tokyo Electric Power Company Holdings, Inc.

137 The 78th Secretariat Meeting of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment, "Reference 3-1: Progress Status in Rooftop Rainwater Measures"

138 The 84th Study Group on Monitoring and Assessment of Specified Nuclear Facilities "Reference 1-3: Progress and status of studies on measures to control the generation of contaminated water, amount of groundwater and rainwater inleak per building"

139 The 81st Secretariat Meeting of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment, "Reference 3-1:Progress Status of Megafloat Project at Fukushima Daiichi NPS to Reduce Tsunami Risks

140 Daily Analysis Results of Radioactive Materials at Fukushima Daiichi NPS, (Website), Tokyo Electric Power Company Holdings, Inc.

141 The 14th Study Committee on Accident Analysis of the Fukushima Daiichi NPS "Reference 3: Progress of on-site Investigation"

142 The 32nd Study Group on Monitoring and Assessment of Specified Nuclear Facilities "Reference 2: Status of measures for reducing the concentration of waste water in drainage K"

143 The 63rd Study Group on Monitoring and Assessment of Specified Nuclear Facilities "Reference 2: Measures for rainwater inleak control (Progress status of installing purification materials for rainwater drainage in turbine buildings)"

144 The 74th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment "Reference 3-6: Starting of operation of PSF monitor in the drainage K"

Table A4- 1 Risk sources that are not explicitly addressed in the major risk sources (3/3)

Issue	Risk source	Descriptions
Important issues to progress decommissioning	Exhaust stack	Exhaust stack of Units 1/2 : dismantlement work was carried out since August 2019, and the upper part of 61 m out of the total height of 120 m was divided into 23 blocks in total for dismantling. On May 1, 2020, a lid was installed on a barrel 59 meters above the ground to prevent rainwater inleak, and dismantling was completed[145]. Exhaust stack of Units 3/4 : Measured 3mSv/h at the base[146].
	Contaminated soil	As a result of the topsoil analysis, more than half of the samples are in excess of the designated standards (8,000 Bq/kg) based on the Act on Special Measures Concerning the Handling of Environmental Pollution by Radioactive Materials[147]

145 “Completion of Dismantling of Exhaust Stack of Units 1/2 at Fukushima Daiichi NPS” (May 1, 2020), Tokyo Electric Power Company Holdings, Inc.

146 The 19th Committee on Accident Analysis of the Fukushima Daiichi NPS “Reference 4 : Interim report on the investigation and analysis of the accident at TEPCO’s Fukushima Daiichi NPS (proposal)”」

147 Results of daily analysis of Radioactive substances at Fukushima Daiichi Nuclear Power Station (Website , Tokyo Electric Power Company Holdings, Inc.

Attachment 5 Change in risk over time

Overview of the concept of risk management in the UK is shown in Fig. A5-1. Even if the current risk level is plotted in the white region of the graph, it does not mean such risk level can always be accepted over time, but the time will come when such risk level cannot be accepted in the future (yellow region). In addition, as time passes, the risk level may increase caused by degradation of facilities and risk sources (represented by the dotted line). On the other hand, when risk reduction measures are taken, the risk level can be reduced so that it may not reach the unacceptable region (red region) with careful preparation and thorough management, although it may be temporarily increased. In this way the risk level shall be targeted to be sufficiently reduced (represented by the solid line) so that it may not reach into the unacceptable or intolerable region.

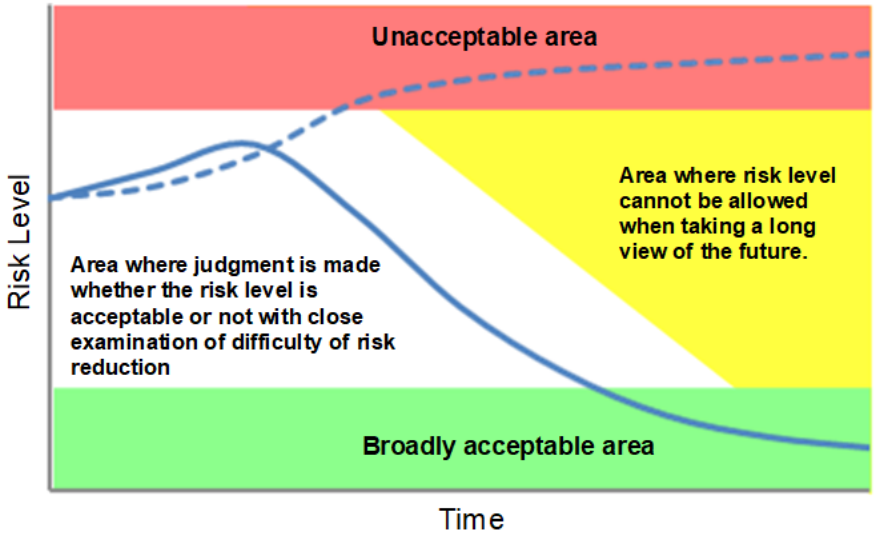


Fig. A5-1 Change in risk over time[148]

[148] V. Roberts, G. Jonsson and P. Hallington, "Collaborative Working Is Driving Progress in Hazard and Risk Reduction Delivery at Sellafield" 16387, WM2016 Conference, March 6-10, 2016. M. Weightman, "The Regulation of Decommissioning and Associated Waste Management" 1st International Forum on the Decommissioning of the Fukushima Daiichi Nuclear Power Station (April 2016)..

Attachment 6 Coverage of fuel debris retrieval

In the Mid-and-Long-term Roadmap issued on December 21, 2011, fuel debris is described as "material in which fuel and its cladding tubes, etc. have melted and re-solidified", namely, fuel debris is "fuel assembly, control rod and structures inside reactor have melted and solidified together" according to the report by IAEA[149],[150].

The condition inside PCV is as shown in Fig. A6-1, as the comprehensive estimations from the inside investigation of reactor, the past accidents including TMI-2 or ChNPP-4, and the result of the simulation test. It does not show any of specific unit. For more detail, as shown in the Fig A6-1, fuel debris can be classified by form such as damaged pellets, debris, crust, etc.

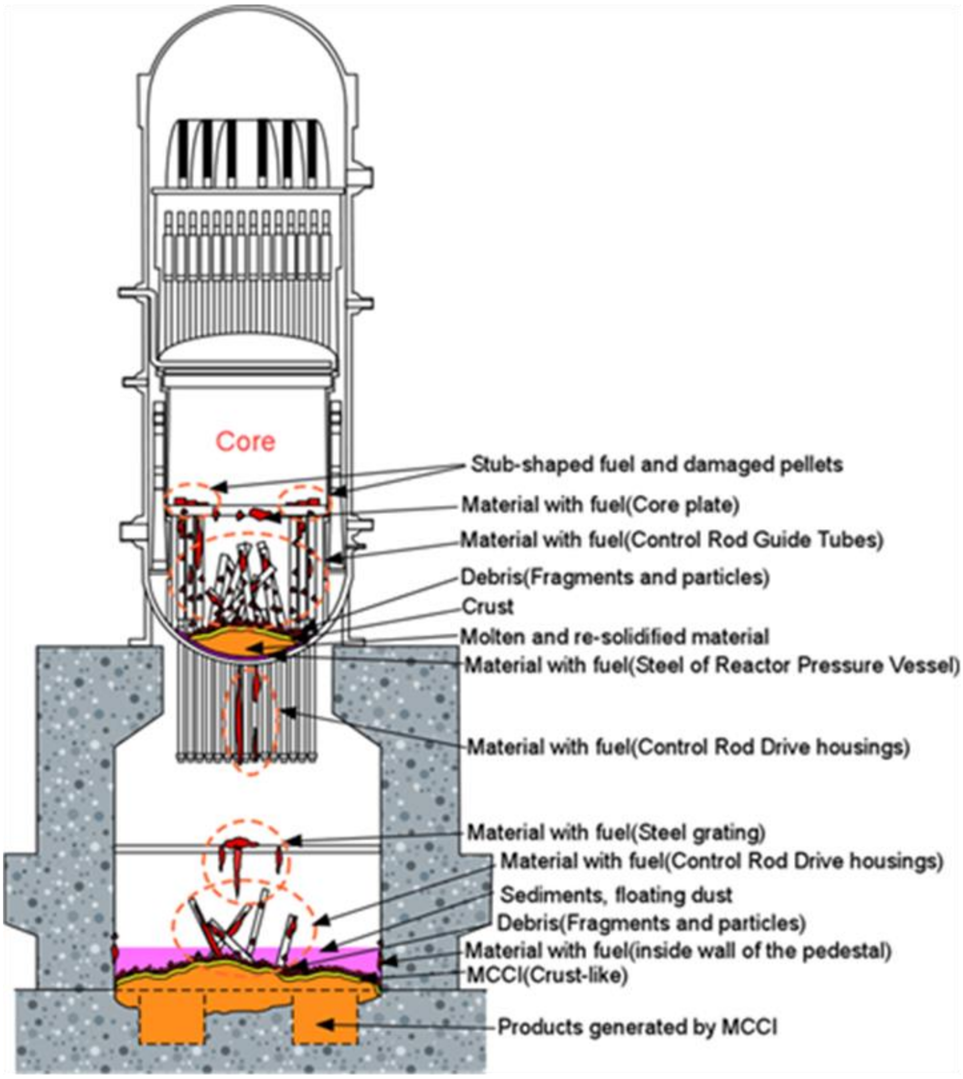


Fig. A6-1 Estimated inside of the PCV of the Fukushima Daiichi NPS

149 International Atomic Energy Agency Experiences and Lessons Learned Worldwide in the Cleanup and Decommissioning of Nuclear Facilities in the Aftermath of Accidents, IAEA Nuclear Energy Series No. NW-T-2.7, Vienna (2014)

150 Managing the Unexpected in Decommissioning, IAEA Nuclear Energy Series No. NW-T-2.8, Vienna (2016)

Since nuclear fuel material requires considerations to prevent criticality, it is rational that objects which exist inside PCV should be broadly sorted into two from the viewpoint of retrieval, containment, transfer and storage. The one includes nuclear fuel material and the others. The one that does not include nuclear fuel material is to be treated as a radioactive waste in case radioactive cesium or cobalt are contained or adhered.

Based on this, an example of fuel debris concept as a retrieval target of fuel debris is as shown in Fig. A6-2. Objects generated by core damage have been classified depending on necessity of criticality measures and the content of fuel, in spite that a lot of names are used according to the content of fuel component or form in appearance.

