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

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Nuclear Damage Compensation and

Decommissioning Facilitation Corporation

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1. Introduction

The long-term approach to the decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc. (hereinafter referred to as the “Fukushima Daiichi NPS”) has proceeded under “the Mid-and-Long-term Roadmap towards the Decommissioning of Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.[1]” (hereinafter referred to as “Mid-and-Long-term Roadmap”), developed by the Japanese Government. (Fig. 1).

Accident / Early period	Phase 1	Phase 2	Phase 3	
			Phase 3−①	Phase 3−②
● From the time the accident occurred (March 2011) To Step 2 was completed* (December 2011)	● From Step 2 was completed (December 2011) To the start of spent fuel removal from the first implementing unit (November 2011)	● From the end of Phase 1 (November 2013) To the start of fuel debris retrieval from the first implementing unit	●From the end of Phase 2 (the start of fuel debris retrieval from the first implementing unit) To the end of 2031	●From the end of Phase 3- ① Through the end of decommissioning (Target period will be 30 to 40 years after Step 2)

* Situation where “releases of radioactive material are controlled, and radiation levels are significantly reduced”.

Fig. 1 Decommissioning process as defined in the Mid-and-Long-term Roadmap

Decommissioning works have been making progress, as shown by the facts that the inside of the primary containment vessel was investigated using drones during the internal investigations of Unit 1, the milestones in reducing the amount of contaminated water generation were achieved ahead of schedule and a new target was set, and ALPS-treated water was discharged into the sea 8 times since August 2023. At present, the trial retrieval of fuel debris has started, entering Phase 3–[1], the development of analytical methods and the securing of analytical personnel are also being promoted, based on examination of retrieval methods for further expansion of the retrieval scale and the formulated analysis plan. As a series of problems have occurred since October 2023, TEPCO takes this situation seriously and is working to establish a system to prevent human errors.

Nuclear Damage Compensation and Decommissioning Facilitation Corporation (hereinafter referred to as “NDF”) has supported efforts related to the decommissioning of the Fukushima Daiichi NPS as an organization that conducts research and development, as well as provides advice and guidance, required for decommissioning since 2014. This “Technical Strategic Plan for Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station” (hereinafter referred to as the “Technical Strategic Plan”), as a part of these supports, has been compiled annually since 2015 with the following objectives (Attachment 1).

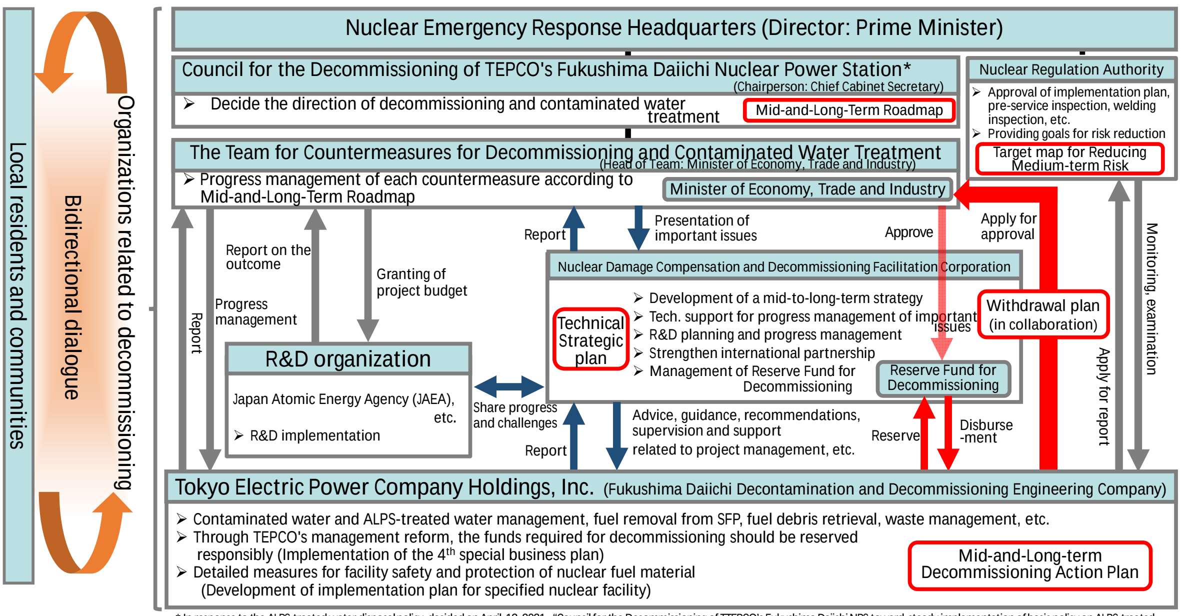
[1] Material 2: “The Mid-and-Long-term Roadmap towards the Decommissioning of Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.”, The 4th Inter-Ministerial Council for Contaminated Water and Decommissioning Issues, December 27, 2019,

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

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

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

In order to safely and steadily conduct the decommissioning of the Fukushima Daiichi NPS, the government, NDF, Tokyo Electric Power Company Holdings, Inc. (hereinafter referred to as the “TEPCO”), Japan Atomic Energy Agency (hereinafter referred to as “JAEA”.), and other research and development organizations are working together on the efforts based on their roles. Fig. 2 shows the division of roles the related organizations responsible for decommissioning. Under such a system, TEPCO, the operator of the decommissioning project, is working to strengthen the project management system for steadily advancing the decommissioning work by systematically implementing responses to various issues with a view to the medium-to long-term of the decommissioning work (details in Chapter 6).



* 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.

Fig. 2 Division of roles of related organizations responsible for decommissioning of the Fukushima Daiichi NPS

From the financial aspect, to ensure the decommissioning work in the immediate future, decommissioning work is being implemented in accordance with the Reserve Fund for Decommissioning established by partially revised the Nuclear Damage Compensation Facilitation Corporation Act passed in May 2017. The main steps in this process are as follows.

① TEPCO sets aside the amount of money determined by the NDF and approved by the Minister of Economy, Trade and Industry every year.

② NDF and TEPCO jointly prepare a Withdrawal Plan for Reserve Fund (hereinafter referred to as "Withdrawal Plan").

③ TEPCO withdraws the Reserve Fund based on the Withdrawal Plan approved by the Minister of Economy, Trade and Industry, and implements decommissioning.

Under this Reserve Fund system, NDF assumes the roles and responsibilities of appropriate management of funds related to decommissioning, management of proper implementation structures, and steady work management, as an organization to manage and oversee TEPCO's decommissioning activities. Specifically, prior to the formulation of the Withdrawal Plan, NDF presents the work targets and major works to be incorporated in the Withdrawal Plan to TEPCO by organizing the Policy for Preparation of Withdrawal Plan based on the Technical Strategic Plan. Through the process of jointly preparing the Withdrawal Plan with TEPCO, NDF supports the proper and steady implementation of decommissioning, as well as assesses the appropriateness of TEPCO's efforts from the perspective of project execution by examining and presenting the works to be included in the Plan (Fig. 3).

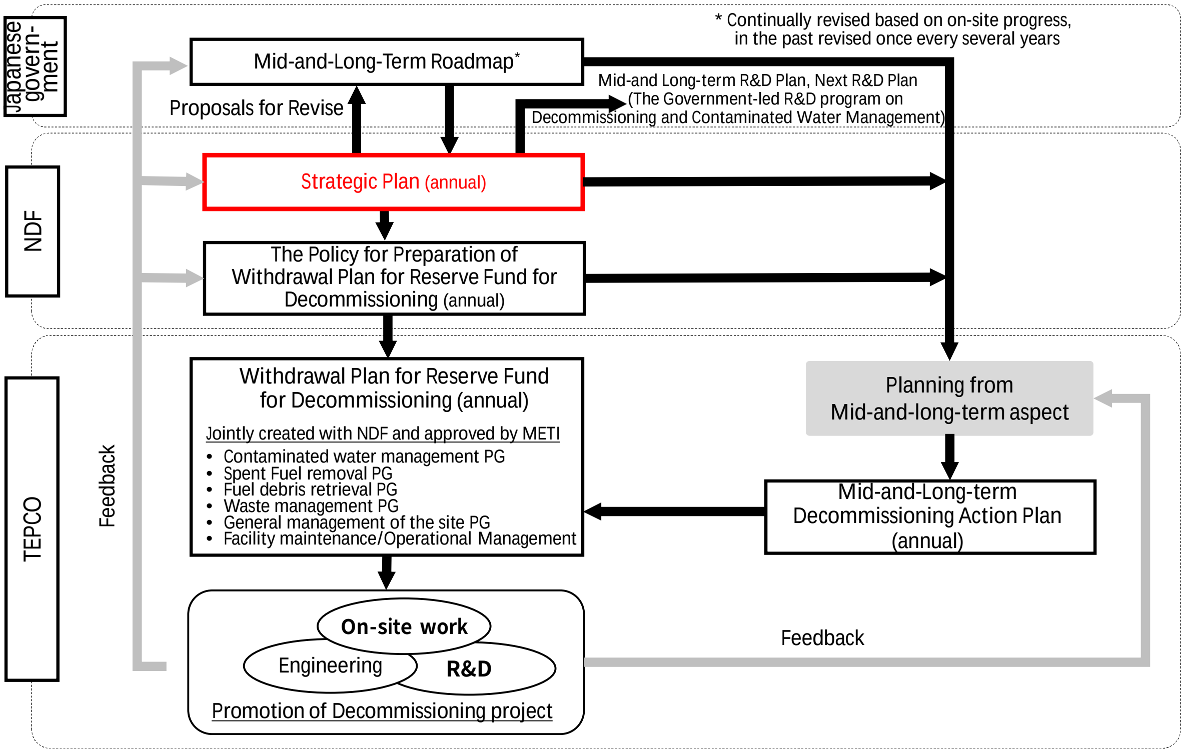


Fig. 3 Positioning of the Technical Strategic Plan based on the Reserve Fund

1.2 The Technical Strategic Plan 2024

The Technical Strategic Plan 2024 consists of six chapters and characteristically features below:

- Issues to be discussed in Phase 3 of the Mid-and-Long-term Roadmap
- Unit 1; Implementation status of the results of internal investigation using drones and other devices
- Unit 2; Implementation status of preparatory works related to trial retrieval (internal investigation and fuel debris sampling)
- Unit 3; Examination results of selecting the retrieval methods toward further expansion of the retrieval scale and status of response
- Efforts toward the discharge of ALPS-treated water into the sea/Implementation status of third-party analysis.

Including the above, the major changes in the Technical Strategic Plan 2024 are as follows. The accomplishment of the efforts to date for the Fukushima Daiichi NPS are shown in Attachment 2.

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

- Issues to be discussed in Phase 3 of the Mid-and-Long-term Roadmap are described.
- The SED assessment [2] was reviewed in terms of the Hazard Potential and Requiring Level for Safety Management based on the radioactivity levels and management status of each risk source as at the end of March 2024. The most notable changes since the end of March 2023 include decreasing of Hazard Potential as the progress of the transfer work of the ALPS slurry stored in the HIC, and decreasing of Hazard Potential of fuel debris due to the revised evaluation of the time to reach the flammable limit of hydrogen concentration are described.
- This chapter includes safety functions and issues that need to be strengthened based on a series of problems that have occurred in the last year.

Chapter 3 Technological strategies toward decommissioning of the Fukushima Daiichi NPS

(1) Fuel debris retrieval

- In addition to the results of the investigation using a submersible ROV conducted in March 2023 in the Unit 1 PCV, this section describes the results of the dry area survey by the drone conducted in February and March 2024 provided a lot of information, including the state of the existing structures outside and inside the pedestal, and images of deposits and fallen objects.
- Regarding the trial retrieval from Unit 2, this section describes that TEPCO intends to collect fuel debris for the purpose of understanding the properties of fuel debris reliably at an early stage, using a telescopic-type device (a device with a mechanism that can change its total length of the device by pulling out or storing a combination of cylinders of different sizes. Hereinafter referred to as “telescopic device”), after that, the internal investigation and fuel debris sampling are continued with robot-arm.
- For further expansion of the retrieval scale in Unit 3, the section also describes the details of each method examined and evaluated in the Sub-Committee for the evaluation of fuel debris retrieval methods (hereinafter referred to as the “Sub-Committee”), the recommendations on the method that should be examined in the design study at this point, and the progress of TEPCO's study and future course of action based on the recommendations.

[2] A method based on the Safety and Environmental Detriment score (SED) developed by the Nuclear Decommissioning Authority (NDA) to express the magnitude of risk (risk level) for radioactive materials. For details, refer to Attachment 5.

(2) Waste management

- As the study policy for establishing an entire waste stream, this section describes that it is established by accumulating the streams of measures for individual solid wastes (individual waste streams) and bundling them together.
- For storage and management, it describes the policy for establishing a method to control radioactivity concentration as required by the Target Map for Reducing Risks.

(3) Contaminated water and treated water management

- This section describes about the achievement of the target to control the amount of contaminated water generated to 100 m^3/day or less within 2025 ahead of schedule, and strategies including measures for the newly set target (to be reduced to about 50 to 70 m^3 /day by the end of FY 2028).
- It describes the results of the discharge of ALPS-treated water into the sea, which started in August 2023, and the status of future efforts and third-party analysis.

(4) Fuel removal from spent fuel pool

- This section includes the status of fuel removal immediately after the accident and the changes in fuel storage status with a list of future goals.
- The example of a concrete cask that is being examined as a storage method is described.

Chapter 4 Analysis strategy for promoting decommissioning

- Specific issues and initiatives for improving the number of analyses are described.
- The status of studies and policies on analysis of fuel debris and solid waste are comprehensively described.

Chapter 5 Efforts to facilitate research and development

- This section stated that In FY2024, in response to the recommendations of the Sub-Committee, the four-parties has proceeded with the study of issues including basic/fundamental research and the study of its implementation specifics as special tasks of the Four Party Cooperative Activities. It also stated that the results are reflected in the R&D medium-and-long-term plan and the next fiscal year's decommissioning R&D plan, and the collaboration between basic/fundamental research and applied practical application research will also be promoted.
- Regarding the Project of Decommissioning, Contaminated water and Treated water Management, the purpose of the project and the efforts made so far are described for easy understanding even for those who are not familiar with the project.

Chapter 6 Activities to support our technical strategy

(1) Capability, organization and human resources to facilitate decommissioning

- This section describes the establishment of procurement system with a view to long-term decommissioning project and the study on the on-site management in collaborating with partner companies for building cooperative relationships with business partners.
- This section includes organizational restructuring to appropriately respond to changes in the situation at the site and the needs of society and local communities.

(2) Strengthening international cooperation

- In the Section “6.2.2 Major Issues and Strategies (1) Integrating and giving back wisdom and knowledge from around the world”, the three strategies described in the Technical Strategic Plan 2023 have been reorganized as new items and given individual titles.

(3) Stakeholder involvement

- To show that decommissioning project is supported by local communities, the local employment rate of workers engaged in the work is listed.