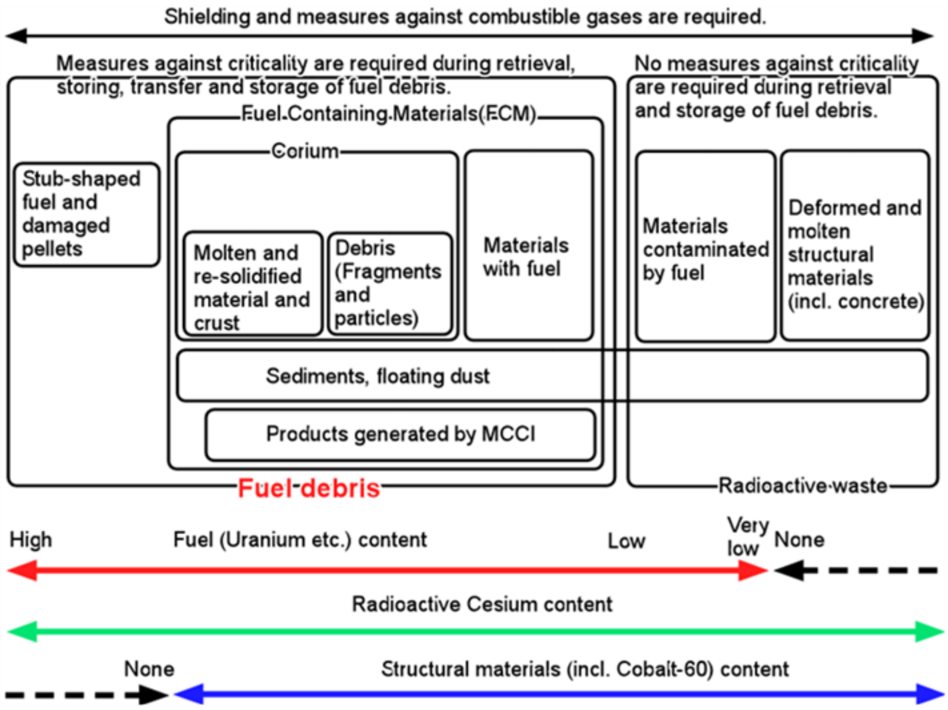


Fig. A6-2 An example of organized concept of fuel debris as fuel debris retrieval target at the Fukushima Daiichi NPS

【Glossaries and Terms】

FCM : Fuel Containing Materials. It refers broadly that molten fuel component comes to solidify in conjunction with structural materials. It is also called lava-like FCM due to its appearance.

Corium : A substance that mainly fuel assembly and component of control rod as core component have molten and solidified.

Crust : A hard outer layer or shell on the surface. When molten fuel is solidified, it may become a hard solid state of shell because of higher cooling speed on the surface layer.

MCCI product : A product generated by Molten Core Concrete Interaction, that includes calcium, silicone, etc. which are concrete component.

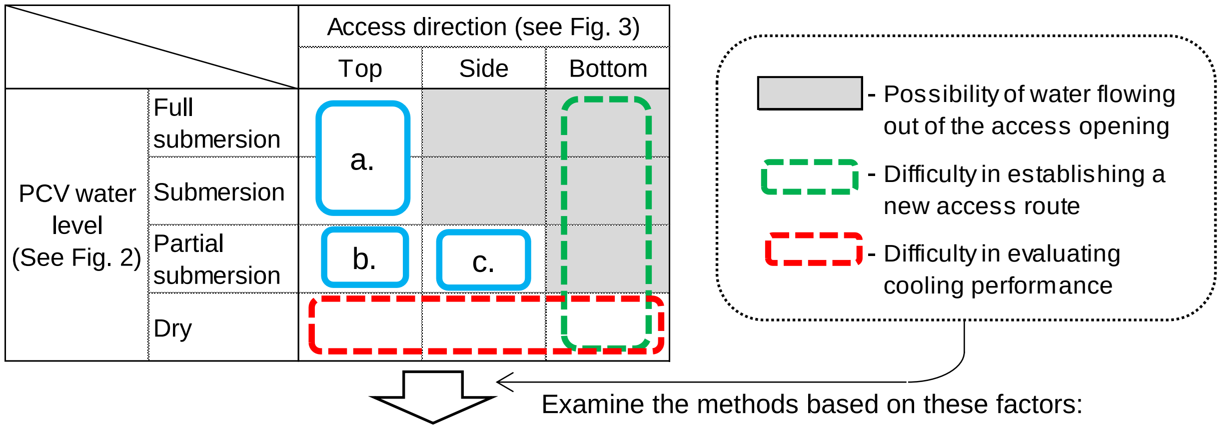
Material with fuel : A substance that molten fuel has adhered to material that does not include fuel component originally, like CRD housing, grating and s, then solidified. It is possible to confirm fuel adhesion state by sight.

Material contaminated by fuel : A substance that adhering molten fuel cannot be confirmed by sight, but fuel component can be detected with α ray detector. It is impossible to locate fuel component other than using by electron microscope because particle of adhered fuel component is extremely small and whit.

Attachment 7 Changes in considerations on retrieval methods in the previous Technical Strategic Plans

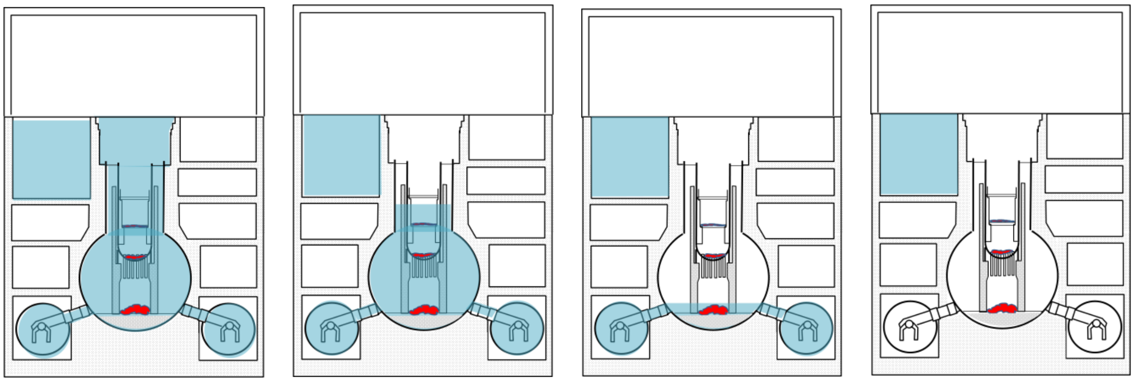
In the Technical Strategic Plans 2015 and 2016, options for fuel debris retrieval methods were explored based on a combination of the PCV water level (full submersion, submersion, partial submersion, and dry methods) and access directions (top, side, and bottom-access) to fuel debris. As a result, three priority methods ([1] Submersion-Top access method, [2] Partial submersion-Top access method, and [3] Partial submersion-Side access method) have been selected and examined. (See Figures 1 to 3.)

Combination of PCV water level and access direction



	Method of focus and its name		
a.	Full submersion and submersion methods with access from the top	→	Submersion-Top access method
b.	Partial submersion method with access from the top	→	Partial submersion-Top access method
c.	Partial submersion method with access from the side	→	Partial submersion-Side access method

Fig. A7-1. Examination of the methods by a combination of the PCV water level and access directions to fuel debris



- Full submersion method : Fill the reactor well to the top with water.
- Submersion method : Fill water to the top from the point where fuel debris is distributed.
  (Supplement) It is currently assumed that fuel debris is not distributed above the core region, and the water level above the upper end of the core region is referred to as the submersion method.
- Partial submersion method : Fill water to a level below the highest point of the distributed fuel debris, and retrieve fuel debris while pouring water into the fuel debris that is exposed to the air.
  (Supplement) It is currently assumed that there is fuel debris exposed to the air at the water level below the upper end of the core region. This is referred to as the partial submersion method.
- Dry method : Expose the entire area of the distributed fuel debris to the air, with no water-cooling or spraying at all.

Fig. A7-2. Classification of methods according to the PCV water level

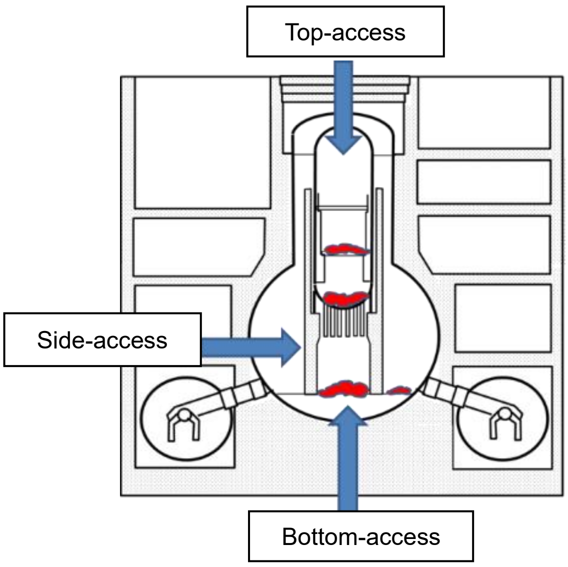


Fig. A7-3. Access direction to fuel debris

In the Technical Strategic Plan 2017, the feasibility of the above three fuel debris retrieval methods was evaluated on three technical requirements ([1] containing, transferring, and storing; [2] handling of waste generated during retrieval operations; and [3] safeguards for the safe and stable storage of fuel debris in addition to nine technical requirements {[1] containment functions; [2] cooling functions; [3] criticality control; [4] structural integrity; [5] reduction of radiation exposure; [6] work safety; [7] access route; [8] device and equipment development; and [9] system installations and area construction}), all of which should be satisfied for the safe retrieval of fuel debris. Then, based on the comprehensive evaluation based on the five guiding principles (safe, proven, efficient, timely, and field-oriented), strategic recommendations for determining a fuel debris retrieval policy were made (recommendations for determining a fuel debris retrieval policy and post-determination actions. In the Mid-and-Long-term roadmap revised in September 2017, the fuel debris retrieval policy was determined as follows based on the details of the strategic recommendations.

Policy on Fuel Debris Retrieval

① Step-by-step approach

In order to reduce associated risk as early enough, adopt a step by step approach to flexibly coordinate the direction based on information that comes out as retrieval proceeds, after setting method of fuel debris retrieval to be started first,

Fuel debris retrieval operation and internal investigations of PCV/RPV should be performed in a coordinated, integrated manner. Fuel debris retrieval starts from a small-scale and the scale of retrieval should be expanded by step up, while reviewing operations flexibly based on new findings obtained from the property of fuel debris and working experiences.