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 been maintained and managed in a state with a certain level of safety through various measures taken continuously since the accident, and it also satisfies the requirements of “the matters for which measures should be taken” mandated by the Nuclear Regulation Authority.

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. 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 impact on the environment and public and radioactive exposure of workers (Attachment 1), however, risk reduction measures need to be continued. In this chapter, the issues to be discussed in proceeding to Phase 3 of Mid-and Long-term Roadmap are shown in Section 2.1.1. Next, the risk management to be addressed in Phase 3-[1] is shown in Section 2.1.2, and the concept of reducing risks caused by radioactive materials is shown in 2.2. Section 2.3 shows the approach to ensuring safety during decommissioning. Section 2.1.2 states the general risk expected during the decommissioning work in Phase 3-[1], and section 2.2 describes the concept of reducing risks to the general public according to the state of radioactive materials existing inside the Fukushima Daiichi NPS. Section 2.3 also addresses risk, but both risk to workers engaged in safety assurance operations and risk to the public.

2.1.1 Matters to be discussed in Phase 3

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

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

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

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

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

The specific method and timing of processing and disposal to come after that will be studied after characterization and analysis of the fuel debris to be retrieved and stored are complete. For that reason, for the ideal disposal method, specific technical requirements will be presented in the Technical Strategic Plan once fuel debris retrieval, analysis, and studies have progressed to a certain degree.

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

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

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

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

In Phase 3-[1], several processes for risk reduction are 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 to 6.
- Undertake trial retrieval of fuel debris and promote gradual expansion of fuel debris retrieval.
- Minimize and stably maintain the amount of contaminated water generated.
- Eliminate the temporary storage of rubble etc., as a waste management measure.

Regarding fuel debris retrieval, preparation of methods for further expansion of the retrieval scale, which will be full-scale decommissioning work, is promoted. Even though more than thirteen 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, risks that were previously perceived as small may become relatively large, or unknown risks may become newly apparent. In preparation for these risks, to effectively respond to risks toward further expansion of the retrieval 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 the retrieval 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 the retrieval 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.

2.1.2.1 Risk reduction

2.1.2.1.1 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 2.1.2.

- Liquid radioactive materials

The migration of liquid radioactive materials, which are as likely to migrate as gaseous and dusty radioactive materials, should be controlled without fail. Specifically, for the lowering of the water level in the suppression chamber (hereinafter referred to as “S/C”) that TEPCO is currently undertaking, minimization of the amount of PCV water is promoted while ensuring consistency with the examination of fuel debris retrieval method and the medium- to long-term measures against contaminated 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.

2.1.2.1.2 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, the effects due to contact with the molten core materials and their heat also occurred. In the pedestal of Unit 1 PCV, exposure of inner wall reinforcement and inner-skirt was observed. 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 (Attachment 2) 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.

2.1.2.2 Requirement for the further expansion of the retrieval scale

The following is required to conduct safe and reliable fuel debris retrieval toward the phase of the further expansion of the retrieval 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 the retrieval scale.
- Proceed with designing, manufacturing, and installing systems related to retrieval methods.
- Establish a system for securing, training and managing operators and conduct 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 proceed with 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 so that it 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 Concept of reducing risks caused by radioactive materials

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 Requiring Level for Safety Management 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” × “Requiring Level for Safety Management” (Formula 1)

“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. “Requiring Level for 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)[3].

The major risk sources of the Fukushima Daiichi NPS are listed in Table 1, and Fig. 4 shows the risk level in each risk source as at the end of March 2024. In addition, Fig. 5 shows the risk level of the Fukushima Daiichi NPS and their changes over time as the sum of these risk sources. In Fig. 4, Hazard Potential and Requiring Level for Safety Management are reviewed based on the radioactivity levels and management status of each risk source as at the end of March 2024. The most notable changes since the end of March 2023 are two points: (1) transition of the hazard potential of “ALPS slurry (to be transferred to other HICs)” to “ALPS slurry” according to the progress of the transfer work of the ALPS slurry stored in the HIC, which exceeded the standard

[3] This was called “Safety Management” until the Technical Strategic Plan 2022, which was revised to “Requiring Level for Safety Management” in the Technical Strategic Plan 2023. This revision was made to explicitly indicate that a higher level of safety control measures is required when the facility containing the risk source has inadequate integrity, packing/monitoring conditions, etc., or when the risk source itself is highly reactive.

for cumulative absorbed dose[4, 5, 6]; and (2) decrease in the Hazard Potential of “fuel debris”, as a result of the re-evaluation of the changes in the hydrogen concentration after the suspension of nitrogen filling, which affects the time allowance (Control Factor: a factor of Hazard Potential, see Attachment 5) in consideration of the radioactivity decay and the distribution of fuel debris, and the evaluation of a more certain state of extended time allowance than previously assumed.[7, 8] Regarding the impact on the Requiring Level for Safety Management for “fuel debris” and “contaminated structures, etc., in the buildings” based on the partial loss of concrete in pedestals found by the PCV internal investigation of Unit 1, it was determined that the Requiring Level for Safety Management will be maintained considering the series of evaluations performed by TEPCO[9,10,11]:

- in an event assuming that the RPV has fallen, and a large opening was created on the PCV as a result of loss of the supporting function of the pedestal, the effective radiation dose at the site boundary is below 5 mSv/event, the standard at the time of the accident, even considering multiple conservative dust generation scenarios (maximum of 0.04 mSv/event);
- a structural integrity evaluation conducted based on the partial loss of concrete in pedestals found that the load of the pedestal superstructure applied to the pedestal foundation by an earthquake equivalent to Ss900 can be supported by the inner skirt alone taking into account the impact on the strength and property of steel members with the temperature history at the time of the accident, and the PCV stabilizer or bulkhead, that bear the horizontal load of

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[4] Material 4-1: “Progress of the HIC slurry transfer operation”, The Technical Meeting on the Examination of the Implementation Plan of the Measures for the Specified Reactor Facilities (112th), , April 26, 2024

[5] Regular meeting on cooling by circulating injection water and stagnant water at Fukushima Daiichi NPS, “Progress of the HIC slurry transfer operation”, April 5, 2024

[6] The HIC, which is estimated to have an integrated absorbed dose exceeding 5000 kGy by the time the ALPS slurry stabilization facility begins operation, is being transferred one by one. The HIC scheduled for transfer by the end of FY 2024 is included in the "ALPS slurry (HIC to be transferred)" (29 units, including 6 units whose transfer was not completed as originally planned by the end of FY 2023 and 23 units scheduled for transfer by the end of FY 2024). The number of HIC units with integrated absorbed dose exceeding 5000 kGy by the end of FY 2025 and FY 2026 is estimated to be 26 and 48, respectively. The evaluation of the potential hazard of "ALPS slurry (HIC to be transferred)" in the following fiscal year and thereafter will vary according to the progress of the transfer operation in the future.

[7] Material 1-3: “Status of Study on PCV Containment Function Enhancement (Hydrogen Explosion in PCV),” The Technical Meeting on the Examination of the Implementation Plan of the Measures for the Specified Reactor Facilities (10th), June 5, 2023

[8] The evaluation of the time allowance is roughly classified into "several days", "several weeks", and "several months", and the difference is reflected in the evaluation of the Hazard potential. Up to the Technical Strategic Plan 2023, the evaluation of "several weeks" was evaluated as more likely as the evaluation of the time allowance, but this was revised to "several months" in the evaluation in the Technical Strategic Plan 2024.

[9] The Technical Meeting on the Examination of the Implementation Plan of the Measures for the Specified Reactor Facilities (10th), Material 1-1: “Action Based on Situation of Unit 1 Pedestal,” June 5, 2023

[10] Material 2: “Status of Action Based on Situation of Pedestal inside Unit 1 PCV (Reply to Comments),” The Technical Meeting on the Examination of the Implementation Plan of the Measures for the Specified Reactor Facilities (12th), July 11, 2023

[11] Material 2-1: “Status of response to the directives on future responses based on the situation of the Unit 1 pedestal,” The 109th meeting of the Committee on Oversight and Evaluation of Specified Nuclear Facilities, October 5, 2023

the pedestal superstructure, alone can support the horizontal load at the time of an earthquake;

- provided, however, that the evaluation results above include uncertainties in the evaluation conditions due to limitations in the estimation of temperature history at the time of the accident and in the scope of equipment inspection, and will be affected by these factors, and therefore studies on measures to mitigate effects of dust dispersion, etc., will be promoted.

Above are the results of risk level evaluation as of the end of March 2024. The current evaluation method for the Requiring Level for Safety Management requires overall assessment such as the evaluation of “fuel debris” and “contaminated structures, etc., in the buildings” as stated above, and does not directly indicate the current state of risk sources. For that reason, how to improve the evaluation method is currently being studied. The Requiring Level for Safety Management is expressed as a product of the Facility Descriptor (FD; indicator of sufficiency of containment function) and the Waste Uncertainty Descriptor (WUD; indicator of long-term stability), and the FD and WUD are evaluated by applying the risk source to be evaluated to combinations of 10 each of prescribed descriptions (categories), that explain the nature of the risk source, and scores. However, descriptions to explain the nature of risk sources are broad and categorization of risk sources requires overall assessment after analyzing the current state. In the aforementioned evaluation of fuel debris and contaminated structures, etc., in the buildings, the focus will be placed on the description of safety assessment standards in the classification of FD, but the currently implemented evaluation has only two assessment options, and that is, whether safety assessment standards are “met” or “not met.” In the latest evaluation it was determined that the safety assessment standards were “met.” However, evaluation involving safety assessment standards should have more assessment grades that take into account the impact of damage from the accident and the degree of uncertainty in evaluation conditions, not just bipolar options. Such viewpoints of assessment to be incorporated into evaluation of risk sources are currently studied for the purpose of improving the evaluation method to directly indicate the state of risk sources from the results of evaluation by individual viewpoints of assessment, by preparing multiple descriptive indicators of the evaluator's judgment of the magnitude of risk and applying the results of the evaluator's assessment of the risk sources to these statements. They are planned to be reflected in this evaluation in the future.

In the Mid-and Long-term Roadmap, management of these risk sources is broadly classified into the following three major categories. They are prioritized and the most appropriate measures are being taken.

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).

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[12]. In considering the station-wide risk reduction strategy for the Fukushima Daiichi NPS, the above-mentioned SED is a semi-quantitative indicator of relative positions between risks attributable to radioactive materials at a certain time, and is an effective method for determining the priority of measures for risk sources.

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. These issues have also been presented since the Technical Strategic Plan 2019. In particular, regarding 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 6).

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[13] 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[14]. 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[15], with its epicenter off the coast of Fukushima Prefecture,

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[12] In Fig. 4, for the risk level that the major risk sources at the Fukushima Daiichi NPS, the "sufficiently stable management" region" is defined to encompass Likelihood of Occurring of risk sources stored in facilities that were safely designed and used before the accident and were not affected by the accident, such as the Common Spent Fuel Storage Pool and Dry Cask Temporary Custody Facility, and in facilities designed for long-term storage after the accident, such as sorption vessels.

[13] TEPCO, Material 4: "Report on the accident event of the drainage at the shallow draft wharf and storage management of rubble," The 90th Committee on Oversight and Evaluation of Specified Nuclear Facilities, April 19, 2021

[14] TEPCO, Material 3-6: "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)," The 90th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, May 27, 2021

[15] TEPCO, Material 5-1-3: "Additional system inspection and seismic evaluation in response to the earthquake on February 13 at the Fukushima Daiichi Nuclear Power Station," The 90th Committee on Oversight and Evaluation of Specified Nuclear Facilities, May 19, 2021

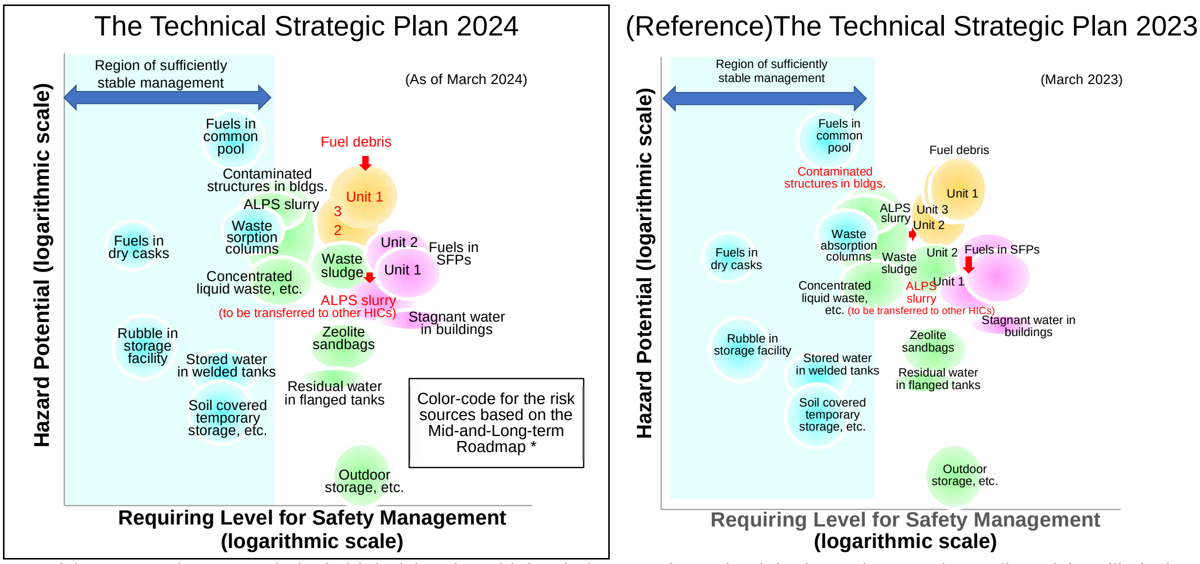
lowering of the PCV water levels at Units 1 and 3, and sliding of tanks on site exceeding the sliding amount evaluated at the time of tank installation were observed. At the time of the earthquake on March 16, 2022, with its epicenter off the coast of Fukushima Prefecture, a lowering of the PCV water levels at Units 1 and 3 was observed and the over-turning of containers in the temporary storage area was confirmed[16]. 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.

[16] TEPCO, Material 1-1: “Condition of the Fukushima Daiichi Nuclear Power Station after the earthquake on March 16,” The 99th Committee on Oversight and Evaluation of Specified Nuclear Facilities, April 18, 2022

Table 1 Major risk sources at the Fukushima Daiichi NPS

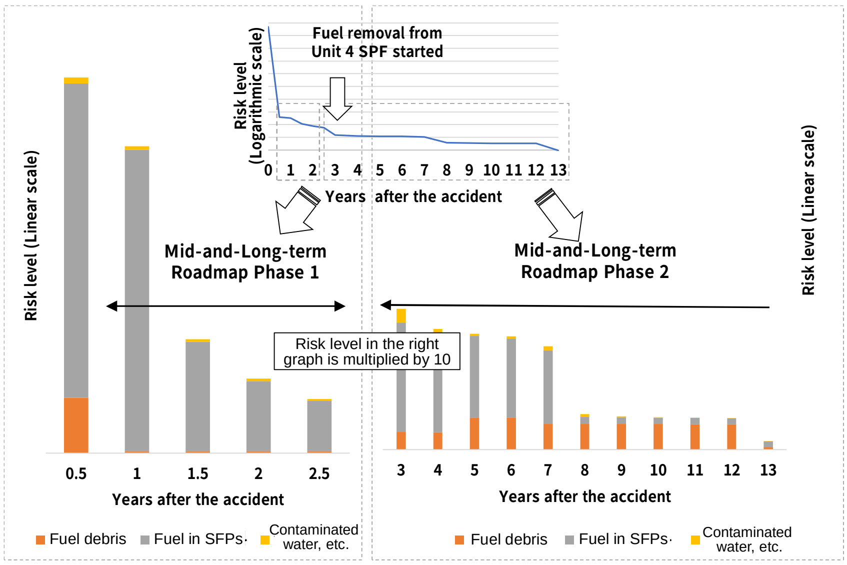
Fuel debris		Fuel debris in RPVs/PCVs in Units 1 to 3
Spent fuel	Fuel in SFPs	Fuel assemblies stored in the spent fuel pools (SFPs) in Units 1 and 2
	Fuel in the Common Spent Fuel Storage Pool	Fuel assemblies stored in the Common Spent Fuel Storage Pool
	Fuel in dry casks	Fuel assemblies stored in dry 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. 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.
	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
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), fallen 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), fallen trees stored in outdoor storage
Contaminated structures, etc., in the buildings		Structures, pipes, components, and other items (shield plugs, standby gas treatment system pipes, etc.) inside the reactor buildings and PCVs/RPVs that are contaminated with radioactive materials dispersed due to the accident; and activated materials generated from operation before the accident



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

The red letters present risk sources that have changed significantly from the evaluation of the Technical Strategic Plan 2023 (as of March 2023), the origin of the arrow indicates the location reported in the Technical Strategic Plan 2023. ALPS slurry (to be transferred to other HICs) was moving downward because Hazard Potential of shifted ALPS slurry (green) has decreased as the progress of the transfer operation. Note that there is little variation in the ALPS slurry (green) on a logarithmic scale, since the shifted percentage of the Hazard Potential of ALPS slurry (green) to the original ALPS slurry (green) is small. Hazard Potential of fuel debris decreased and moved downward as a result of the re-evaluation of the changes in the hydrogen concentration after the suspension of nitrogen filling, which affects the time allowance (Control Factor: a factor of Hazard potential, see Attachment 5) in consideration of the radioactivity decay and the distribution of fuel debris, and the evaluation of a more certain state of extended time allowance than previously assumed.

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



*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 allowance before the risk becomes apparent is increased.

*3 In the 13-year post-accident assessment, as a result of reviewing the evaluation of the time to reach the flammability limit of hydrogen concentration based on the finding that the time to reach the flammability limit of hydrogen concentration (4%) when nitrogen filling and venting in the PCV cease is significantly longer than in the early post-accident period, the risk of fuel debris is lower than in the previous evaluation because the time allowance before the risk becomes apparent is increased.

*4 The aforementioned time allowance before the risk becomes apparent is considered by the Control Factor (CF), which is an indicator of Hazard Potential, and it is evaluated by assigning discrete values to the CF according to rough classifications such as "several days", "several weeks", and "several months". Therefore, changes in the risk level also appear discretely.

Fig. 5 Reduction of risks present in the Fukushima Daiichi NPS

2.2.2 Risk reduction strategy

2.2.2.1 Interim targets of the risk reduction strategy

As indicated by Formula 1, measures to reduce the risk level assessed by SED include reducing the impact of radioactive materials on the public presented by “Hazard Potential” and reducing “Requiring Level for Safety Management”.

“Hazard Potential” can be expressed as the product of the Inventory, which is the amount of radioactive materials contained in the risk source, and factors related to the ease of release depending on differences in the properties of the risk sources, such as gas, liquid and solid, and the time allowance until the risk becomes apparent in the event of loss of safety functions. 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. Treating contaminated water to change it into secondary waste is an example of form change.

“Requiring Level for Safety Management” can be expressed as the product of two factors: one pertaining to the sufficiency of the containment function of the facility that contains the risk sources (hereinafter referred to as “containment performance”), and the other pertaining to the long-term stability and handleability of the risk source, such as its characteristics (degradation and activity level), packing, and monitoring conditions. As a method to reduce the likelihood of an event expressed in “Requiring Level for Safety Management”, the first is to improve the containment performance of the facilities that contain risk sources. Measures to improve the containment performance include transferring the risk sources to more sound facilities on higher ground that are less susceptible to tsunamis, as well as repairing damaged parts of existing storage facilities. The second is to improve long-term stability by reducing uncertainty in handling risk sources and by enabling long-term and stable management based on the characteristics of risk sources. To this end, it is important to obtain sufficient information by investigating the distribution of risk sources, identifying their characterization through analysis and measurement, and improving monitoring conditions, and to reflect this information appropriately in methods of collection and storage according to the characteristics of risk sources. Such efforts to reduce uncertainty in the handling of risk sources also help to keep the temporary increase in risk levels associated with risk reduction measures, such as source recovery operation, to a low level.

Of the various risk reduction measures, reduction of in the likelihood of occurrence of an event expressed by this “Requiring Level for Safety Management” is generally considered to be easily realized from an engineering perspective. Consequently, the interim target of the risk reduction strategy in 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), is to bring “Requiring Level for Safety Management” into the “Sufficiently stable management” region (the pale blue area) as shown in Fig. 4 with the above measures. Even within “Sufficiently stable management” region, to further lower “Requiring Level for Safety Management” leads to achieve a state that secures passive safety, i.e., a state in which dynamic measures such as water injection or nitrogen injection are not required to maintain a stable state.

Fig. 6 shows the process to bring major risk sources into the “Sufficiently stable management” region as the interim target, and representing the decommissioning work progress along this process.

Fig. 6(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. 6(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. The number of spent fuel assemblies as an indicator to make the work progress easier to see in Fig. 6(b), and for Cs-137, the estimated radioactivity (Bq) common to various risk sources as an indicator in Fig. 6(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. 6(b) has made no progress since Technical Strategic Plan 2023. Fig. 6(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 2023. Fig. 6(d) shows the transition of Requiring Level for Safety Management corresponding to risk sources and their treatment process indicated in the flow graphically by risk source category. The Requiring Level for Safety Management shown is divided into two components, one for containment performance and the other for long-term stability, which correspond to the methods for reducing the Requiring Level for Safety Management described above[17]. This will help determine whether containment performance or long-term stability measures should be prioritized to bring the risk source into the “Sufficiently stable management” region. In addition, in the processing process that is the scope of a future or ongoing study in the flow, the blue and orange arrows in Fig. 6 (d) indicate what needs to be improved to bring the Requiring Level for Safety Management into the Sufficiently Stable Management region (in the pale blue area in the graphs). The containment performance related to the Requiring Level for Safety Management of retrieved fuel debris in Fig. 6 (d -1) and secondary waste generated by water treatment after stabilization treatment in Fig. 6 (d -4) is equivalent to that of facilities, such as dry casks and solid waste storage facilities. The long-term stability is assumed to be in a state where appropriate

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[17] Of the Requiring Level for Safety Management indicators shown in Attachment 5, the FD-related components are mapped to containment performance, and the WUD-related components to long-term stability. In Fig. 6(d), the Likelihood of Occurring shown is divided into two components, one for containment performance and the other for long-term stability, by using the logarithm of the Likelihood of Occurring of each risk source (FD × WUD)[4]. The heights of the blue and orange bars represent the logarithm of how many times the product is multiplied by the component related to containment performance and other component related to long-term stability when multiplying the Hazard Potential by Likelihood of Occurring. The representative risk source is indicated if the risk source consists of multiple risk sources.

storage and management can be achieved, considering the reactivity of the risk sources. This is an assumption at present, and it may change depending on the progress of future studies.

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

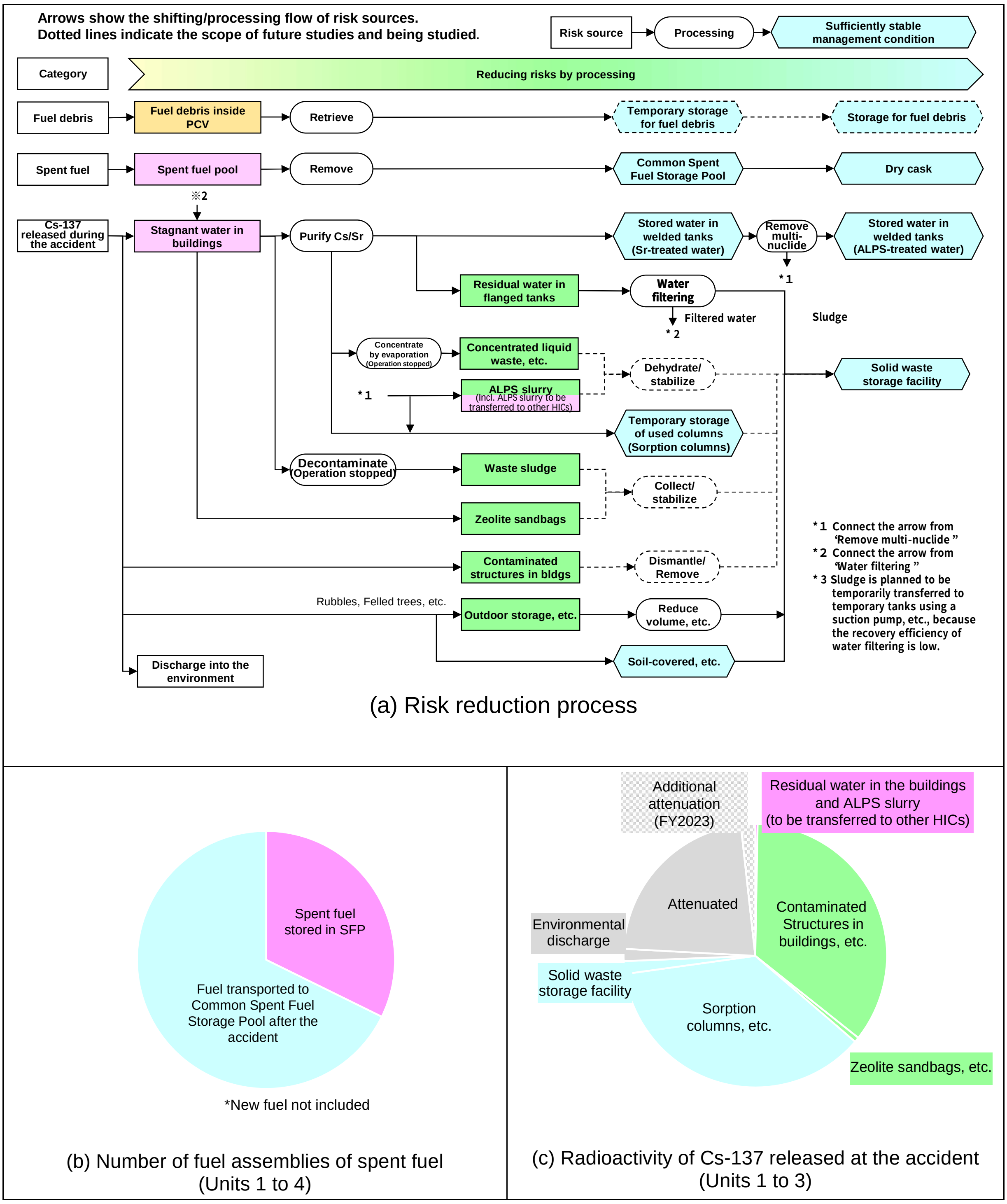
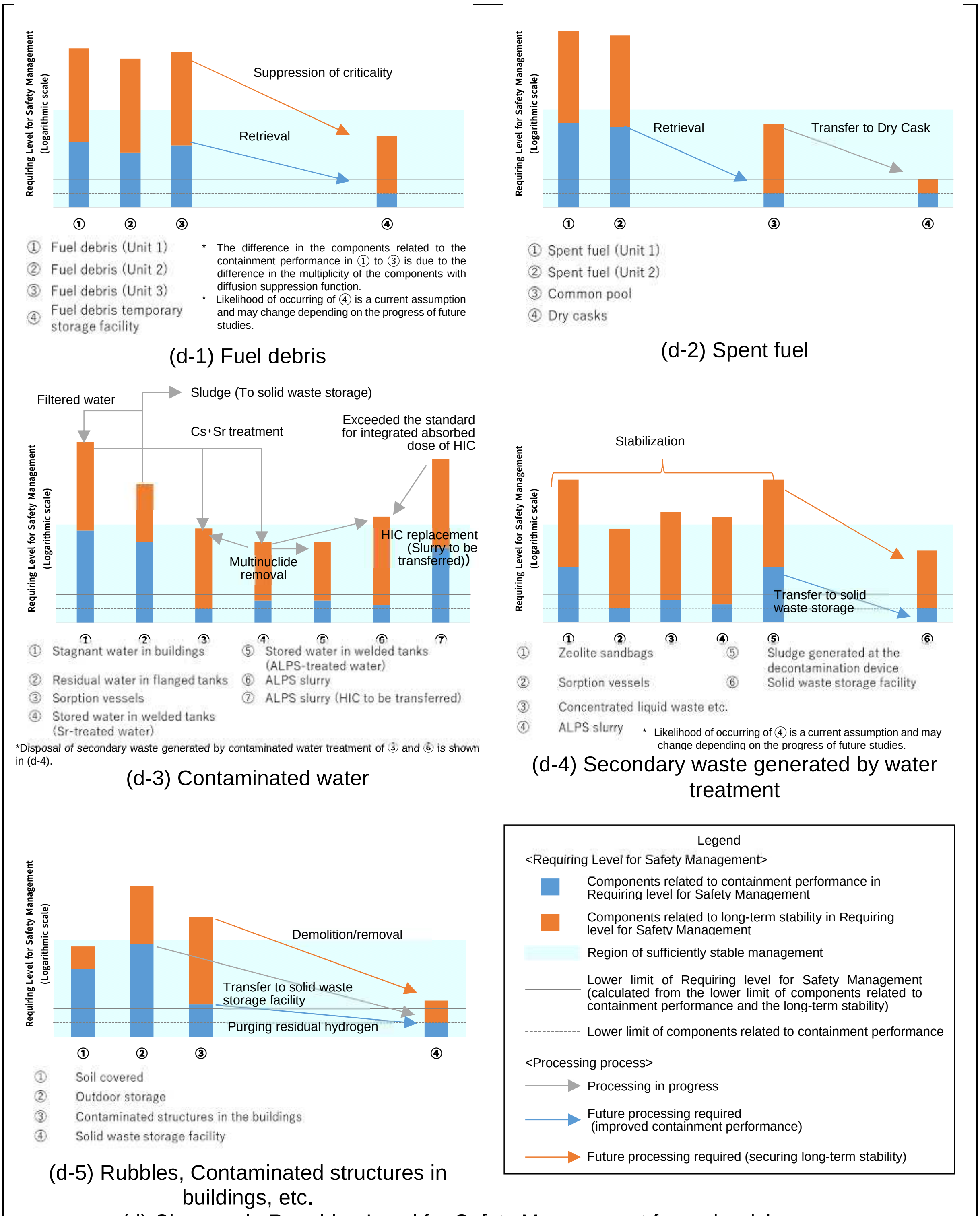


Fig. 6 Risk reduction process for major risk sources and the progress (as of March 2024) (1/2)



(d) Changes in Requiring Level for Safety Management for major risk sources

Fig. 6 Risk reduction process for major risk sources and the progress (as of March 2024) (2/2)

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

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

2.3 Approach to ensuring safety during decommissioning

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

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
- On the other hand, more than 10 years have passed since the accident and the intrinsic energy (decay heat) is small and the state change is slow, so there is a large time allowance that can be allocated for convergence of abnormal conditions such as failures.