② Optimization of entire decommissioning work

Examine fuel debris retrieval work as a comprehensive project aimed at total optimization, from preparation to cleanup through retrieval work, transportation, processing and storage, including coordination with other construction works at the site.

③ Combination of multiple methods

Combine the optimum retrieval methods for each unit, depending on the locations where fuel debris is considered to be present, instead of making an assumption that all the fuel debris is to be taken out using a single method.

At present, from an accessibility standpoint, examine assuming sideward access to the bottom of the primary containment vessel and downward access into the reactor pressure vessel from the upper part of the vessel.

④ Approach focused on partial submersion method

Given the technical difficulty of stopping leaks at the upper part of the primary containment vessel and expected radiation doses during such works, the full submersion method is technically difficult at present, so make efforts to focus on the partial submersion method that is more feasible.

However, given the advantages of the total submersion method, such as being effective in providing shielding against radiation, consider adopting the full submersion method in the future depending on the progress of R&D.

⑤ Prioritizing fuel debris retrieval by side access to the bottom of the PCV

According to an analysis, fuel debris is expected to be present in both the bottom of PCV and the inside of RPV of each unit, although their distribution varies among the units. In view of mitigating risks from fuel debris as early enough, while minimizing any increase in risks that might be caused by retrieval, prioritize retrieval of fuel debris in the bottom of PCV by sideward access by taking the following into account:

- The bottom of PCV is most accessible and a certain amount of knowledge about it has already been accumulated through the investigation inside PCV;
- There is a possibility that fuel debris retrieval could be started earlier.
- Fuel debris retrieval could be performed at the same time as spent fuel removal

The Technical Strategic Plans 2018 and 2019 examined the first implementing unit and its fuel debris retrieval method. In the process of examining the first implementing unit and its retrieval method, based on the results of research and development and PCV internal investigations, and according to the scenario (draft work schedule) in light of the conceptual study of the fuel debris retrieval system in TEPCO's preliminary engineering and actual site applicability by unit, the overall optimization combining scenarios for each unit and the site-wide plan were considered in order to provide recommendations for determining fuel debris retrieval methods for the first implementing unit. The examination flow is shown in Fig. A7-4.

As a result of the above discussion, as "a fuel debris retrieval method" involving a series of continuous operations from fuel debris retrieval, containing/transferring to safe storage, the plan is to initiate "timely" small-scale retrieval while minimizing the increase in risk associated with the retrieval, leading to reducing the overall risk of fuel debris in Units 1 - 3 by obtaining "timely" information/experience toward expanded-scale retrieval and retrieval other than in the first implementing unit. Specifically, using the existing safety systems without significantly changing the site condition, in principle, evaluation has indicated that fuel debris retrieval may be carried out "safely, reliably, and promptly," starting with methods such as gripping and sucking with arm-type access equipment and an airtight enclosure for containing the equipment, which have good prospects for actual site applicability. In addition to gripping and sucking, cutting fuel debris during the small-scale retrieval should also be performed to the extent that significant modification of the existing safety systems is not required.

Lastly, the Technical Strategic Plans 2020 and 2021 proposed approaches and policies for fuel debris retrieval methods. Since no new progress has been made in examining the methods themselves, however, this Attachment omits the details of the Strategic Plans.

Progress of ancillary R&D and PCV internal investigation

- It was observed that there are some movable pebble size deposits in Unit 2.
- Get development of arm-type access equipment and the canister for retrieved fuel debris into shape.

Progress of work environment improvement

- In contrast with relatively low radiation dose in Unit 2, radiation dose reduction is needed in Units 1&3 as well as lowering of water level in PCV in Unit 3.

Progress of site-wide planning

- Fuel removal operation from SFP completes in Unit 3 first. Fuel debris retrieval work and spent fuel removal work can be done in parallel at every unit.

↓

Study on concept of fuel debris retrieval

- Use of existing safety system.
- Use of arm-type access equipment that actual site applicability is getting in sight and use of air-tightend enclosure which contains it.
- Start from small-scale retrieval by such gripping or sucking, and progress to plan fuel debris retrieval by crushing.
- Contain retrieved fuel debris in a small canister, transfer it, contain it in a canister and stored it in dry condition at the temporary storage facility within site

Study result of actual site applicability of fuel debris retrieval work by Unit

- Unit 1: Maintaining relatively high airtightness with current safety system, but the radiation dose is high in working environment and deposits potential of fuel debris and access route to reach them are unidentified.
- Unit 2: Maintaining high airtightness with current safety system and the radiation dose is relatively low in working environment, deposits potential of fuel debris is movable and access route to reach them has been identified.
- Unit 3: Deposits potential of fuel debris and access route to reach them has been identified, but airtight level with current safety system is lower than Units 1&2, the radiation dose is relatively high in working environment.

↓

Comprehensive assessment

【Fuel debris retrieval method】 →The arm-type access equipment & the canister enables to retrieve fuel debris safely, reliably and promptly.

- Actual site applicability of the arm-type access equipment/canister for retrieved fuel debris are getting in sigh.

【The first implementing unit】 → Unit 2 is judged to be appropriate because fuel debris retrieval can be started "safely", "reliably" and "promptly" and overall decommissioning work can be optimized.

- Safe : The radiation dose in working environment is relatively lower than other units and the airtightness with existing safety system is higher than other units.
- Reliable : Some deposits with potential for fuel debris are movable, and access route to reach them has been identified.
- Prompt : It has a possibility to start fuel debris retrieval work promptly, as well as to accumulate information and experiences on fuel debris retrieval work.

⇩

<u>Unit 2</u> has <u>potential to reduce risks resulted from entire fuel debris at unit 1, 2 and 3 promptly</u> because <u>the essential information and experiences will be accumulated necessary for expanded scale of fuel debris retrieval work in the future through a series of operations from fuel debris retrieval</u> by using the arm-type access equipment <u>to containing, transfer and storage of the retrieved fuel debris safely, reliably and promptly.</u>

↓

The points to be recommended for determining fuel debris retrieval method of the first implementing unit

① <u>Fuel debris retrieval work</u> is <u>to start from small-scale operation such as gripping and sucking</u> <u>by using the arm-type access equipment</u> that actual site applicability is getting in sight and <u>the air tightened enclosure that contains the arm-type access equipment</u> <u>combined with existing safety system without significant modification</u>.

② <u>Using information and experiences accumulated through fuel debris retrieval operations</u> by gripping and sucking, <u>crushing method for fuel debris retrieval and removing of obstacles are to be studied</u>. Fuel debris retrieval by crushing or cutting during the small-scale fuel debris retrieval work phase is also to be performed under without significant modification of existing safety system.

③ <u>Retrieved fuel debris firstly contained in the small container is transferred</u>, contained into the canister and <u>stored in dry condition</u> at the temporary <u>storage facility</u> built within Fukushima Daiichi NPS site.

④ <u>From the view point of optimization of entire decommissioning work of Fukushima Daiichi NPS, unit 2 is currently judged to be appropriate for the first implementing unit</u>. Thus, <u>a series of operations from fuel debris retrieval to containing, transferring and storing of the retrieved fuel debris will be continued</u> at unit 2, and <u>information and experience will be accumulated necessary for expanded-scale of fuel debris retrieval work in the future</u>. However, <u>certain hold points should be appropriately defined on the process of necessary study or planning to start fuel debris retrieval work for verifying the appropriateness of current study/planning</u>.

⑤ Retrieval methods including containing, transferring and storing the retrieved fuel debris applicable for the <u>expanded-scale of fuel debris retrieval work phase or other than the first implementing unit need to be established by proceeding with PCV internal investigation, necessary R&D and improvement of working environment such as lowering of PCV water level, radiation dose reduction and securing working space</u>, as well as <u>engineering of new safety system, fuel debris retrieval and storage facility</u> using accumulated information and experience through fuel debris retrieval work of the first implementing unit including <u>study on safety evaluation and actual site applicability of engineering results</u>.

Fig. A7-4 Flow of examinations for determining the fuel debris retrieval method for the first implementing unit"

Attachment 8　Terms related to radioactive waste management

IAEA Safety Requirements GSR-Part 5[151] explains that predisposal of radioactive waste encompass all stages of radioactive waste management from generation to disposal, including processing, storage and transportation. Terms related to the management of radioactive waste as defined in the IAEA glossary are shown in Fig A8-1. Within the pre-disposal management, processing of radioactive waste is classified into pretreatment, treatment and conditioning. Processing is carried out to be in the form of waste suitable for selected or anticipated disposal options. Radioactive waste may also be stored in for its management, therefore it is thought to be necessary that the form is suitable for transportation and storage.

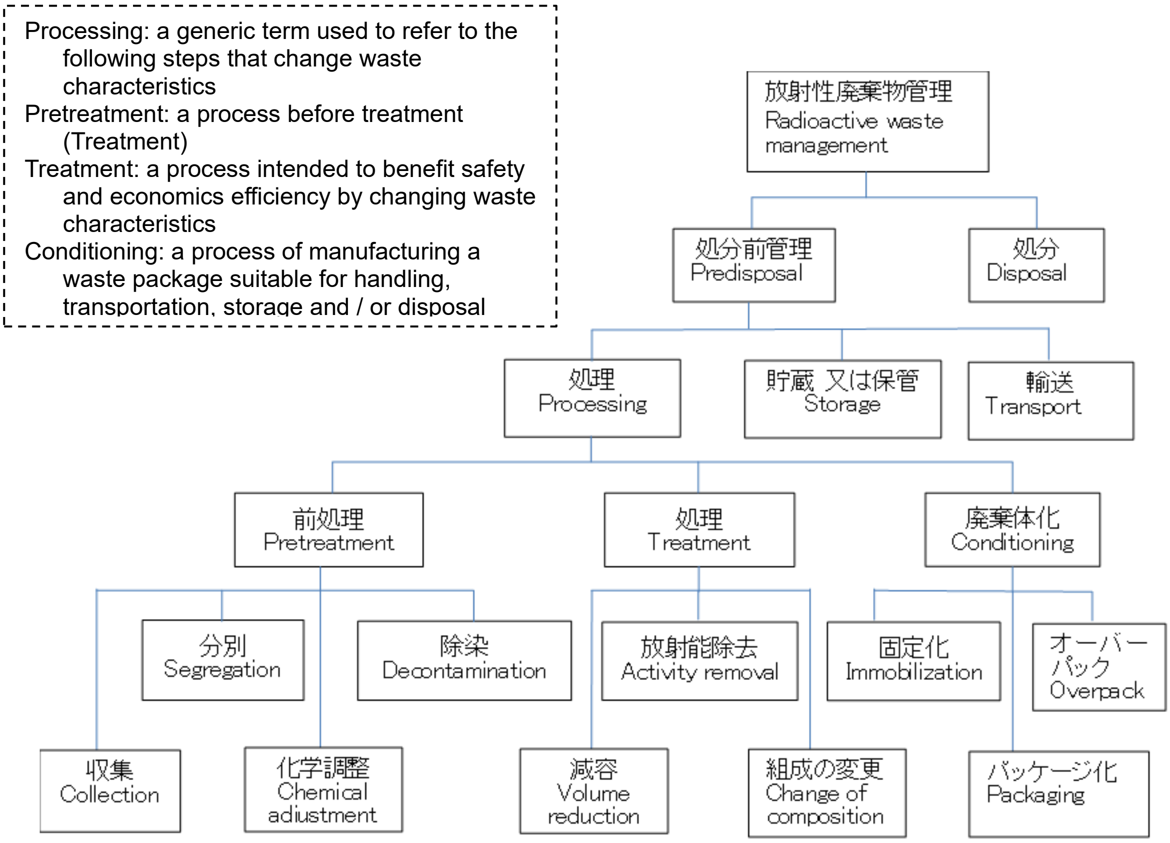


Fig. A8-1 Terms related to radioactive waste management (IAEA)[152] and their translation examples (For the Japanese translation example, refer to the materials of the Japan Atomic Energy[153,154])

---

[151] IAEA, Predisposal Management of Radioactive Waste, IAEA Safety Standards Series No. GSR Part 5, (2009). (NSRA, IAEA Safety Standard/Predisposal of Radioactive Waste/General Safety Requirement 5, No. GSR-Part5, July, 2012)

[152] IAEA, IAEA Safety Glossary Terminology Used in Nuclear Safety and Radiation Protection 2007 Edition, p.216, (2007).

[153] AESJ, The Report of 2013, - Organizing information of radioactive waste and matters to be considered for solving the issues (p.7), March 2014, the Expert Committee, “Processing /disposal of radioactive waste generated by the accident of Fukushima Daiichi NPS”

[154] AESJ, Seiya Nagao and Masafumi Yamamoto, “Introduction to radioactive waste - Management of radioactive waste from operation and decommissioning of nuclear and other facilities” Perspective of radioactive waste management, the 56 of (9) of Journal of the Atomic Energy Society of Japan, p.593, (2014).

Attachment 9　Disposal of radioactive waste[155,156,157]

1． International classification of radioactive waste

Radioactive waste contaminated with radioactive materials is generated through operation and dismantling of nuclear power plants and the use of radioisotopes in medical and industrial applications. Radioactive waste shall be classified appropriately according to the radioactivity level and properties of waste, types of radioactive materials, etc., and strictly controlled, and then shall be reasonably processed and disposed of so as not to affect the human living environment.

The IAEA's Specific Safety Requirements SSR-5 “Disposal of Radioactive Waste” (2011)[158] specifies that a preferred strategy for the management of radioactive waste that is internationally agreed is to contain the waste and isolate it from the living environment, while minimizing the generation of radioactive waste. The required isolation and containment depend on the magnitude of the hazards of the waste and the time, thereby a disposal option (design and depth of facilities) being selected accordingly.

The IAEA’s General Safety Guide GSG-1 “Classification of Radioactive Waste”[159] indicates the relationship between the classification of radioactive waste and disposal options depending on the magnitude of the hazards (amount of radioactivity) and the duration (the half-life) of the radioactive waste, as shown in Fig. A9-1. Each classification is also shown in Table A9-1.

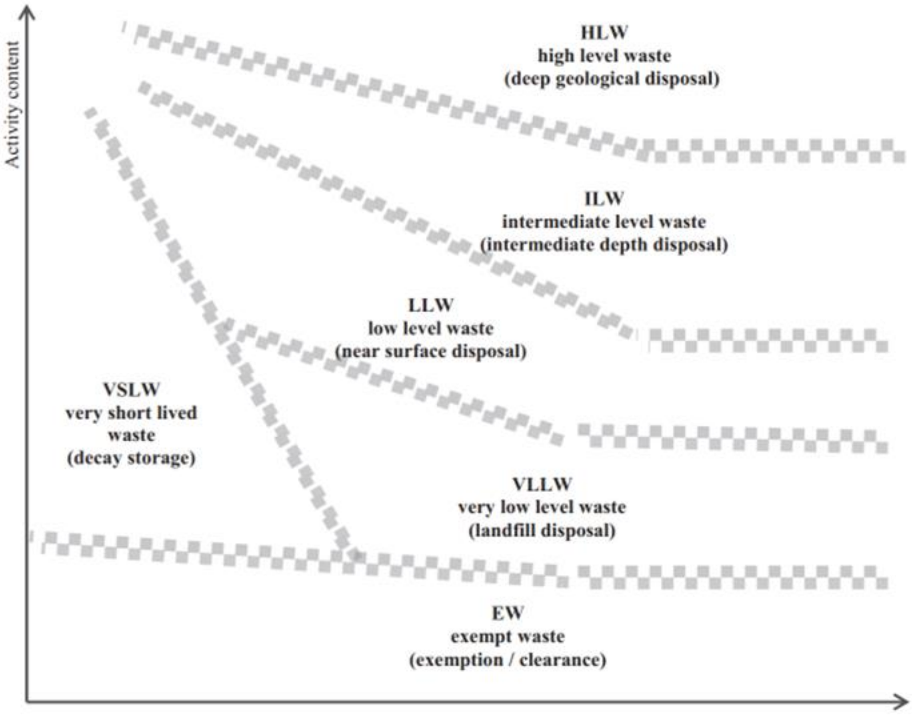


Fig. A9-1 Conceptual diagram of waste classification

155 Osamu Tochiyama, Principles and Basics of Radioactive Waste Disposal, Radioactive Waste Management Funding and Research Center (a Public Interest Incorporated Foundation) (2016)
156 https://www.enecho.meti.go.jp/category/electricity_and_gas/nuclear/rw/
157 https://www.fepc.or.jp/nuclear/haikibutsu/index.html
158 IAEA SSR-5 "Disposal of Radioactive Waste" (2011)
159 IAEA GSG-1 "Classification of Radioactive Waste" (2009)

Table A9-1 Classification of radioactive waste in GSG-1

Classification	Description of Classification
Exempted waste (EW)	Waste satisfying the criteria for clearance, exclusion and exemption from regulatory control for radiation protection purposes
Very short-lived waste (VSLW)	Waste that is decay-stored for a limited period of time up to several years and then exempted from regulatory control, as approved by the regulatory body.
Very low level waste (VLLW)	Waste that does not necessarily satisfy EW standards but does not require high-level containment and isolation. Suitable for disposal in shallow landfills where regulatory control is limited.
Low level waste (LLW)	Waste that exceeds clearance levels but has a limited amount of long-lived nuclides. Rigid isolation and containment are required for periods of up to several 100 years and are suitable for disposal in engineering facilities in shallow soils.
Intermediate level waste (ILW)	Waste that requires higher-level containment and isolation than the near surface disposal because of the nuclides it contains, especially long-lived nuclides. However, considerations on heat removal are hardly required. Because ILW may contain concentrations of long-lived nuclides (especially α-nuclide) that are not manageable in near surface disposal, a depth of tens to hundreds of meters are required for disposal.
High Level waste (HLW)	Waste with a large amount of heat generation at high activity concentration levels or waste containing large amounts of long-lived nuclides for which a design equivalent to a disposal facility for such waste needs to be considered. Generally, waste is disposed of in a stable stratum at the depth of several hundred meters or more from the ground surface. In some countries, spent fuel is classified as HLW.

2. Classification and disposal in Japan

In Japan, radioactive waste is broadly divided into “low-level radioactive waste” (equivalent to VLLW to ILW in GSG-1), which is generated through the operation of nuclear power plants, and “high-level radioactive waste” (equivalent to HLW of GSG-1), which is generated through the reprocessing of spent fuel that is generated through the operation of nuclear power plants and is vitrified with a high level of radioactivity. When disposed of, waste shall be classified appropriately according to its radioactivity level and properties, types of radioactive materials, etc., and shall be strictly controlled, and reasonably processed and disposed of under the principle that responsibilities lie with those who have generated the waste.

“High-level radioactive waste” is a vitrified liquid waste with a high radioactivity level that is produced in the process of reprocessing spent fuel generated through the operation of nuclear power plants. In Japan, the act (the Designated Radioactive Waste Final Disposal Act (the Final Disposal Act)) stipulates that radioactive waste shall be disposed of in strata more than 300 meters deep underground.

The term “low-level radioactive waste” refers to all types of radioactive waste other than “high-level radioactive waste”, and is further divided into several categories depending on where it is generated and the level of radioactivity.

The types of radioactive waste generated by the operation of nuclear power plants and the disposal methods assumed are shown in Table A9-2.

Of these, only waste with relatively low-level radioactivity generated through the operation of nuclear power plants has been subject to disposal in pits since 1992 at the Rokkasho Low-level Radioactive Waste Disposal Center of Japan Nuclear Fuel Limited in Rokkasho Village, Aomori Prefecture. Including the existing facilities, approximately 1 million drums of waste contained in 200-liter drums are planned to be buried, and eventually the scale will be enlarged to approximately 3 million drums using 200-liter drums.