Therefore, in proceeding with decommissioning work, TEPCO, as the decommissioning project executor, needs to consider the following points with particular attention, based on the five guiding principles.

First, with regard to “safe”, when giving consideration to decommissioning work, the basic premise is to confirm that safety can be reliably assured by assuming a wide range of possibilities (cases), fully taking into account the above-mentioned special characteristics of the decommissioning. Based on this premise, it is necessary to comprehensively improve safety from the following perspectives: (1) how much safety will ultimately be improved by decommissioning, (2) how long it will take to achieve this, and (3) to what extent safety will change along with the work.

Second, with regard to “field-oriented”,

- The on-site environment is unique, with high radiation levels, etc., and attention must be paid to the on-site feasibility when constructing/taking safety measures, and
- Response by design alone is limited due to large uncertainties.

It is essential to reflect the information obtained from the actual site in engineering appropriately. In order to reliably implement unprecedented engineering such as fuel debris retrieval, it is important to value the viewpoints and senses of people and organizations (operators) who are directly involved in the actual site work (operation, maintenance, radiation control, instrumentation, analysis, etc.) and familiar with the site, and to respect the viewpoints and judgments that are directly addressed at the site (hereinafter referred to as the “operator’s perspective”). Moreover, in promoting long-term decommissioning, it is necessary to maintain and strengthen the operator's viewpoint and sensibility, TEPCO itself should take over the operator's perspective. To this end, TEPCO needs to make efforts that are constantly aware of the site throughout the decommissioning work, such as inviting outside experts, people with experience in difficult tasks, and engineers with an operator's perspective such as those who have left the frontline, and asking for guidance and education.

In the actual study of the decommissioning work, TEPCO, as the decommissioning project executor, should define the “requirements” to satisfy regulatory demands for the work, 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.

In this decommissioning work with significant uncertainties, it is frequently difficult to uniquely define requirements and the equipment/operational specifications that will satisfy those requirements. Even in such cases, the decommissioning work should be carried out flexibly and promptly by verifying and improving the selected, specifical safety measures with the “preliminary implementation and utilization of the obtained information in the latter stages” and “iteration-based engineering[18]” as described later.

This section first calls for promulgation of the “Safety First” by operators. Next, in terms of the characteristics of Fukushima Daiichi NPS, the section describes the importance of the safety assurance measures based on safety assessment which includes the operator’s perspective, and the operator’s perspective that should be incorporated at multiple levels in the safety assurance process. Lastly, the section refers to the importance of optimization as a project. Moreover, the relationship between these points and the aforementioned Five guiding principles of risk reduction will be discussed.

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

2.3.1.1 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) leading up to the use of methods and devices on the site, keep safety first in mind as they engage in their work (hereinafter referred to as “safety first”). The specific application of the general “safety first” principle in the projects means, “The highest priority is placed on improving the safety associated with the use of any retrieval method/equipment, and in addition to this, taking into account factors such as technical reliability, reasonableness, speed, and actual site applicability to optimize the methods and equipment and determine 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.

The above concepts can be organized on the basis of the Five Guiding Principles, and it can be said that “safety” is the most important principle in proceeding with a project, and the other four principles should be considered next to “Safe” as a safety-first principle. However, as described in 2.3.1.3, in the decommissioning operation of the Fukushima Daiichi NPS, “Field-oriented” is a principle that should function in a complementary manner to “Safe”.

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

In decommissioning work that is technically difficult, has significant uncertainties, and handles a large amount of radioactive materials, such as fuel debris retrieval, it must be conducted with a “safety-first” mindset, in which it is most important to ensure the safety by taking appropriate measures. On that mindset, by using a well-reviewed safety assessment as the basis for making decisions on safety measures, resources can be allocated neither sparingly nor excessively, and necessary, sufficient, and feasible safety measures can be realized (Proven and Efficient).

In addition, the importance of making progress in the decommissioning work without delay can be mentioned as the safety perspective unique to the decommissioning of Fukushima Daiichi NPS. Considering the high radiological impact that has already been observed, and danger of progressive 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 (Timely).

The above concepts can be organized on the basis of the Five Guiding Principles, which are that “Proven” and “Efficient” safety measures can be realized by making judgments through sufficient safety assessment based on the premise of safety first, and that this will lead to “Timely” progress in decommissioning work.

2.3.1.3 Ensuring safety by incorporating “the operator’s perspective”

It is essential to reflect the information obtained from the actual site in the engineering work appropriately, because it is necessary to pay attention to the on-site feasibility when constructing/implementing safety measures, and there is a limit to be addressed by design alone due to significant uncertainties. In other words, to make safety measures truly effective, it is necessary to respect the viewpoints and judgments of people and organizations that are familiar with the actual site and are responsible for practical operations, maintenance, radiation control, instrumentation, analysis, or other tasks at the site (operator's perspective). The operator's perspective is also important from the following points, which differ from those of normal reactors.

- Complementation of design by operations, including operating controls: :

  Since there is a limit to addressing all situations by design alone due to significant uncertainties, 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.) has a high measurement uncertainty due to difficulties in the measurement on site. Even in such an environment, it is necessary to proceed with fuel debris retrieval on 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, information obtained from monitoring and analysis through on-site operations will be utilized in designing in the next phase to make it more appropriate.

- Consideration of time available for response to 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.

2.3.1.4 Selection of retrieval method/equipment based on safety

For safety, there is a minimum level of safety standards that must be met before the relevant retrieval method/equipment can be used. After satisfying this minimum level, how high the level of safety shall be raised should be determined considering practically available resources (cost, duration, etc.), while placing the utmost priority on safety. In the process of determination, it is important to decide retrieval methods /equipment to be adopted eventually through the cycle of “defining the safety standards (safety perspective)”, “indicating the feasibility on-site (operator’s perspective)”, and “examining and discussing as a project (project management)” as shown in Fig. 7. As shown in this figure, the safety perspective and the operator’s perspective are not independent from each other. The determination of retrieval method/equipment selection made by the project based on the safety perspective will be linked to the eventual decision of the retrieval method/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.

The above concepts can be organized on the basis of the Five Guiding Principles, which are the same as 2.3.1.3 in that “Safe” and “Field-oriented” should be complementary principles. This is to consider the perspectives of project promotion, such as “Proven”, “Efficient”, and “Timely”, provided that initiatives to improve safety as much as possible will be implemented.

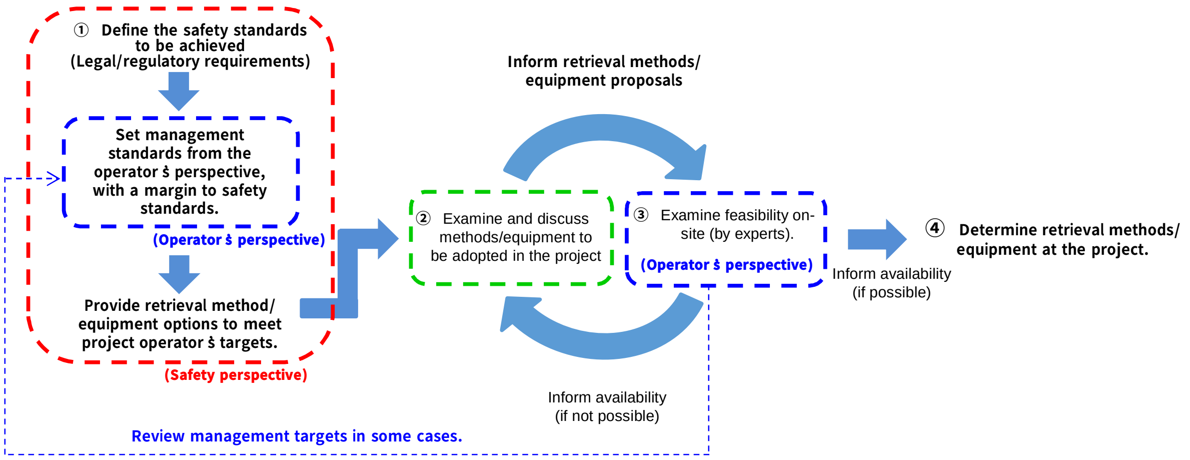

Fig. 7 Selection of retrieval method/equipment centered on safety (conceptual diagram)

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 a large-scale project such as fuel debris retrieval is implemented based only on existing knowledge, assumptions of a large enough 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[19], 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[20]. 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 stages 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[21].

As a related activity, though not a sequential type approach itself, 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. Based on this knowledge, TEPCO reduced the water injection amount for Unit 2 while maintaining continuous water injection on March 10, 2022. Also, a reactor water injection shutdown test spanning 3 months was planned for Unit 3 based on past test results, but water injection was resumed only after 5 days (water shutdown: June 14 to 19, 2022) as the PCV water level dropped rapidly and went below the water level gauge installed inside the S/C after the accident. As for Unit 1, the amount of water injection has been reduced as one of the means to lower the water level in the S/C since March 26, 2024.

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

[20] 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.

[21] This is stated in the Decommissioning Implementation Plan (February 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/2022/1693977_8712.html

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. The examples are shown below.

- Risk identification associated with hydrogen at the time of fuel debris retrieval: Testing to reduce nitrogen supply and exhaust flow rate for an experimental purpose may help identify the risk of leading to hydrogen accumulation and combustion, which contributes to determining functions to ensure safety, such as the necessary amount of nitrogen supply, and air volume and number of exhaust systems. Associated with that, in response to the confirmation of exposure of inner wall reinforcement and inner-skirt in the pedestal of Unit 1 PCV, a test to vary the nitrogen supply rate and exhaust flow rate was conducted from November 1 to 28, 2023. This test found that slightly negative pressure can be maintained by adjusting the settings for the nitrogen supply rate and exhaust flow rate even within the flow rates the existing exhausts can handle.
- Basis for contributing to the design of water injection facilities during fuel debris retrieval: Information, such as number of water injection pumps required during fuel debris retrieval, appropriate amount of water to be injected, changes in the cooling status of fuel debris due to differences in water injection points, etc., will be obtained.

By accumulating successful/unsuccessful experience gained in the process of these sequential approach as a track record, allowing gradual reduction in major uncertainties associated with decommissioning work. It is important to combine this with uncertainty reduction measures, for example, by sampling, and to reduce uncertainty. These efforts to reduce uncertainties will lead to steady progress in decommissioning and help 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 keep it as low as reasonably practicable by thorough preparations.

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, cautious and comprehensive decision making is required for early implementation of decommissioning in consideration of many constraints such as time and cost needed for relevant preparations and work, while giving priority to limiting the risks involved in the decommissioning work (Attachment 8).

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

In FY 2023, two major problems occurred, namely, “physical contamination during the cleaning of additionally installed ALPS piping” (October 25, 2023) and “leakage of water containing radioactive materials from the High-incinerator building” (February 7, 2024). These two problems occurred during work for maintaining the integrity of equipment necessary for progressing the decommissioning. Namely, this can be understood that it was necessary to perform work that would temporarily increase worker’s radiation exposure risk, for the purpose of reducing medium- to long-term risk. However, these cases involved unintended leakage of radioactive materials, primarily arising from human errors. As a result, the workers were exposed to radiation in the former incident, and workers nearby were put at risk of being exposed to radiation in the latter incident.

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

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

For the latter problem, the pipes that have an opening outside the building, from which radioactive materials leaked, are planned to be changed to have an opening in a controlled area inside the building. Meanwhile, like the former incident, in the case of work that changes the state of equipment only during inspection or may generate force to spread air or liquid containing radioactive materials, the containment function of the equipment shall be improved, including an option to enhance human responses, according to the amount of radioactive materials in the equipment, frequency of work, work environment (e.g., access is limited due to high radiation dose), and expected changes in the driving force for dispersing radioactive materials during work. This viewpoint also applies to equipment to be installed in the future.

2.3.3.2 Importance of worker safety

Improving safety of workers including reduction of radiation exposure risk is by itself “Safe” of the Five Guiding Principles and important. As stated in 2.3.1.1 (Establishment of safety first), in the decommissioning of the Fukushima Daiichi NPS, “Safe” is achieved complementarily with “Field-oriented". In terms of this point, retrospectively speaking, "Safe" was insufficient in the two incidents in 2.3.3.1. Now, what about "Field-oriented" to complement "Safe"? We know that, in these incidents, the opening of pipes was outside the building and a large reaction force was applied to the end of a temporary installation hose. It may be too much to ask for them to predict possible adverse effects of these factors or the event itself to occur, but considering that the main cause of the two incidents was human error by workers, we have to say that "Field-oriented" was also insufficient.

If an incident to lose "Safe" occurs during work, the need arises to address the issue. Automatically, the work or related work will have to be delayed, and "Timely" will be lost. In the case of damage to an electric cable during excavation work that occurred on April 24, 2024, workers sustained burns due to arc discharge ("Safe"). In this case, damage to an electric cable caused the ALPS-treated water dilution and discharge equipment to automatically stop, resulting in several hours of stop in the discharge of ALPS-treated water ("Timely").

If events like this continue to occur, an excessive amount of resources may have to be allocated to address such issues. That may go against the principle "Efficient".

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

2.3.4 Common tasks that became apparent from a series of problems

Multiple incidents occurred in series since the "physical contamination during the cleansing of additionally installed ALPS pipes" incident.

[Case 1] Physical contamination during the cleansing of additionally installed ALPS pipes (October 2023)

[Case 2] Leak of water containing radioactive materials from high-temperature incinerator buildings (February 2024)

[Case 3] Fire alarm going off in additional solid waste incineration facility due to generation of steam in waste storage pit, etc. (February 2024)

[Case 4] Loss of on-site electric power system A and personal injury (April 2024)

Since Cases 1 and 2 are similar incidents involving the handling of highly concentrated radioactive fluids, TEPCO judged the necessity of analyzing the common factor of the incidents, considering that they have occurred consecutively over a period of several months. In addition, Case 3 occurred around the same time, and Case 4 occurred in FY2024, then Cases 3 and 4 were also added to the scope of the common factor analysis in light of the fact that serious work-related problems continue to occur.

TEPCO conducted a review process of i. Understanding the facts → ii. Direct causes → iii. Organizing the background factors → iv. Analysis of common factors → v. Proposals for improvement measures, and identified the following common factors based on the background factors extracted (see Table 2).

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

Table 2 Common factor analysis result [22]

Case	Background factors	Common factor
Physical contamination during the cleansing of additionally installed ALPS pipes	Insufficient consideration of risk in the design phase/operational phase (defects and changes in condition)	①
	Insufficient prior consideration of risks and facility measures for work involving chemicals and highly radioactive materials	②
	Low awareness of work safety in handling chemicals and highly radioactive materials	③
	Insufficient understanding of the actual situation onsite by TEPCO and prime contractors	④
Leakage of water containing radioactive materials from HTI building	Insufficient consideration of the risk of release out of the system during the design phase/post-operational design change phase	①
	Lack of review and evaluation of procedures at the PTW (Permit to Work) preparation and review stage	②
	Insufficient sharing of work risks by TEPCO and prime contractors	③
	Insufficient understanding and sharing of the actual situation on site at the work planning and implementation stage	③
	Inadequate management of system configuration	③
	Failure to comply with work procedures	③
Generation of steam in waste storage pit, of additional solid waste incineration facility	Lack of consideration of fire risk at the design stage	①
	Inadequate risk-based operational planning	①
	Inadequate management of receiving and storage volumes based on operational performance	①
	Inadequate risk management due to lack of shared handover	②
	Lack of sharing and reporting of abnormal signs	③
	Lack of consideration of fire risk at the design stage	①

[22] Material 2-1: "Future efforts based on work inspection and common factor analysis", The 113th Committee on Oversight and Evaluation of Specified Nuclear Facilities, July 16, 2024v

Loss of on-site electric power system A	Inadequate risk-based operational planning	②
	Inadequate management of receiving and storage volumes based on operational performance	③
	Inadequate risk management due to lack of shared handover	③

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

Common Task ①: Further enhancement of risk assessment[23]

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

(1) Initiatives to address Common Task ①

Considering the need for raising the safety of work carried out at the Fukushima Daiichi NPS through the combined efforts of all individuals at the NPS, TEPCO has been identifying on-site risk factors related to each operation at the NPS after checking the on-site situation, conducting "work inspection" to verify the appropriateness of protection measures[24,] and thereby working on the improvement of the protection measures aiming at further improvement of work safety based on the latest on-site situation.

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

TEPCO had been conducting risk assessments jointly with prime contractors, such as advanced safety assessment of work, but they learned from the series of problems that such assessments were not good enough. TEPCO needs to further reinforce its initiatives to heighten the risk sensitivity of all personnel working at the Fukushima Daiichi NPS by involving its employees, prime contractors, and workers at the front line on site. For example, TEPCO may consider establishing risk assessment guidelines suitable for the Fukushima Daiichi NPS and distributing them to contracting companies, and making continued efforts to raise the awareness and understanding of risk assessment by holding lecture sessions targeting construction staff of TEPCO as well as construction workers and work team leaders of contracting companies.

[23] Risk assessment refers to a series of techniques to identify hazards and harm of work, estimate "risk" by combining the severity of workplace injury or health impairment (degree of damage) caused by them and the probability of the occurrence of the injury, determine the priority of measures based on the level of the risk, consider action to eliminate or reduce the risk, and record the outcome. (Source: Ministry of Health, Labour and Welfare website)

[24] Work inspection was started on May 7 (with some being conducted in advance from May 1) and was completed on June 7. The risk of the work was reevaluated for 995 works, and although no serious cases requiring review were confirmed, improvement of the work procedure and clarification of the operation instruction of radiation protection equipment were carried out for 675 works from the viewpoint of further improvement of safety.

(2) Initiatives to address Common Task ②

All of the incidents above occurred under the multilayered subcontracting system for construction work. Multilayered subcontracting is practiced not only for the Fukushima Daiichi NPS but also for other nuclear and thermal power stations of TEPCO, for power stations of other power companies, and in other industries. In this contracting system, the owner (orderer) manages the worksite indirectly based on a contract agreement concluded with the prime contractor. However, NPSs handle radioactive materials and any problem at an NPS will have an enormous social impact if it occurs, and the license holders of NPSs, power companies, are required to manage the worksites more strictly than others. In addition, the Fukushima Daiichi NPS, the very site of the accident, needs to have much stricter worksite management than any other nuclear power station.

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

The decommissioning of the Fukushima Daiichi NPS needs to be promoted with the broad understanding of not only the government, NDF, TEPCO, and others, but also of a wide range of people, including local residents. To this end, it is essential for them to fully understand the overall risk reduction efforts described in this chapter and to gain their understanding of the decommissioning project. In particular, it is important to establish a system for continuous risk monitoring that is easy to understand for a wide range of people and to communicate to the public how the decommissioning work will be conducted based on the risk reduction strategy, how the safety of the decommissioning work will be ensured, and how the overall risk reduction of the site is continuously progressing through the decommissioning work, and to disseminate these information to society.

In addition to sharing the status of risks regard to the decommissioning of the Fukushima Daiichi NPS through the Technical Strategic Plan on a constant basis, NDF is considering providing the risk reduction process along with the progress of the decommissioning work described in 2.2.2.1. 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 the decommissioning of the Fukushima Daiichi NPS

3.1 Fuel debris retrieval

3.1.1 Target

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

② For the trial retrieval (internal investigation and fuel debris sampling) in Unit 2, the first fuel debris retrieval was launched in September 2024. The future course of action includes analysis of retrieved debris, internal investigations, a series of operations such as gradual expansion of fuel debris retrieval to acquire knowledge and experience necessary for further expansion of the retrieval scale (for the fuel debris targeted for retrieval, see Attachment 8).

③ Moreover, the method of further expansion of the retrieval scale, including those for containing, transferring, and storing of fuel debris, is determined through the assessment of fuel debris retrieval in Unit 2, internal investigations, research and development, and the on-site environmental improvement, etc.

3.1.2 Progress

The progress on fuel debris retrieval in each unit is also shown below.

Fig. 8 shows the estimated fuel debris distribution, access route and surrounding structures of Units 1 to 3.

a. Unit 1

In addition to information on the basement floors obtained by surveillance using submersible ROVs performed up to FY 2023, PCV internal investigation (dry area surveillance) was carried out in February and March 2024 mainly for the first floor, which gave visual information on the state of existing structures, deposits, fallen objects, and other matters inside and outside the pedestal.

In this investigation, a small wireless drone and a serpentine robot (equipped with a wireless relay and placed at PCV penetration X-2) were introduced to the first floor inside the PCV though PCV penetration X-2 to visually inspect the state at the south and north sides outside the pedestal (Fig. 9). Further, a serpentine robot was placed near the opening used to replace the CRD (on the CRD replacement rails), and a small wireless drone was introduced into the pedestal through the opening used to replace the CRD to visually inspect inside the pedestal.

Below is the main information obtained by the PCV internal investigation (dry area surveillance) using small wireless drones.

① No major damage was present on the outer wall of the pedestal. It was confirmed that existing structures were mostly intact and no noticeable obstructions were present around the CRD replacement rails, although there were fallen objects outside the opening used to replace the CRD.

② A fallen CRD housing (including multiple CRD-related devices) was blocking a part of the opening used to replace the CRD on the pedestal. Lumpy objects (with some parts having an icicle-like form) were found adhered above the opening, indicating that the housing migrated from above. (Fig. 10）

③ No major damage was found on the inner wall of the pedestal, and existing installations such as a cable relay box and the existing TIP (Traversing In-core Probing System) opening were observed.

This investigation demonstrated that, by installing a wireless relay near the opening used to replace the CRD, small wireless drones can be used not only outside the pedestal but also inside the pedestal and provide a substantial amount of visual information albeit limited by the relatively short duration of flight. Meanwhile, it was found to be misty inside the pedestal, which makes the visibility of the camera poor and causes clouding of the lens. This needs to be addressed in future investigations.

As stated above, small wireless drones were found to be useful in PCV internal investigation, and the outcome of this investigation will be reflected on future PCV internal investigation plans for Units 1 to 3, including measures to address issues newly identified.

Meanwhile, regarding the drainage of water contained in high-radiation-dose equipment (Reactor Building Cooling Water System) to reduce radiation doses in the reactor building, sampling and analysis of contained water was completed in FY 2023. According to this result, the plan to drain water (including dilution and treatment) is being carried forward. Moreover, due to the high-water level in the PCV, lowering of the PCV water level started in March 2024, with a view of improving the seismic resistance of the S/C. Ahead of that, a new water level gauge was installed to monitor lower water levels.

b. Unit 2

The arm-type access equipment (hereinafter referred to as “robot arm”) to be used in trial retrieval has been undergoing performance confirmation tests, verification tests in a simulated environment of an actual machine (hereinafter referred to as “mock-up tests”), and training at the JAEA Naraha Center for Remote Control Technology Development since February 2022 (Fig 11). So far, function confirmation tests on the robot arm alone have been completed, and confirmation tests when the robot arm is incorporated inside an enclosure (housing for the machinery) are currently in progress. Since the actual work will require repeated access to narrow sections using robot arms, the control program will be optimized, and confirmation tests will be continued from the viewpoint of improving the positional accuracy and hardware/software coordination in on-site application to avoid contact during the work. In addition, as on-site preparatory work, the isolation chamber installation work for opening the hatch of the existing PCV penetrating part X-6 (hereinafter referred to as “penetration X-6”) was completed in April

2023. In the hatch opening work performed after that, the hatch bolt was found to be stuck, and addressing the issue took time. However, removal of the hatch bolt was completed in October, and the hatch was opened. As the area near the penetration X-6 inlet was covered with deposits, after the deposits were knocked down using a dozer tool (push-in jig), removal of the deposits by low-pressure water spray, removal of deposits inside the penetration X-6 by high-pressure water spray, removal of the CRD rail guide by AWJ, and cable push-in operations were carried out (Fig. 12). and completed in May 2024. (Fig. 13) The work to install penetration X-6 connection structures and pipes was completed in June.

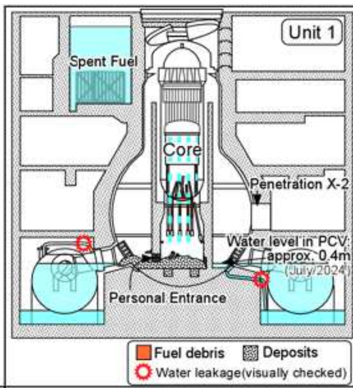
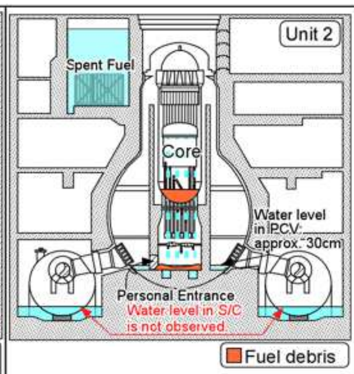
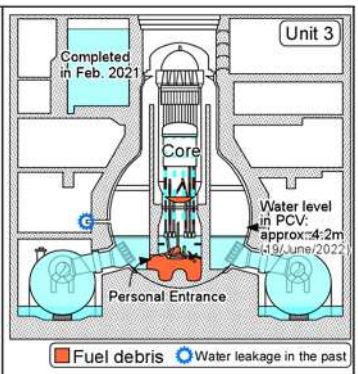
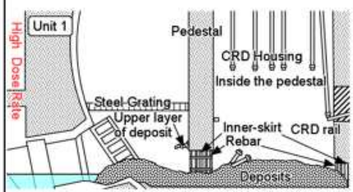
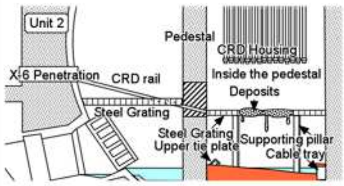
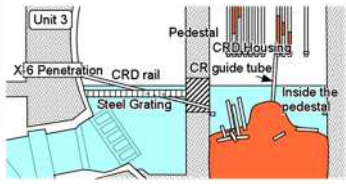
In addition to the uncertainty of on-site operations, since the robot-arm requires time to prepare for access to the pedestal and a certain amount of time to continue testing to confirm reliability, TEPCO took a policy to accomplish early and assured sampling of fuel debris for its characterization first.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

A plan for the gradual expansion of fuel debris retrieval is also underway, and the retrieval device with a robot-arm will be improved by increasing the weight capacity and enhancing accessibility based on the improvements identified during the verification of the devices for trial retrieval. 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 and stored in the first storage facility on site (receiving/delivery cells and storage containers, etc.). In addition, some of the fuel debris will be collected in the receiving/delivery cells for analysis and transported to the Radioactive Material Analysis and Research Facility Laboratory-2 or the facilities for analysis located in Ibaraki Prefecture. The Basic design of the first storage facility has been completed and detailed design is in progress (Fig. 15).

c. Unit 3

TEPCO is proceeding with the study on the concepts for further expansion of the retrieval scale in Unit 3, ahead of other units. Among them, the partial submersion method, the partial submersion method option (filling and solidification method), and the submersion method are under discussion. Since February 2023, through discussions at the Decommissioning Strategy Committee of NDF, the Sub-Committee for the Evaluation of Fuel Debris Retrieval Methods has been established under the Committee, where the technical feasibility and other aspects of each fuel debris retrieval method are comprehensively studied and evaluated while placing the utmost priority on safety, and recommendations are made on which methods for design study should currently be advanced. TEPCO is promoting specific design studies based on the recommendations. (See Section 3.1.3.4 for details.)

Moreover, due to the high-water level in the PCV, the plan is to lower the PCV water level, taking into account conducting the PCV internal investigation and the improved seismic resistance of the S/C. In the reactor water injection shutdown tests in June 2022, water injection was resumed when it was determined that the PCV water level fell below the lower end of the PCV thermometer/water level gauge at that time. After that, to further reduce the PCV water level, a water gauge that enables measuring at a lower position was installed. Installation of the PCV water intake facility has already been completed. Currently, purging of hydrogen found stored in the S/C is in progress. The PCV water level is planned to be reduced after that.

			
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 and on inner surface of the pedestal.		
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. · The dropped CRD housings are fallen on the CRD rail connecting into the pedestal from the penetration X-6.	· 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. · Neutron and gamma-rays of Eu-154 were detected on the deposits outside the pedestal.	· 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.