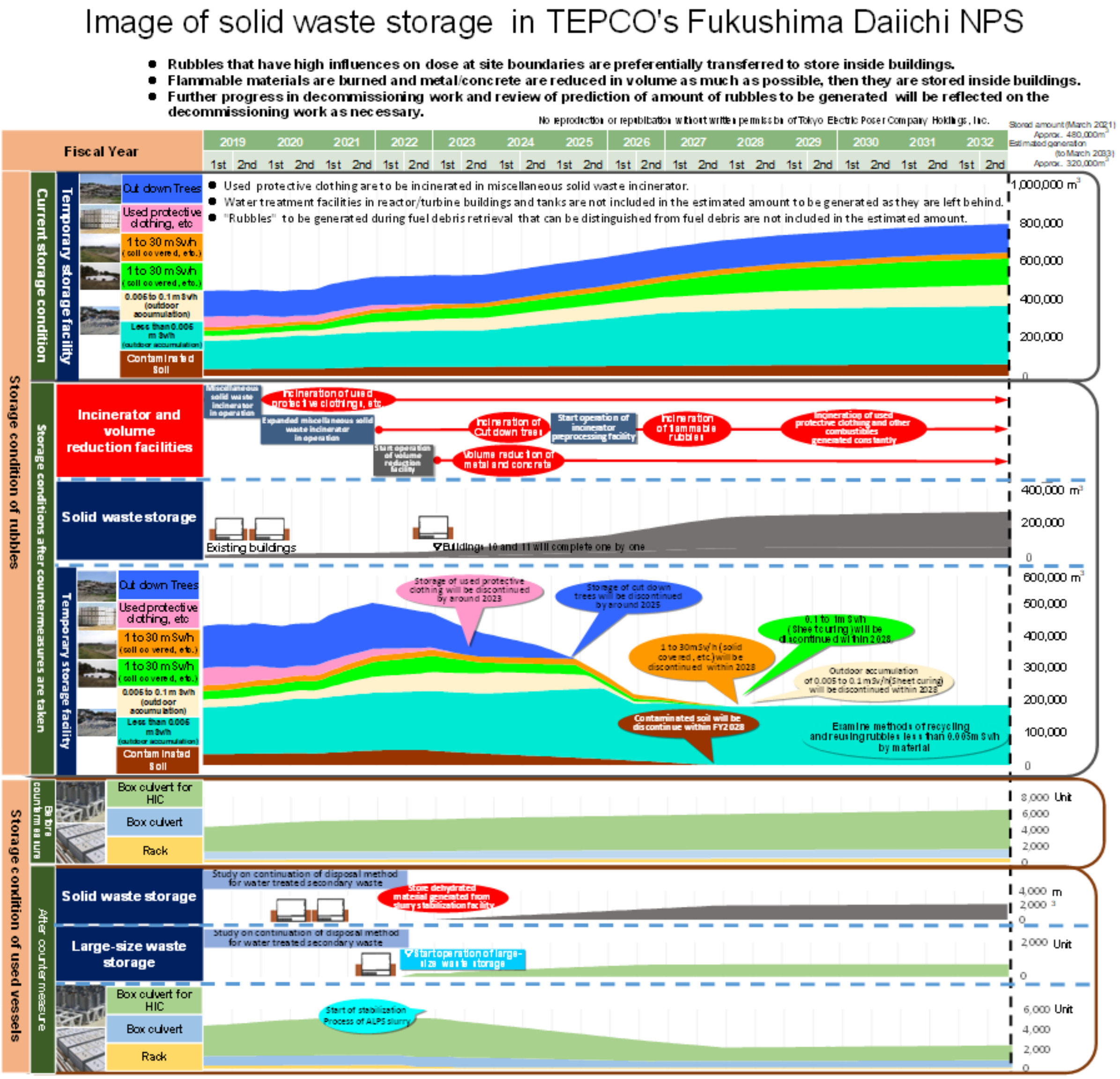
Table A9-2 Types of Radioactive Waste Generated by the Operation of Nuclear Power Plants

Types of Radioactive Waste			Examples of Waste	Site generated	Disposal Method (example)
Low-level Radioactive Waste	Waste from Nuclear Power Plants	Waste with extremely low radiation level	Concrete, metal, etc.	Nuclear Power Plant	Trench disposal (Near surface disposal (L3))
		Waste with relatively low radiation level	Effluent, filter, waste equipment, solidification of consumables		Pit disposal (Near surface disposal (L2))
		Waste with relatively high radiation level	Control rod, structures inside reactor		Intermediate depth disposal (L1)
	Uranium Waste		Consumables, sludge, waste equipment	Uranium enrichment and fuel processing facility	Intermediate depth disposal, Pit disposal or Trench disposal, geological disposal in some cases
	Radioactive Waste includes Transuranic Nuclide (TRU Waste)		Parts of control rod, effluent, filter	Spent fuel reprocessing facility, MOX fuel fabrication facility	Geological disposal, Intermediate depth disposal or Pit disposal
High-level Radioactive Waste			Vitrified waste	Spent fuel reprocessing facility	Geological disposal

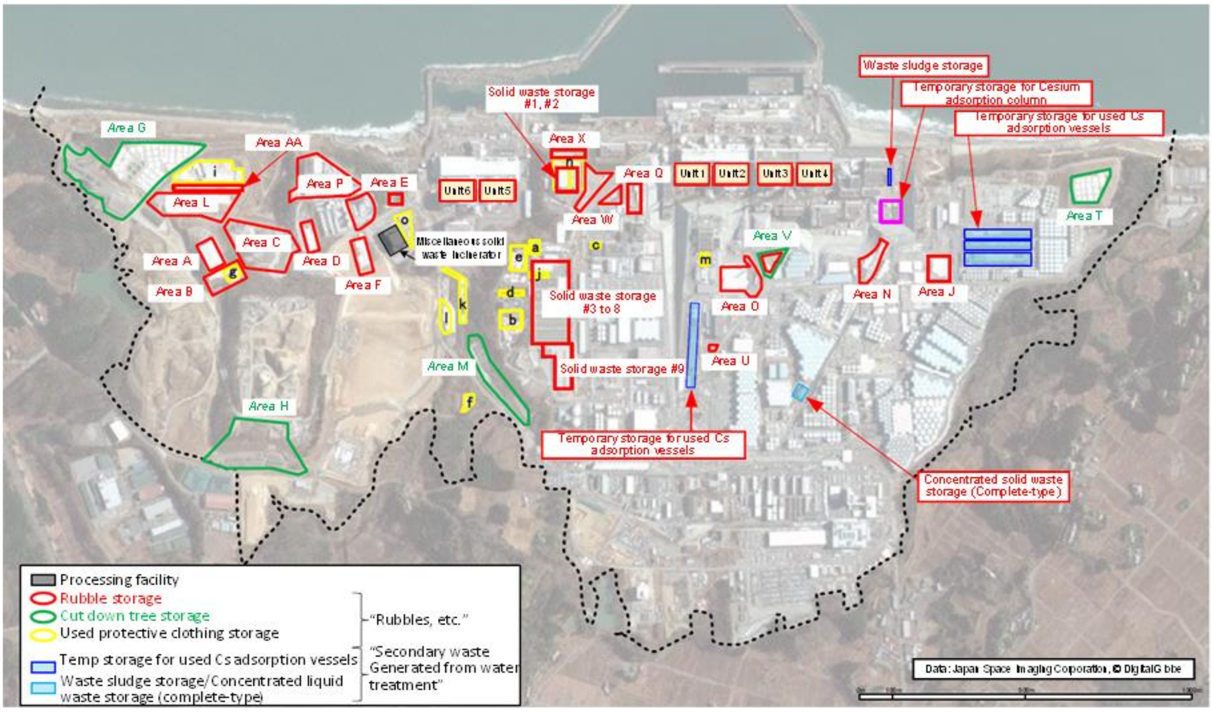
Waste below the clearance level	Most of demolition waste of nuclear power plants	All the above sites	Reuse / Disposal as general goods

Fig. A9-2 Japan Nuclear Fuel Ltd. Low-level Radioactive Waste Disposal Center

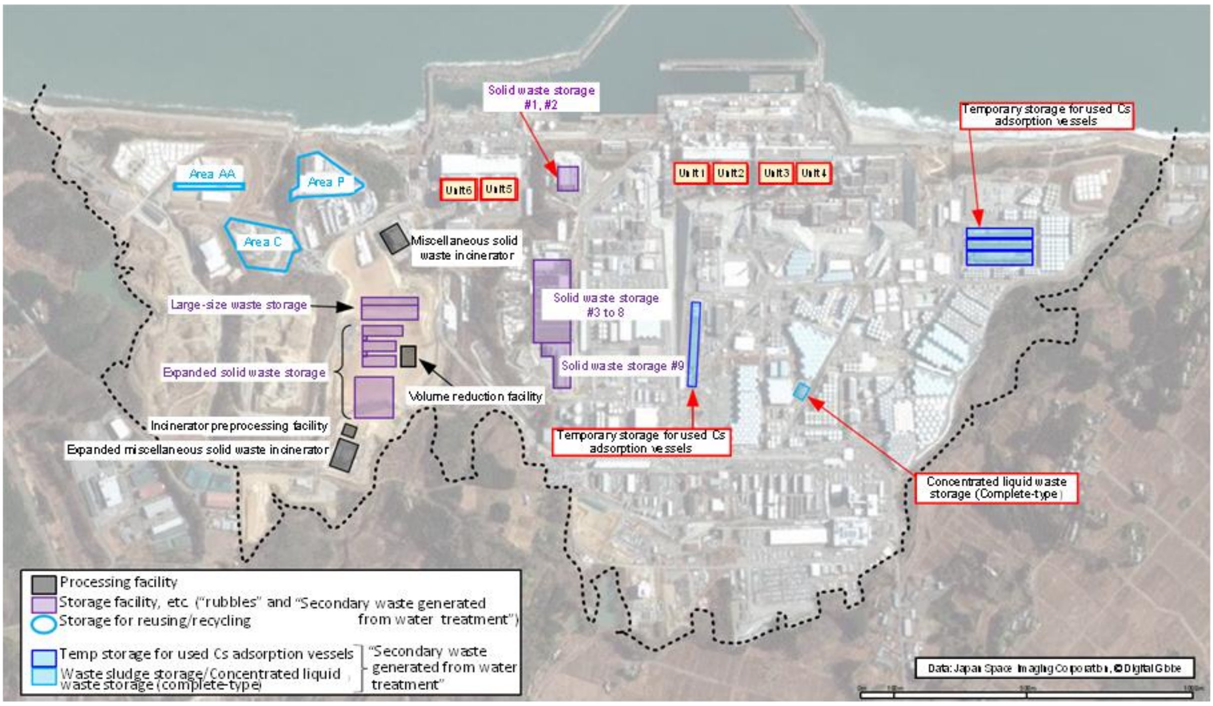
Attachment 10 Overall image of Storage Management Plan for the Fukushima Daiichi NPS [160]



160 TEPCO, Solid Waste Storage Management Plan for Fukushima Daichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc., July 2021 edition (issued on July 29, 2021)