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

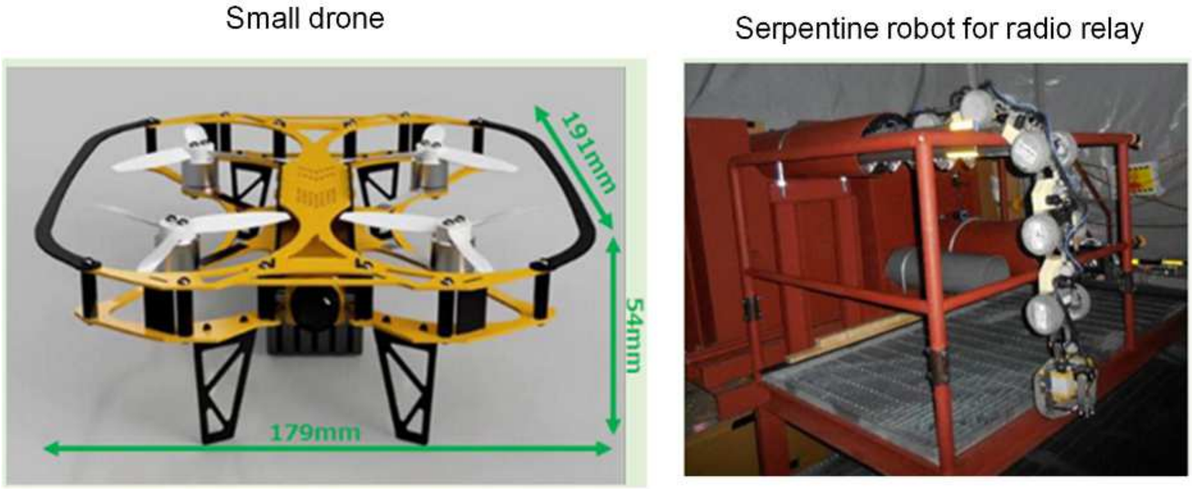


Fig. 9 Investigation equipment for dry area surveillance inside Unit 1 PCV[25]

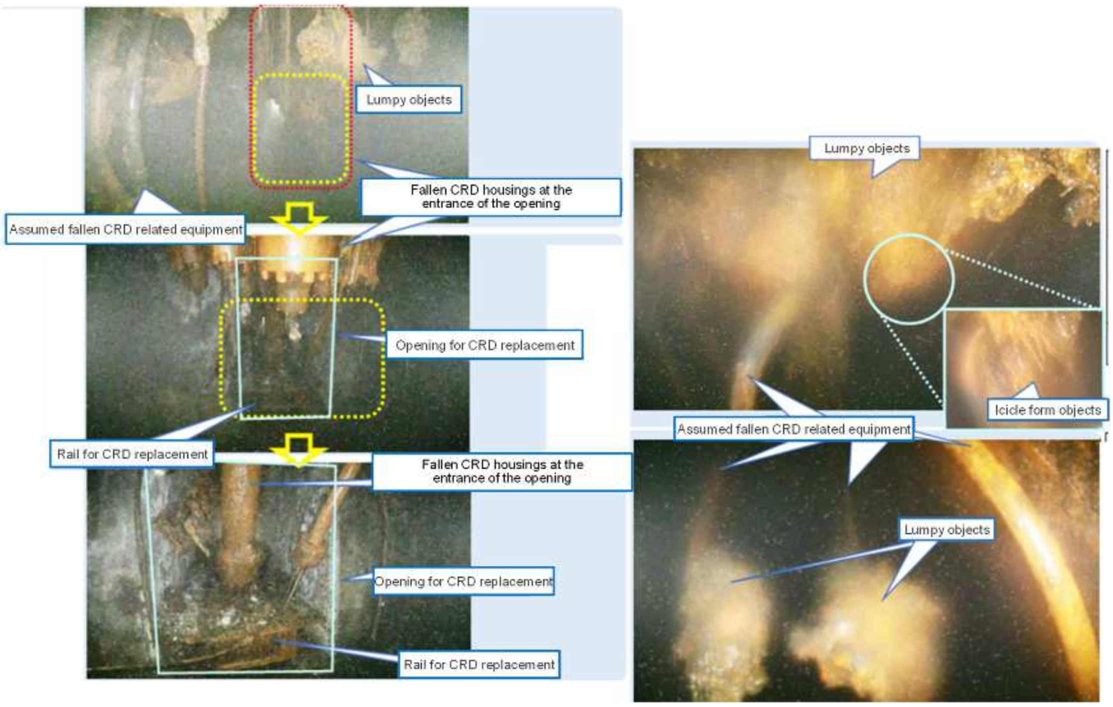


Fig. 10 Investigation results
(CRD housing around the opening for CRD replacement in the pedestal) [26]

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[25] TEPCO, "Progress of Unit 1 PCV internal investigation (dry area surveillance)", The 123rd Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, February 29, 2024

[26] TEPCO, "Progress of Unit 1 PCV internal investigation (dry area surveillance)", The 124th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, March 28, 2024

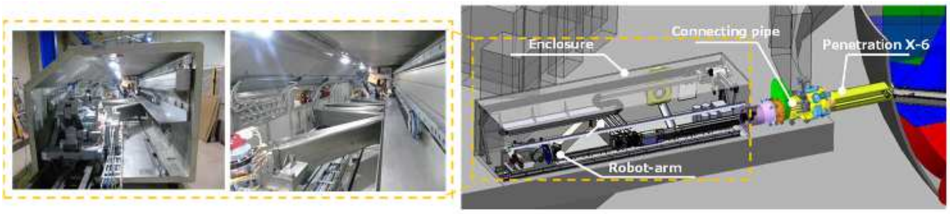


Photo : Robot arm and Enclosure

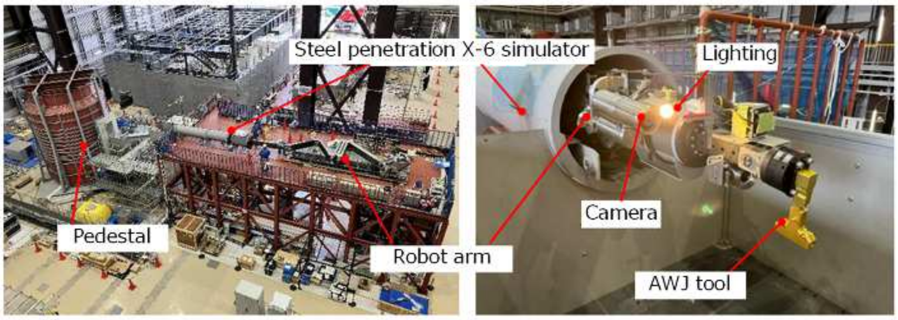
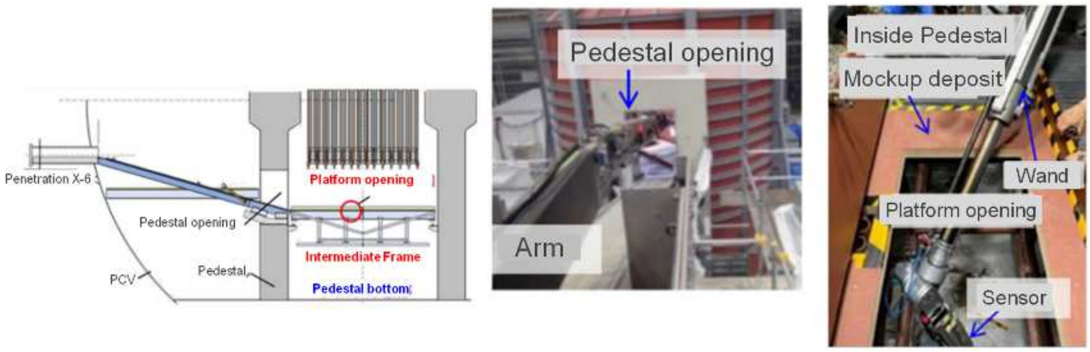
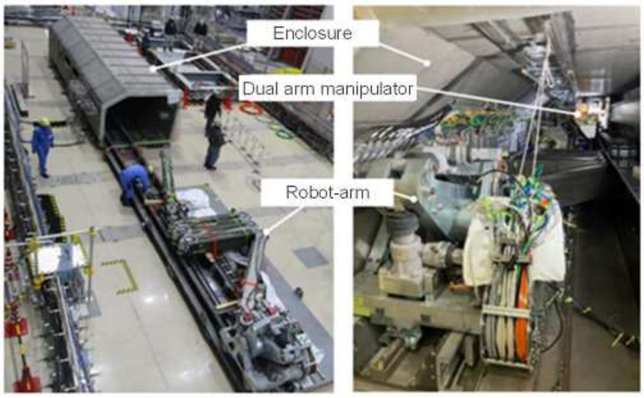


Photo: Status of performance verification test of the robot arm passing through the penetration X-6
(Testing facility in Naraha Center for Remote Technology Development (JAEA))



Installation of the robot arm

in the enclosure



(Prepared by NDF based on TEPCO and IRID materials)

Fig. 11 Image of fuel debris retrieval system[27]
(Trial retrieval and gradual expansion of fuel debris retrieval)

[27] IRID/ TEPCO, “Preparation of PCV Internal Investigation and trial retrieval operation for Unit 2”, the 115th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, June 29, 2023

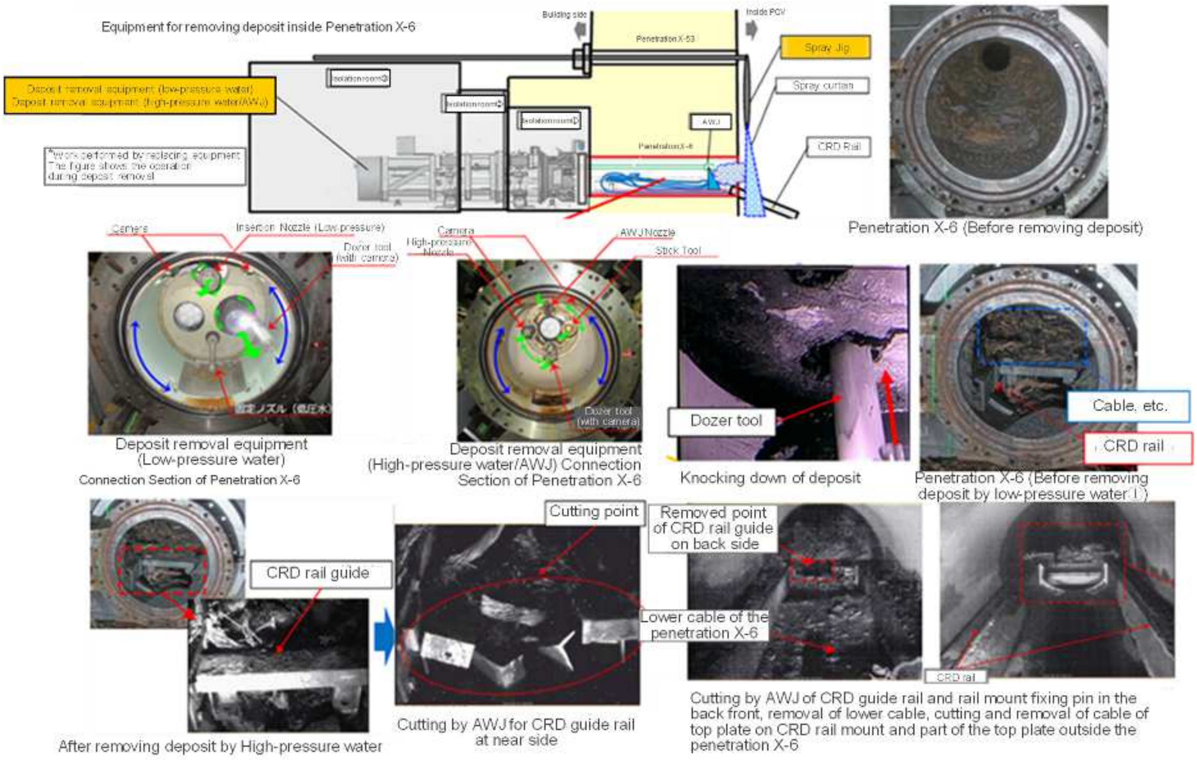


Fig. 12 Deposit removal inside penetration X-6[28]

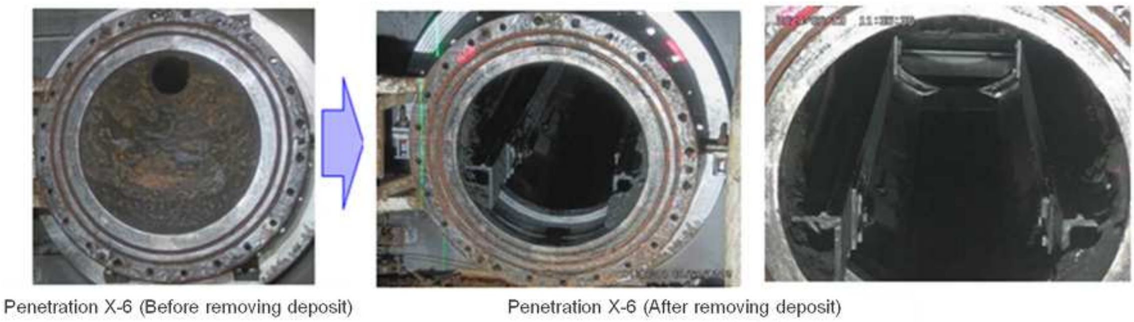


Fig. 13 Deposit removal inside penetration X-6[29]

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[28] IRID/ TEPCO, "Preparation of PCV Internal Investigation and trial retrieval operation for Unit 2", the 122nd, 124th, and 125th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, January 25, March 28 and April 25, 2024,

[29] IRID/ TEPCO, "Preparation of PCV Internal Investigation and trial retrieval operation for Unit 2", the 116th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, May 30, 2024,

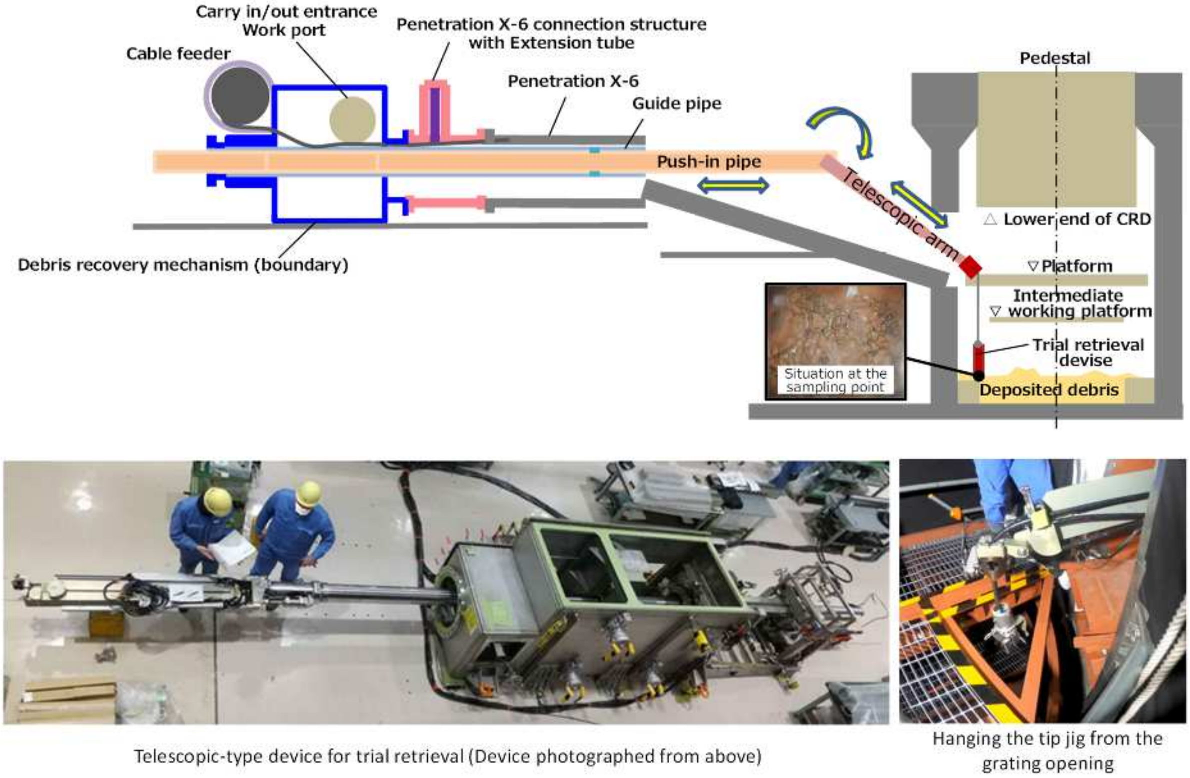
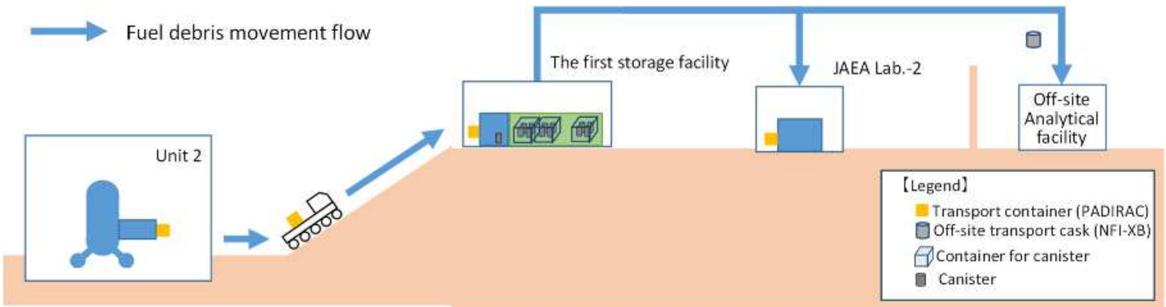


Fig. 14 Image of trial retrieval using telescopic device and preparation of the device[30]



(TEPCO material edited by NDF)

Fig. 15 Conceptual drawing from retrieval to storage of fuel debris
(Gradual expansion of fuel debris retrieval)

[30] TEPCO, "Telescopic-type device for trial retrieval for fuel debris retrieval in Unit 2", the 111th Committee on Oversight and Evaluation of Specified Nuclear Facilities, February 19, 2024,
IRID/TEPCO, "Preparation of PCV internal investigation/ trial retrieval operation for Unit 2", the 124th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, March 28, 2024

3.1.3 Key issues and technical strategies

With regard to the design and planning of fuel debris retrieval, the challenge is to adequately incorporate the findings to be gained (through internal investigations, R&D results, etc.) and information and experience acquired from trial retrieval in Unit 2 into the subsequent gradual expansion and further expansion of the retrieval scale.

TEPCO established Toso Mirai Technology Company (hereinafter referred to as “Decom. Tech”) in October 2022 to engage in the basic design and R&D of systems and installations for the further expansion of the retrieval scale, and it has moved forward with activities for debris retrieval under an appropriate division of roles among relevant organizations including this Decom. Tech. The technologies cultivated through these initiatives should be effectively leveraged to improve engineering based on TEPCO’s own safety and operator’s perspectives, as will be mentioned later.

This section describes the following.

- 3.1.3.1：Fuel debris retrieval strategies in each unit
- 3.1.3.2：Trial retrieval (Internal investigation and fuel debris sampling)
- 3.1.3.3: Gradual expansion of fuel debris retrieval
- 3.1.3.4: Further expansion of the retrieval scale
- 3.1.3.5: Status of accident analysis activities
- 3.1.3.6: R&D status

3.1.3.1 <u>Fuel debris retrieval strategies in each Unit</u>

Below are the strategies common for all units and strategies specific to each unit. Items considered important as of the 2024 update are indicated with a frame ( ) for clarity.

(1) Common strategies for each unit

- Since each unit has many areas where direct visual information is unavailable, it is important to conduct further internal investigations to gain diverse information. Assuming further expansion of the retrieval scale, the investigation will proceed while developing and updating the internal investigation plan in the future, while incorporating new investigation technologies that will be developed, to clarify which areas should be prioritized. In particular, as it has been demonstrated that drones are extremely accessible and useful surveillance tools, their use will be expanded, as well as submersible ROVs. Based on the information acquired by these internal investigations, the direction of the fuel debris retrieval strategy should be verified to avoid engineering backtracking and to increase the certainty of the method to be selected.
- The issues are to analyze and determine the causes of the problems experienced on-site and make improvements, including to the organization and structure, then prevention of recurrence will be incorporated into the following work. Based on these experiences, the

retrieval methods that eliminate anticipated risks should be developed, and measures should be prepared in advance for risks that cannot be eliminated in case such risks occur.

- Fuel debris retrieval will be executed in a high-dose, severe environment. Although remote control devices are used under various circumstances, workers will have many on-site operations. The maintenance of remote-control devices and restoration in case of failure also need to be considered. The issue is examining the retrieval methods in consideration for each process including the entire construction sequence from preparation to completion of retrieval and required resources to be allocated/volume (waste).
- Methods that enable retrieval even if all on-site conditions cannot be identified, and other methods (robust methods) not easily affected by external events such as earthquakes should be examined while taking into account on-site conditions such as damage to facilities and equipment.
- Since work under high radiation doses is required, the following measures should be taken. In advancing these initiatives, it is important to develop a database that can streamline work plans and exposure management.
  - ✓ Prevention of concentration of worker radiation exposure on specific individuals
  - ✓ Reduction of radiation exposure for all workers (including improvement of working environment by conducting decontamination/shielding)
  - ✓ Securing of human resources from a long-term perspective in operations
- Further consideration should be given to the events during the accident, and more knowledge should be gained through internal investigation in each Unit. In Unit 1, it has been confirmed that deposits flowed out of the pedestal. Therefore, methods of removing deposits inside and outside the pedestal and the possibility of deposits flowing into the S/C should be examined and incorporated into fuel debris retrieval methods, including for other Units.

(2) Unit 1

The following should be considered to proceed with planning for the further expansion of the retrieval scale.

- R&D and engineering to apply the R&D results on-site will be promoted. The findings gained through trial retrieval and the gradual expansion of fuel debris retrieval in Unit 2 will be incorporated into device design, retrieval procedures, and safety assessments. The initial study results of the retrieval method for Unit 3 will also be incorporated.
- In previous investigations and analyses using muon, it has been assessed that there is almost no fuel debris in the core. There have been PCV internal investigations, but not RPV internal investigations. In light of all this, the issue is to obtain more information about the inside of the RPV/PCV and take into account the information obtained.

- As a result of the PCV internal investigation (submersible ROV and drone surveillance), the following findings have been obtained and will be considered.
  - ✓ Outside the pedestal, deposits are distributed over a wide area.
  - ✓ There are deposits of nearly uniform height and some upper structures, such as CRD housings, at the inner bottom of the pedestal.
  - ✓ A fallen CRD housing (including multiple CRD-related devices) is blocking a part of the opening used to replace the CRD from inside the pedestal.
  - ✓ The lower concrete near the pedestal opening (worker access opening) and the inside wall of the pedestal is missing around the entire periphery. Meanwhile, as for the upper concrete, no major damage has been observed on the inner wall of the pedestal.
- Appropriate consideration is also given to the following differences from other Units.
  - ✓ The sizes of the RPV and PCV are smaller than those of Units 2 and 3, and the system layout is different as well.
  - ✓ As a result of the previous investigations, it was revealed that the distribution of deposits inside/outside the pedestal is different from that of Units 2 and 3.

(3) Unit 2

- Currently, trial retrieval is underway, and the plan is to gradually expand fuel debris retrieval.
- The issue is leveraging the knowledge gained through trial retrieval for the further gradual expansion of fuel debris retrieval. The design, production, and installation of the following facilities needed for fuel debris retrieval should proceed based on this knowledge.
  - ✓ Facilities for retrieving fuel debris/safety systems (containment, fuel debris cooling, criticality control, etc.)
  - ✓ Fuel debris storage facilities (The first storage facility)
  - ✓ Maintenance installations for retrieval system
- 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 there being some fuel in the core. Furthermore, it is unlikely that the fuel debris that fell to the PCV bottom has spread outside of the pedestal. Investigations inside the RPV and outside the pedestal have not been conducted. In light of all this, more information about the inside of the RPV/PCV should be obtained.
- The issue is leveraging the knowledge gained through trial retrieval in Unit 2 for further expansion of the retrieval scale. However, since it is not the plan to retrieve all the fuel debris with this side-access method, retrieval methods should be examined based on the knowledge gained and the initial study results of the method for Unit 3.

(4) Unit 3

- Considering that the removal of fuel in SFP has been completed and there is little interference with other operations, and the working environment of the reactor building will be improved faster than Unit 1, it was determined that retrieval methods will be examined for further expansion of the retrieval scale ahead of other Units. In response to the recommendations by the "Sub-Committee for the Evaluation of Fuel Debris Retrieval Methods", TEPCO needs to proceed with the examination of the technical feasibility, etc., of retrieval scenarios and methods.
- Previous PCV internal investigations (inside the pedestal) revealed that the CRD housing support has partially fallen and deformed, that several structures have fallen on the lower part of the pedestal, including structures presumed to be structures inside the 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. Investigations inside the RPV and outside the pedestal have not been conducted. In light of all this, more information about the inside of the RPV/PCV should be obtained.

3.1.3.2 Trial retrieval (Internal investigation and fuel debris sampling)

The trial retrieval in Unit 2 is intended to access the inside of the pedestal from outside the PCV for further internal investigations and collect small amounts of fuel debris.

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 the opening of the hatch of penetration X-6, and an enclosure to be newly provided (which encloses a robot-arm, etc.), since the conventional containment barrier was located in the hatch of the penetration X-6. Although it is small in scale, this is a fundamental form of site construction for future retrieval work, in which containment barrier outside the PCV is extended by opening the existing hatch of penetration X-6 of the PCV. It is highly significant to be an approach that enters a new stage.

The information obtained will be used for subsequent gradual expansion of fuel debris retrieval and further expansion of the retrieval scale. In addition, since this will be the first fuel debris retrieval at the Fukushima Daiichi NPS, the experience gained during the process from the examination to the retrieval operation and the information obtained through the analysis of the retrieved samples will be used in future decommissioning efforts.

The issue is to gradually proceed with the series of trial retrieval operations described below (Fig. 16). Moreover, due to the uncertainty of the conditions inside the PCV, assuming the possibility that additional work or rework may be required depending on the actual on-site situation and that the work may not go as planned. Bearing this in mind, the work should proceed safely and carefully. Furthermore, each of these operations has no precedent, and the valuable information, experience, etc., gained through them should be leveraged appropriately in subsequent retrieval operations. In addition, it is important to consider in advance troubleshooting and a system for a prompt response to go with it.

Since February 2022, mock-up testing of the newly developed robot arm has been conducted at the JAEA Naraha Center for Remote Control Technology Development. Modification and verification of the control software and improvement of some devices, which have become required as a result of these tests, were performed, and the functionality verification test of the robot arm itself was completed. Currently (as of September 2024), confirmation tests where the robot arm is incorporated inside an enclosure are in progress. Since the actual work will require repeated access to narrow sections using robot arms, the control program will be optimized, and confirmation testing will be performed from the viewpoint of improving the positional accuracy and hardware/software coordination in on-site application to avoid contact during the work. Further, in addition to testing, development of robot arms is continuing while checking their actual site applicability, taking into account the actual work procedure, operability by operators, and reliability of the device.

In preparation for application of robot-arms to uncertain sites, the issues faced are functional verification checks under various conditions and ensuring that equipment can be saved in an emergency. Therefore, it is necessary to make the necessary preparations, to reliably ensure that the required functions are satisfied by conducting mock-up tests that simulate the actual site, even if it takes time, and to ensure that newly identified risks are eliminated. Furthermore, thorough preparation of the measures should be performed for the practical application, not only by simulating severe environments on-site in mock-up testing, but also by clarifying any areas that are not simulated, such as the current situation after the accident in particular.

On the other hand, in constructing an on-site access route, the installation of the isolation chamber, which had been delayed while operational and design defects were addressed, and seismic countermeasures, were completed in April 2023. After that, removal of the hatch bolts and nuts and opening of the hatch of the penetration X-6 was completed in October 2023. Equipment to remove deposits inside the penetration X-6 was installed in December, and removal of deposits inside the penetration was performed by low-pressure water spray, high-pressure water spray, AWJ cutting, pushing-in, etc., and completed in May 2024. Then, the installations of the penetration X-6 connection structure, connecting pipes and the enclosure (with a built-in telescopic device, etc.) were completed in July.

During the installation of the isolation chamber, it took time to take measures to address damage to the rubber box of the isolation chamber (damage due to contact during installation work of the isolation chamber), bending of the guide roller and misalignment of the shielding door (impact of the earthquake that occurred on March 16, 2022), and damage to the pressing mechanism parts (insufficient margin of design strength). In particular, there was an issue of the design not having adequately considered the workability in a high radiation dose environment or the repair workability in the unlikely event of parts damage.

In addition, in the work to open the hatch of the penetration X-6, because several bolts were more severely adhered than previously expected and could not be removed, the removal method was revised to cope with this. In order to flexibly respond to such events that differ from the prior assumptions, it is important to prepare in advance for the occurrence of unexpected events, such as by identifying and minimizing them in a broad range and then formulating a response policy for unexpected events that may still occur. Moreover, it is also important to be prepared in advance, including reflecting the past on-site work exposure results in the exposure dose plan for future work.

When the hatch of the penetration X-6 was opened, the area near the penetration inlet was covered with deposits, contrary to expectation. However, the deposit could be knocked down using a dozer tool, and the work to remove the deposits inside the penetration X-6 was completed as planned. This is an outcome of adequate preparations and training based on experience gained in past on-site operations.