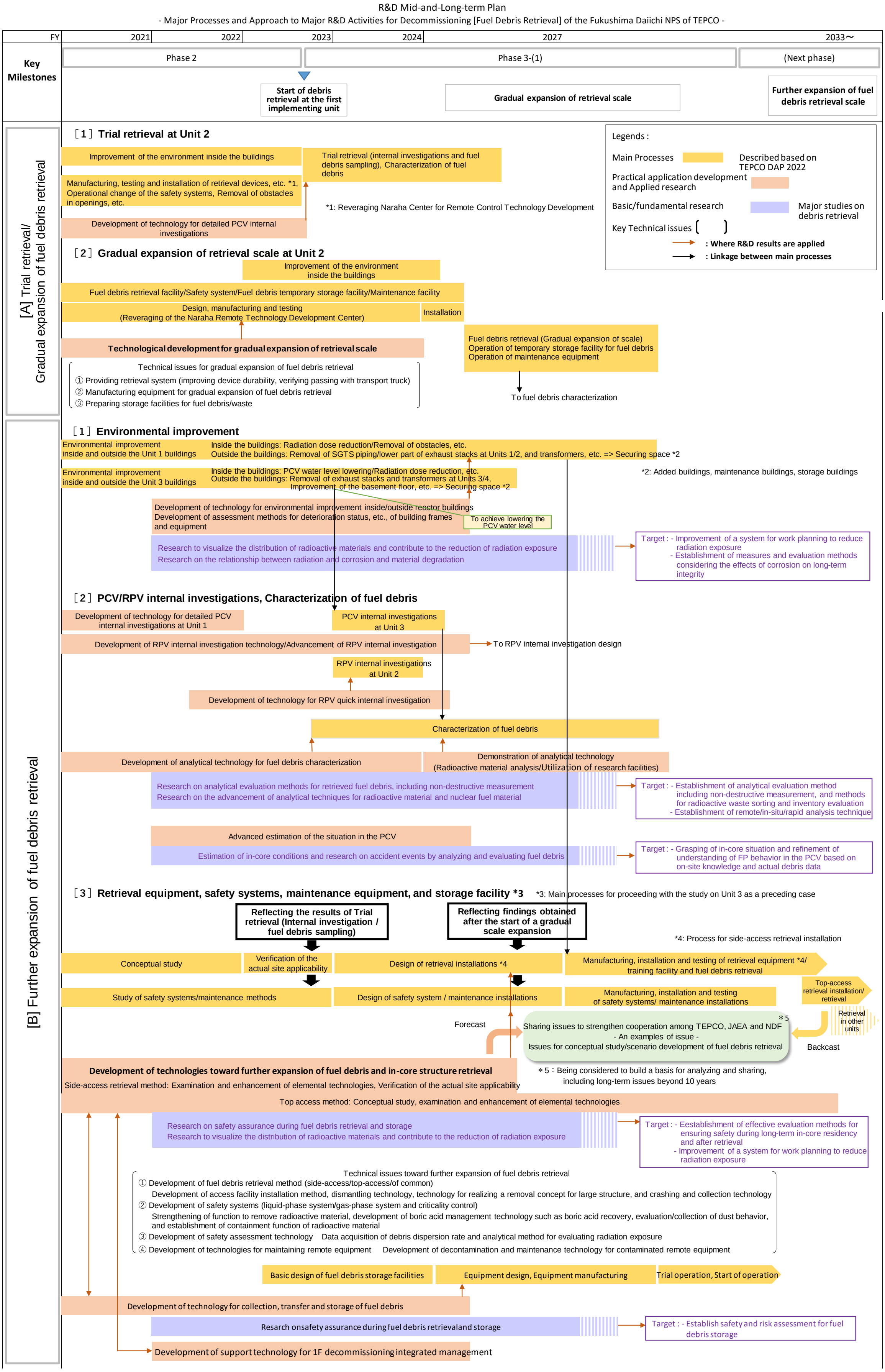
(a) Present storage condition of "rubble, etc." and "secondary waste generated by water treatment"



(b) Future storage condition of "rubbles, etc." and "secondary waste generated by water

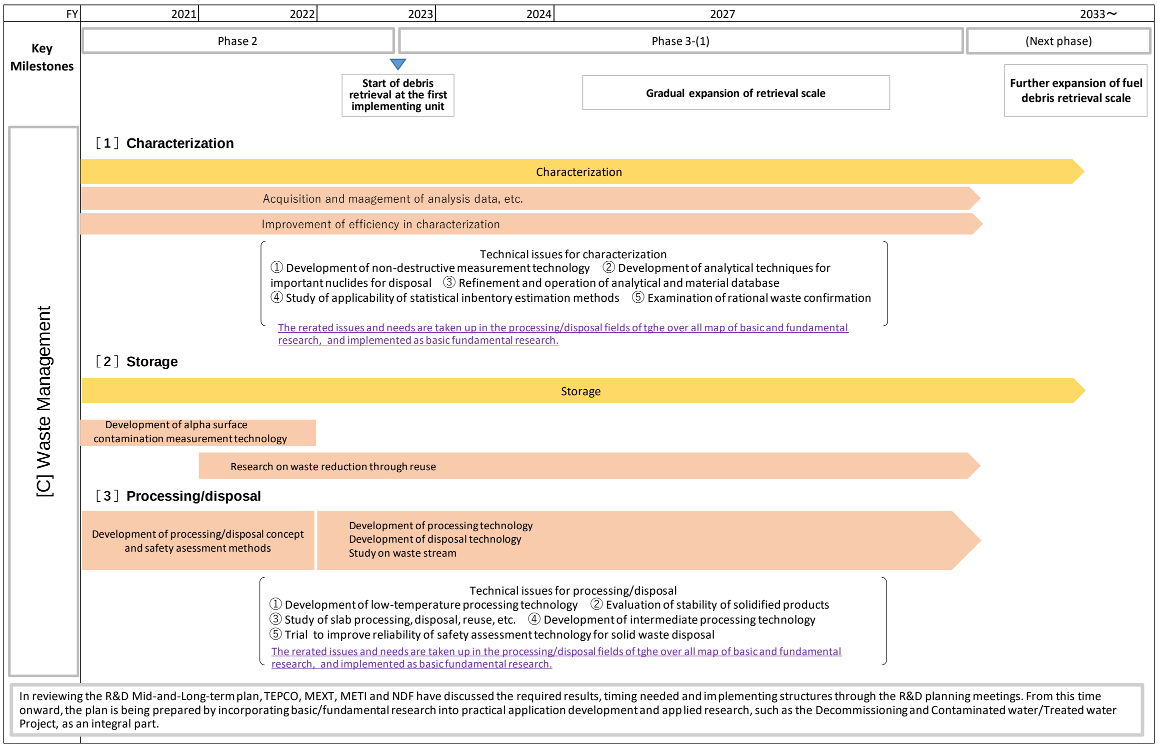
Fig. A10-1 Present and future storage conditions of "rubble, etc." and "secondary waste generated by water treatment" on site of the Fukushima Daiichi NPS

Attachment 11 R&D medium-to-long-term plan



R&D Mid-and-Long-term Plan

- Major Processes and Approach to Major R&D Activities for Decommissioning [Fuel Debris Retrieval] of the Fukushima Daiichi NPS of TEPCO -



Attachment 12 Current progress of the Project of Decommissioning and Contaminated Water Management[161]

【A】Trial retrieval/Gradual expansion of fuel debris retrieval

［A 1］ Trial retrieval in Unit 2

・Development of technologies for in-depth investigation of PCV inside (Field demonstration of technologies for in-depth investigation using penetration X-6) (FY2018 – 2019)

(Related projects) Development of technologies for the detection of fuel debris inside reactors (using muon) (FY 2014 - 2015)
Development of investigation technologies of inside of PCV (FY 2016 - 2017)
Development of technologies for in-depth investigation of PCV inside (FY 2017 - 2018)

［A 2］ Gradual expansion of fuel debris retrieval in Unit 2

・Development of technologies for retrieving fuel debris to be gradually expanded in scale (FY2017 – 2022)

*Change in the project name in 2020 : (Former title : Development of sampling technologies for retrieving fuel debris and internal structures)

【B】Further expansion of fuel debris retrieval in scale

［B 1］ Environmental improvement of inside and outside the buildings

・Development of technology for environmental improvement of inside the buildings (FY 2021 - 2022)

・Development of evaluation methods of seismic performances of RPV and PCV and the impacts of the damages (FY 2016 - 2017)

(Related projects) Development of evaluation methods for the structural integrity of RPV and PCV (FY 2011 - 2013)
Development of evaluation methods for the structural integrity of RPV and PCV (FY 2014 - 2015)

・Development of remote decontamination technology in the reactor building (FY 2014 - 2015)

(Related projects) Development of remote decontamination technology in the reactor building (FY 2011 - 2013)

［B 2］ Investigation of PCV/RPV inside and grasping properties of fuel debris

① Development of technologies for in-depth investigation of PCV inside (FY2021 – 2022)

(Related projects) Development of technologies for in-depth investigation of PCV inside (Field

[161] Information Portal for the Research and Development for the Fukushima Daiichi Decommissioning (http://www.drd-portal.jp/)

demonstration of technologies for in-depth internal investigation assuming deposit control measures) (FY2018 – 2020)

② Development of investigation technologies inside RPV (FY 2013 - 2023)

③ Development of analytical and estimation techniques for characterization of fuel debris (FY2017 – 2022)

(Related projects) Characterization of fuel debris using mock-up debris and development of fuel debris processing technologies (FY 2011 - 2014)

Construction of material accountancy method related to fuel debris (FY 2011 - 2013)

Property analysis of actual debris (FY 2014)

Grasping properties of fuel debris (FY 2015 - 2016)

Development of techniques for characterizing and analyzing fuel debris (FY 2017 - 2018)

(Other R&D)

・Formulation of comprehensive radiation dose reduction plan (FY 2012 - 2013)

・Development of technologies for non-destructive detection of radioactive material deposited in S/C, etc. (FY 2014)

・Advancement of comprehensive grasping of state inside reactor (FY 2016 - 2017)

(Related projects) Advancement of accident progression analysis technology for assessing conditions inside reactor (FY 2011)

Assessing conditions inside reactor by advancement of accident progression analysis technology (FY 2012 - 2013)

Assessing conditions inside reactor through application of severe accident analysis code (FY 2014)

Advancement of grasping conditions inside reactor by accident progression analysis and actual data, etc. (FY 2015)

［Ｂ３］ Retrieval facility/safety system/maintenance facility/storage

① Development of retrieval method of fuel debris (FY2021 – 2022)

(Related projects) Development of technologies for retrieving fuel debris and internal structures (FY 2014)

Advancement of retrieval method and system of fuel debris and internal structures (FY 2015 - 2018)

Development of basic technologies for retrieving fuel debris and internal structure (FY 2015 – 2018)
Development of technologies toward further expansion in scale for retrieving fuel debris and internal structures (FY2019 - 2021)

② Safety system (FY2021 – 2022)
(Related projects) Development of criticality control technologies of fuel debris (FY 2012 - 2016)

③ Development of technologies for maintaining remote equipment (FY2021 – 2022)

④ Development of technologies for containing, transferring, and storing fuel debris (FY 2014 - 2022)

⑤ Development of support technologies for integrated management of Fukushima Daiichi NPS decommissioning (FY2021 – 2022)

(Other R&D)
・Development of PCV closed water circulation systems (FY 2018 - 2019)

・Advancement of fundamental technologies for retrieving fuel debris and internal structures (FY 2017 - 2018)
(Related projects) Development of fundamental technologies for retrieving fuel debris and internal structure (FY 2015 - 2016)

・Development of repair methods for leak spots in PCV (FY 2016 - 2017)
(Related projects) Development of identification technology of leaks in PCVs (FY 2011 - 2013)
Development of repair method for PCVs (FY 2011 - 2013)
Development of repair (water stoppage) technology toward water filling in PCV (FY 2014 - 2015)

・Full-scale test of repair methods for leak spots in PCV (FY 2016 - 2017)
(Related projects) Full-scale test of repair methods for leak spots in PCV (FY 2014 - 2015)

・Development of corrosion inhibition technology for RPV and PCV (FY 2016)

【C】Waste management
・Research and development of processing and disposal of solid waste (FY 2013 - 2023)
(Related projects) Development of technologies for processing/disposal of secondary waste by

treatment of contaminated water (FY 2012)
Development of technologies for processing/disposal of radioactive waste (FY 2012)
Development of technologies for processing/disposal of waste generated from the accident (FY2014)

(Other R&D)

【Ⅰ】Spent fuel management

・Evaluation of long-term integrity of fuel assembly removed from SFPs (FY 2015- 2016)

(Related projects) Evaluation of long-term structural integrity of fuel assemblies removed from SFPs (FY 2012 - 2014)

・Investigation of method for processing damaged fuel, etc. removed from SFPs (FY 2013 - 2014)

【Ⅱ】Contaminated water management

・ Verification tests of tritium separation technologies (FY 2014 - 2015)

・ Verification of technologies for contaminated water treatment (FY 2014)

・ Large-scale verification of impermeable walls (frozen wall) (FY 2014)

・ Development and verification of high-performance multi-nuclide removal equipment (high-performance ALPS) (FY 2014)

Attachment 13 Selected subjects in the Nuclear Energy Science & Technology and Human Resource Development Project (the World Intelligence Project)

Selected subjects in the 2021 issue-solving decommissioning research program (8 subjects)

Subject of proposal	Study representative [Organization]	Participating institution
Research and development of a hybrid-type evaluation method of the long-term integrity of reactor buildings using building response monitoring and damage imaging technology	Masaki Maeda [Tohoku University]	Shibaura Institute of Technology, Tokyo Institute of Technology, Nippon Institute of Technology, National Institute of Technology, Kisarazu College, Japan Atomic Energy Agency (JAEA)
Clarification of the actual debris formation mechanism by synthesizing mock-up debris based on the analysis results of materials around fuel debris and the sophistication of the debris property database by verifying the severe accident progression analysis results	Masayoshi Uno [University of Fukui]	Osaka University, Tokyo Institute of Technology, Tohoku University, Japan Atomic Energy Agency (JAEA)
Study on water sealing, repair, and stabilization of the lower part of the PCV by geopolymer and other substances	Shunichi Suzuki [The University of Tokyo]	Tokyo City University, National Institute of Advanced Industrial Science and Technology, ATOX Co., Ltd., Japan Atomic Energy Agency (JAEA)
Establishment of a characterization analysis method for small amounts of fuel debris using the world's first isotope analyzer	Tetsuo Sakamoto [Kogakuin University]	Nagoya University, Tokyo Electric Power Company Holdings Inc., Japan Atomic Energy Agency (JAEA)
Sophistication of mass spectrometry of single particles for actual measurement of alpha particles	Atsushi Toyoshima [Osaka University]	Kyoto University
Research and development of a robotic system for source exploration through cooperative measurement	Keitaro Hitomi [Tohoku University]	National Institute of Technology, Toyama College, Fukushima University, Japan Atomic Energy Agency (JAEA)
Development of a continuous tritium water monitoring method through mid-infrared laser spectroscopy	Ryo Yasuhara [National Institutes of Natural Sciences, National Institute for Fusion Science]	Hirosaki University
Challenges to the novel hybrid solidification of difficult-to-stabilize nuclides from the Fukushima NPS accident and development/safety assessment of a rational disposal concept	Masahiko Nakase [Tokyo Institute of Technology]	Radioactive Waste Management Funding and Research Center (RWMC), Okayama University of Science, Tohoku University, Japan Atomic Energy Agency (JAEA)

Selected subjects in the 2021 international cooperative decommissioning research program (4 subjects)

Subject of proposal	Study representative [Organization]	Participating institution
Japan-UK joint research on nuclear energy: 2 subjects		

Study on radioactive aerosol control and decontamination in decommissioning the Fukushima Daiichi NPS	Shuichiro Miwa [The University of Tokyo]	ATOX Co., Ltd., Japan Atomic Energy Agency (JAEA), University of Bristol
Navigation and control of a mechanical manipulator for fuel debris retrieval	Hajime Asama [The University of Tokyo]	RITECS Inc, Japan Atomic Energy Agency (JAEA), University of Sussex
Japan-Russia joint research on nuclear energy: 2 subjects		
Reducing the uncertainties of FPs and debris behavior and determining in-core contamination and debris properties based on the accident progression scenario for Fukushima Daiichi NPS Units 2 and 3	Yoshinao Kobayashi [Tokyo Institute of Technology]	Kyushu University, Japan Atomic Energy Agency (JAEA), Saint Petersburg State University
Sophistication of fuel debris criticality analysis technology using the non-contact measurement method	Toru Obara [Tokyo Institute of Technology]	National Institute of Advanced Industrial Science and Technology, National Research Nuclear University (MEPhI)

Selected subjects in the 2020 issue-solving decommissioning research program (8 subjects)

Subject of proposal	Study representative [Organization]	Participating institution
Grant-in-aid for young scientists: 2 subjects		
Investigation of environment-induced property changes and cracking behavior in fuel debris	Yang Huilong [The University of Tokyo]	Nagaoka University of Technology
Development of genetic and electrochemical diagnosis and inhibition technologies for invisible corrosion caused by microorganisms	Akihiro Okamoto [National Institute for Materials Science (NIMS)]	Japan Agency for Marine-Earth Science and Technology, Central Research Institute of Electric Power Industry, Japan Atomic Energy Agency (JAEA)
General research: 6 subjects		
Technology development of diamond-base neutron sensors and radiation-resistive integrated-circuits for a shielding-free criticality approach monitoring system	Manobu Tanaka [High Energy Accelerator Research Organization]	Hokkaido University, National Institute of Advanced Industrial Science and Technology, Nagoya University, Japan Atomic Energy Agency (JAEA)
Development of a new corrosion mitigation technology using nanobubbles toward corrosion mitigation in a PCV system under the influence of α/β/γ-ray radiolysis	Yutaka Watanabe [Tohoku University]	National Institutes for Quantum Science and Technology, National Institute for Materials Science (NIMS), Japan Atomic Energy Agency (JAEA)
Development of rapid and sensitive radionuclide analysis method through the simultaneous analysis of beta, gamma, and X-rays	Hirofumi Shinohara [Japan Chemical Analysis Center]	Niigata University, Kyushu University, Taisei Corporation, National Institutes for Quantum Science and Technology, Japan Atomic Energy Agency (JAEA)
Quantitative evaluation of long-term state changes of contaminated reinforced concrete considering the actual environments for rational disposal	Ippei Maruyama [The University of Tokyo]	National Institute for Environmental Studies, Taiheiyo Consultant Co., LTD., Taiheiyo Cement Corporation, Nagoya

		University, Hokkaido University, Japan Atomic Energy Agency (JAEA)
Study on the rational treatment/disposal of contaminated concrete waste considering leaching alteration	Tamotsu Kozaki [Hokkaido University]	University of Fukui, Central Research Institute of Electric Power Industry, Japan Atomic Energy Agency (JAEA)
Challenge to the advancement of debris composition and direct isotope measurement by microwave-enhanced LIBS	Yuji Ikeda [iLabo Co., Ltd]	Japan Atomic Energy Agency (JAEA)

Selected subjects in the 2020 international cooperative decommissioning research program (2 subjects)

Subject of proposal	Study representative [Organization]	Participating institution
Japan-UK joint research on nuclear energy: 2 subjects		
Development of environmental mitigation technology with novel water purification agents	Naoki Asao [Shinshu University]	National Institutes of Natural Sciences, Institute for Molecular Science, Tohoku University, Diamond Light Source
Research and development of the sample-return technique for fuel debris using an unattended underwater vehicle	So Kamada [National Institute of Maritime, Port and Aviation Technology, National Maritime Research Institute]	High Energy Accelerator Research Organization, Japan Atomic Energy Agency (JAEA), Lancaster University

Selected subjects in the 2019 common-based nuclear research program (7 subjects)

Subject of proposal	Study representative [Organization]	Participating institution
Grant-in-aid for young scientists: 2 subjects		
Development of tailor-made adsorbents for uranium recovery from seawater on the basis of uranyl coordination chemistry	Koichiro Takao [Tokyo Institute of Technology]	Japan Atomic Energy Agency (JAEA)
Semi-autonomous remote-control technology of an articulated mobile robot to recover from stuck states	Motoyasu Tanaka [The University of Electro-Communications]	-
General research: 5 subjects		
Measurement methods for radioactive source distribution inside reactor buildings using a one-dimensional optical fiber radiation sensor	Akira Uritani [Nagoya University]	Japan Atomic Energy Agency (JAEA)
Study on oxidative stress status in organs exposed to low dose/low dose-rate radiation	Masatoshi Suzuki [Tohoku University]	Hiroshima University, Osaka University
Basic study for online monitoring of tiny particles including alpha emitters by aerosol time-of-flight mass spectroscopy	Atsushi Toyoshima [Osaka University]	(Cooperation within the institution)
Establishing a new evaluation system to characterize radiation carcinogenesis by stem cell dynamics	Daisuke Iizuka [National Institutes for Quantum Science and Technology]	The University of Tokyo
Development of radiation-hardened diamond image-sensing devices	Shinya Omagari [National Institute of Advanced Industrial Science and Technology]	Hokkaido University

Selected subjects in the 2019 issue-solving decommissioning research program (4 subjects)

Subject of proposal	Study representative [Organization]	Participating institution
Estimation of the in-depth debris status of Fukushima Unit-2 and Unit-3 with multi-physics modeling	Akifumi Yamaji [Waseda University]	Osaka University, Japan Atomic Energy Agency (JAEA)
Fluorination method for classification of the waste generated by fuel debris removal	Daisuke Watanabe [Hitachi-GE Nuclear Energy, Ltd.]	Saitama University, Japan Atomic Energy Agency (JAEA)
Development of a stable solidification technique for ALPS sediment wastes with apatite ceramics	Takehiko Tsukahara [Tokyo Institute of Technology]	Central Research Institute of Electric Power Industry, Japan Atomic Energy Agency (JAEA)
Challenge to the investigation of fuel debris in RPV with an advanced super dragon articulated robot arm	Shuji Takahashi [Tokyo Institute of Technology]	Japan Atomic Energy Agency (JAEA)

Selected subjects in the 2019 decommissioning research program for research personnel development (4 subjects)

Subject of proposal	Study representative [Organization]	Participating institution
Human resource development related to remote control technology for monitoring inside the RPV pedestal during the retrieval of fuel debris	Hajime Asama [The University of Tokyo]	Fukushima University, Kobe University, Japan Atomic Energy Agency (JAEA)
Development of methodology combining chemical analysis technology with informatics technology to understand the perspectives property of debris and tie-up style human resource development	Yoshitaka Takagai [Fukushima University]	PerkinElmer Co., Ltd., KAKEN Co.,Ltd., Japan Atomic Energy Agency (JAEA)
Study on the degradation of fuel debris through the combined effects of radiological, chemical and biological functions	Takehiko Tsukahara [Tokyo Institute of Technology]	Visible Information Center, Inc., Japan Atomic Energy Agency (JAEA)
Development of extremely small amount analysis technology for fuel debris analysis	Yasuyoshi Nagai [Tohoku University]	Nagaoka University of Technology, Nippon Nuclear Fuel Development Co., Ltd., Kyushu University, Japan Atomic Energy Agency (JAEA)

Selected subjects in the 2019 international cooperative decommissioning research program (4 subjects)

Subject of proposal	Study representative [Organization]	Participating institution
Japan-Russia joint research on nuclear energy: 2 subjects		
Improvement of critical safety technology in fuel debris retrieval	Toru Obara [Tokyo Institute of Technology]	Tokyo City University, National Research Nuclear University (MEPhI)
Study of corrosion and degradation of objects in a nuclear reactor by microorganisms	Akio Kanai [Keio University]	RIKEN, Japan, Japan Atomic Energy Agency (JAEA), Kazan State University
Japan-UK joint research on nuclear energy: 2 subjects		

Safe, efficient cementation of challenging radioactive wastes using alkali-activated materials with high-flowability and high-anion retention capacity	Tsutomu Sato [Hokkaido University]	ADVAN ENG. co., ltd., Japan Atomic Energy Agency (JAEA), The University of Sheffield
Radiation tolerant rapid criticality monitoring with radiation-hardened FPGAs	Minoru Watanabe [Shizuoka University]	Kobe City College of Technology, Lancaster University

Note: The details of the project implementation (project plan, contract amount, etc.) may be changed, or the adoption of the project may be canceled due to changes in circumstances that arise after the adoption.

Attachment 14 Major activities related to enhancing international collaboration

Table A14-1 Intergovernmental Framework between Japan and other countries

Framework	Descriptions
Annual Japan-UK Nuclear Dialogue	This dialogue is held based on the appendix to the joint statement of the Japan-UK top level meeting in April 2012, "Japan-UK Framework on Civil Nuclear Energy Cooperation" (Since February 2012).
Japan-France Nuclear Energy Committee	It was established under the joint statement of Japan–France top-level meeting in October 2012 (Since February 2012).
Japan-US Decommissioning and Environmental Management Working Group	After the Fukushima Daiichi NPS accident in March 2011, the establishment of the US-Japan Bilateral Commission on Civil Nuclear Cooperation (the Bilateral Commission) was announced in April 2012 based on the relationship between Japan and the US to further reinforce bilateral cooperation. Under this commission, "the Decommissioning and Environmental Management Working Group (DEMWG)" was established (Since December 2012).
Japan-Russia Nuclear Working Group	The Nuclear Working Group was established after confirming that Energy is one of the eight areas of cooperation plan approved at the Japan-Russia top-level meeting in September 2016, (Since September 2016).

Table A14-2 Inter-organizational Cooperation Agreement

Domestic	International	Descriptions
NDF	NDA	Exchange of information for various technical knowledge on decommissioning, etc. and personal exchange are provided. (Concluded in February 2015)
NDF	CEA	Exchange of information for various technical knowledge on decommissioning, etc. and personal exchange is provided. (Concluded in February 2015)
TEPCO	DOE	Umbrella Contract was made and information is exchanged as needed. (Concluded in September 2013)
TEPCO	Sellafield, Ltd.	Information Exchange Agreement for site's operation, etc. was concluded. (September 2014)
TEPCO	CEA	Information Exchange Agreement on for decommissioning was concluded. (September 2015)
JAEA	NNL	Comprehensive Agreement for advanced technology on nuclear R&D, advanced fuel cycles, fast reactor, radioactive waste
JAEA	CEA	Cooperation Agreement for specific technical issues on molten core-concrete interaction, etc.

JAEA	Belgium Nuclear Research Center	Agreement of Cooperation for Nuclear R&D and Research on the accident of the Fukushima Daiichi
JAEA	Nuclear Safety Research Center (Ukraine)	Memorandum for decommissioning research, etc. of the Fukushima Daiichi NPS and Chernobyl was concluded.
JAEA	IAEA	Research Agreement on characterization of fuel debris

Table A14-3 Dissemination of information to the world (Holding or attending International Conference (from September 2021 to August 2022))

Conference Name	Period	Organization
The 64th IAEA Conference Side event	September, 2021	NDF METI TEPCO
IAEA International Conference on a Decade of Progress after Fukushima-Daiichi	November, 2021	NDF METI TEPCO JAEA
Japan-UK Nuclear Dialogue	December, 2021	METI
International briefing	February, 2022	METI
US Waste Management 2022	March, 2022	TEPCO IRID
Regulatory Information Conference (US NRC)	March, 2022	NDF
Fukushima Research Conference	Year round	JAEA

Table A14-4 Dissemination of information to the world (on web (in English)

Site	Organization
Mid-and-long-term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1 to 4 (https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/)	METI
Annual report to the embassies concerning discharging and seawater monitoring from the Fukushima Daiichi NPS	METI, MOFA
Nuclear Damage Compensation and Decommissioning Facilitation Corporation's website (https://www.dd.ndf.go.jp/english/)	NDF
Information Portal for the Research and Development for the Fukushima Daiichi Decommissioning (https://www.drd-portal.jp/en/)	NDF
Activities for Decommissioning (https://fukushima.jaea.go.jp/english/)	JAEA
IRID website (https://irid.or.jp/en/)	IRID

Responsibility for the Revitalization of Fukushima (https://www.tepco.co.jp/en/hd/responsibility/revitalization/index-e.html)	TEPCO
Providing English version of Press release to foreign media	TEPCO
Management Office for the Project of Decommissioning, Contaminated Water and Treated Water Management (https://en.dccc-program.jp/)	MRI (Business consignee)

Table A14-5 Major collaborative projects with foreign organizations

Project	Contents/Period of project	Participating Organization
IAEA Project		
DAROD	・Knowledge and experience obtained from the efforts on challenges of decommissioning and recovery of damaged nuclear power facilities (regulations, technologies, systems, and strategies) are shared among the relevant countries. ・Project period : 2015 to 2017	NDF
OECD/NEA Project		
BSAF	・Researching institutions and governmental organizations from eleven countries joined to conduct benchmark study using severe accident analysis codes developed by these organizations to find out how the accident in the Fukushima Daiichi NPS progressed and how the fuel debris and FPs spread inside the reactors. Knowledge and findings related to the modeling of phenomenological issues obtained by member countries' organizations are being utilized. ・Data measured during the accident and information database regarding the post-accident radiation levels are shared. ・Project period : 2015 to 2018	IRID JAEA TEPCO
ARC-F	・In succession to the BSAF project, researching institutions and governmental organizations from twelve countries joined to investigate the situation of the accident in more detail and utilize it for further research to improve safety of light-water reactor ・Project period : 2019 to 2021	NRA IR JAEA
PreADES	・Sharing characteristics information that helps to understand properties of fuel debris such as its phase state and composition. ・Enhancing "Fuel debris Analytical Chart" that summarizes needs and priority of fuel debris analysis. ・Maintenance of tasks after analysis and analysis facility information ・Project period : 2018 to 2021	METI NRA IR JAEA IRID NDF TEPCO

FACE	・A project launched by integrating ARC-F and PreADES ・Analyzing fuel debris samples and accident scenarios ・Sharing the results of the analysis among participating countries ・Project period : 2022 to 2026	METI NRA JAEA NDF TEPCO
TCOFF	・In reference to the accident progression of the Fukushima Daiichi NPS, (1F) advancing molten core and molten fuel models, FP migration behavior model and thermodynamic database as their basis. Based on the material scientific knowhow, evaluating details of molten core and fuel on condition of 1F accident, and characteristics of fuel debris and its producing mechanism. Then, providing material scientific knowhow and result of detail evaluations to international cooperation project including PreADES, ARC-F, TAF-ID, and domestic decommissioning project like IRID. ・Project budget was contributed from MEXT. ・Project period : 2017 to 2019	MEXT JAEA IR Tokyo Institute of Technology
EGCUL	・Discussing on characterization method for waste from unknown derivation	METI NDF JAEA TEPCO