Given the adhering condition of the penetration X-6 hatch bolts, the state of deposits near the penetration inlet, etc., difficulty in removal of deposits may be also a concern inside the penetration X-6, so it was considered necessary to study in advance a method that enables fuel debris retrieval even if the deposits inside the penetration cannot be completely removed. Considering the factors including the uncertainty of on-site operations, robot arm operations requiring time to establish access routes (e.g., cutting and removal of any possible interference with the robot arm in the access route from the exit of the penetration X-6 to inside the pedestal opening (CRD opening)) as discovered by mockup tests, verification of reliability of robot-arm requiring a certain amount of time for continuing tests, and TEPCO adopted a policy to accomplish early and assured sampling of fuel debris for its characterization first. For that reason, fuel debris sampling was launched with a newly prepared telescopic device that was used for a similar structure in past internal investigations in September 2024, aiming at applying it to the actual worksite while continuing verification of robot arms. After that, as per the initial plan, TEPCO decided to perform internal investigations and fuel debris sampling using robot arms. Introduction of robot arms is expected to realize sampling fuel debris from a wider area in pedestals than telescopic devices can manage.

Fuel debris retrieved in the trial retrieval is planned to be placed in a sealed metal transport container and transported to an existing analysis facility.

In the future, when installing apparatus such as the robot arm system that interface 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 the knowledge and experience so far will be an issue. Paying full attention to the unique characteristics of the Fukushima Daiichi NPS, such as that earthquakes of equivalent or greater magnitude are expected to occur in the future, the work descriptions should be reviewed again, and operation training should be provided to enhance future work safety and reliability. The above characteristics and the knowledge and experience gained this time should be incorporated into examining fuel debris retrieval methods for the further expansion of the retrieval scale.

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

- Considerations in project management

The project should proceed while paying attention to the process of progress management of the contractors including overseas enterprises and subcontractors. As part of their project management activities, TEPCO should 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 and incorporation into gradual expansion of fuel debris retrieval

In the trial retrieval of fuel debris using a telescopic device, deposits at the bottom of the pedestal are collected.

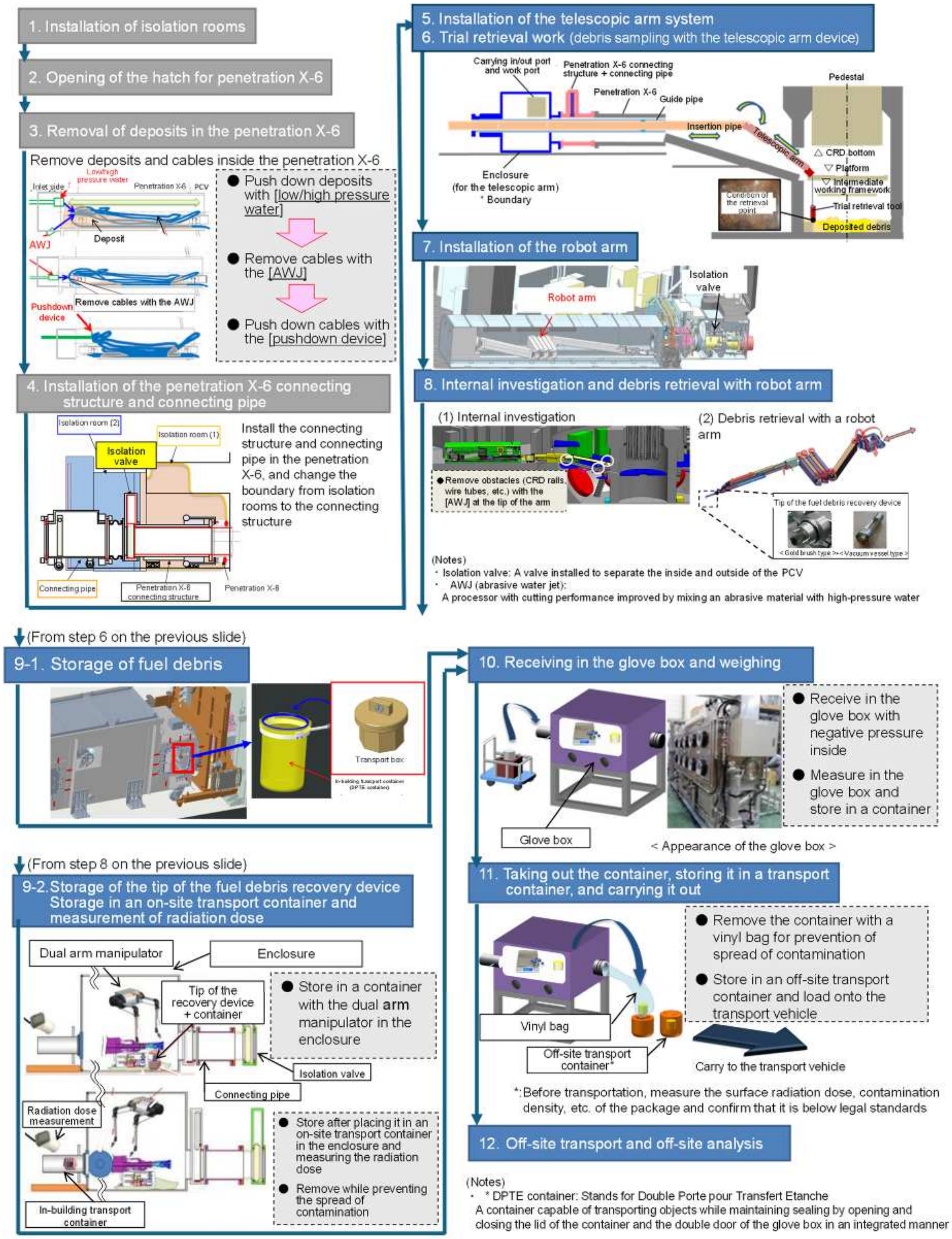
In the PCV internal investigation using a robot arm, following will be ascertained; the state of existing structures, and the distribution of deposits inside the pedestal (3D data), the distribution of gamma rays and neutron counts at the bottom and on the platform. However, since more structures and 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 information obtained from the trial retrieval of fuel debris using telescopic-type device and the results of the arm/tool combinational test in the JAEA Naraha Center for Remote Control Technology Development, the scope and type of data that can be acquired, and the evaluation method of the conditions inside reactor (e.g., fuel debris distribution) based on such data are planned.

Given the limited scope of investigation and trial retrieval, greater consideration is required in advance to determine what information is needed for gradual expansion of fuel debris retrieval as a next step for promoting the retrieval work in a reliable manner.

- Human resource development and technology transfer for gradual expansion of fuel debris retrieval

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.



(TEPCO material edited by NDF)

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

Fig. 16 Major work steps of trial retrieval (internal investigations and fuel debris sampling)[31]

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[31] IRID/TEPCO, "Preparation of PCV internal investigation and trial retrieval for Unit 2", The 47th Fuel debris retrieval Expert Committee, May 30, 2024, ,

3.1.3.3 Gradual expansion of fuel debris retrieval

Preparations of gradual expansion of fuel debris retrieval are underway in Unit 2 with the main objectives of verifying the retrieval equipment, obtaining data on the environmental impact during the retrieval operation, increasing the retrieved volume, obtaining data on the composition and properties, etc. of fuel debris from a larger number of samples, and accumulating experience of workers in retrieval during the period before the start of further expansion of the retrieval scale.

(1) Retrieval equipment

The retrieval equipment to be used for gradual expansion of fuel debris retrieval will be improved by increasing the payload and enhancing accessibility while complying based on the improvements identified during the verification phase of the equipment for trial retrieval. 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. Since the enclosure containing the robot-arm, etc. brings fuel debris from inside the PCV into the enclosure, shielding, measures against hydrogen and prevention of spread of contamination, methods for transferring fuel debris from the enclosure, and methods for confirming the maintenance of containment barrier and dynamic equipment functions and for remote maintenance are being studied.

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[32] and carrying out to the outside of the enclosure for on-site transportation. As a result, the enclosure gradually becomes contaminated, and the issue is 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, the issue is to perform prior mockup test, post-installation test of the equipment, and subsequent abnormality monitoring.

- Ensuring the reliability of the manipulator

  The manipulator to be installed in the enclosure plays an important role in performing various operations and maintenance in the enclosure. Therefore, ensuring the reproducibility of the work is a challenge. Sufficient training for a wide range of operation/maintenance should be provided in advance to train operators.

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[32] One proposal is to retrieve fuel debris from the PCV by putting it in a unit cans, and store the unit cans containing the fuel debris in containers.

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

  Since the work period is in the order of several years, in addition to periodic maintenance, preparation in case of failure is a challenge. Since the Unit 2 reactor building, where the enclosure will be installed, has a high radiation dose and is a difficult place to perform maintenance, 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. Another issue is to leverage the experience gained through the in-service maintenance of equipment/devices for further expansion of the retrieval scale. A system that can reliably preserve maintenance records, including failure histories and corresponding measures, should be established.

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

(2) The first storage facility

When designing the storage facility, there are many connections with related facilities for receiving retrieved fuel debris and sending samples for analysis. Moreover, during installation, they have a lot of interfacing and connections with various types of work and operation, including peripheral work. Although the first storage facility is small in scale, project management by TEPCO is essential for process management and to resolve pending issues during design and installation. The experience and knowledge gained from this design and installation work are expected to be leveraged in project and construction management for further expansion of the retrieval scale in the future.

As various remote-control devices will be used for handling fuel debris in the first storage facility, a critical issue is if they can be operated as we previously envisioned. The work details using these devices should be thoroughly checked and countermeasures against potential risks should be established at the design stage, and they should be incorporated into the design. Furthermore, the design verification and mock-up tests/operator training should be conducted by referring to the knowledge and experience gained from design and operation of remote-control devices in the preceding PCV internal investigation and trial retrieval.

3.1.3.4 Further expansion of the retrieval scale

Toward the further expansion of the retrieval scale, TEPCO should take responsibility for examining the retrieval methods based on the viewpoint that fuel debris retrieval is an important process in decommissioning, and its retrieval in a reliable manner affects the success/failure of the decommissioning project, and from a comprehensive standpoint including cost and its process in anticipation of technical feasibility. (As a reference, changes in considerations on retrieval methods in the previous Technical Strategic Plans are shown in Attachment 4.)

TEPCO has proceeded with the study on the concepts for further expansion of the retrieval scale in Unit 3, ahead of other units. Among them, the partial submersion method, the partial submersion method option (filling and solidification method), and the submersion method were under discussion. Meanwhile, in light of starting work for further expansion of the retrieval scale in the 2030s, it is appropriate to narrow down the retrieval methods and accelerate the studies. Considering these situations, on narrowing down the directionality of design studies amid high uncertainty, the Japanese government, TEPCO, and NDF needed to cooperate in gathering domestic and overseas technical findings and conducting specialized and focused studies. For that reason, since February 2023, through discussions at the Decommissioning Strategy Committee of NDF, it was decided to establish the Sub-Committee for the Evaluation of Fuel Debris Retrieval Methods under the Committee, where the technical feasibility and other aspects of each fuel debris retrieval method are comprehensively studied and evaluated while placing the utmost priority on safety, and to make recommendations on which method a design study shall proceed at the time. The Sub-Committee summarized a report[33] after 12 deliberation sessions, and submitted it to the Decommissioning Strategy Committee in March 2024.

This section first points out the main factors that are making fuel debris retrieval difficult, and discusses considerations when examining or evaluating retrieval methods accordingly. Then, this section outlines the report summarizing the outcome of discussions at the Sub-Committee, and finally it describes the current state of activities taken by TEPCO based on the recommendations made by the Sub-Committee.

3.1.3.4.1 Main factors that are making fuel debris retrieval difficult

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

① Extremely high radiation dose in PCVs and RPVs

The dose equivalent rates in the PCVs/RPVs are on the order of several Sv/h to several hundred Sv/h, and they are inaccessible to humans.

② High-radiation dose in reactor buildings

The dose equivalent rates in reactor buildings are on the order of a few mSv/h to tens of mSv/h, with human access limited to a short time.

③ Insufficient on-site information

[33] NDF, “Report on the Sub-Committee for the Evaluation of Fuel Debris Retrieval Methods” Report, March 7, 2024

Due to the limitations of ① and ② above, it is difficult to obtain on-site information, and there are many areas that must be considered based on presumed with large uncertainties.

④ Building containment barriers

If existing reactor buildings or PCVs are used as containment barriers, consideration must be given to the fact that they are damaged by the accident and to the risk of aging deterioration. On the other hand, if new containment barriers are to be constructed, it requires considering their seismic resistance according to the site conditions and other factors.

⑤ Possibility of criticality

It is necessary to consider the possibility of criticality when the distribution of fuel debris is changed in response to the situation in the PCV • RPV, where the subcritical state is maintained.

⑥ Quantity of waste generated

Regarding solid waste generated by decommissioning, it is necessary to reduce the amount of solid waste generated as much as possible to reduce the overall burden of on-site storage/management.

3.1.3.4.2 Considerations when examining and evaluating retrieval methods

The following are points to be noted when examining and evaluating retrieval methods, in light of the major factors that make it difficult to retrieve fuel debris.

(1) Considerations when examining retrieval methods

- Appropriate establishment of requirements for ensuring safety

Given an unusual environment different from normal reactors, it is necessary to make a comprehensive judgment from the viewpoint of project promotion, considering the level of safety to be aimed at in the end and the work period required to achieve it, on the premise of confirming that safety assurance is definitely feasible. For this reason, it is important to assess the impact if an event that threatens safety occurs, such as an earthquake or criticality, and then to set the requirements appropriately and consider countermeasures.

- Estimation of information needed to study retrieval methods

Information on the location, quantity, and properties of fuel debris, fission product distribution, and PCV internal conditions are important to examine retrieval methods. Therefore, comprehensive analysis and evaluation have been carried out on the basis of the presumption through internal investigations, analysis, knowledge of the previous accidents and studies, experiments, etc., to presume the information necessary to examine retrieval methods. These efforts should be continued hereafter to improve accuracy of retrieval method examination by incorporating the results newly obtained through the internal investigations into the information for the retrieval methods examination.

- Development of retrieval scenarios

Given the limited understanding of the situation in the PCV, it is important to examine scenarios of fuel debris retrieval by each unit and to clarify paths from start to completion in this retrieval method examination. The intention of this study on fuel debris retrieval scenarios is to estimate the different results that will be obtained from the progress of PCV/RPV internal investigations, on-site information and technical studies in the future and then conduct an examination based on the preconditions of using such results. After reviewing these several paths, it is important to combine and narrow down the paths to take according to the information obtained afterward. In considering paths to retrieve fuel debris, it is necessary to control potential issues in each process from preparatory work to the completion of fuel debris retrieval, and it is also necessary to develop the scenario while constantly checking the difficulties and measures of the issues.

- Clarification of requirements

As for the further expansion of the retrieval scale, compared to the case of retrieving fuel debris from Unit 2 (trial retrieval and the gradual expansion of fuel debris retrieval), the operations, devices and equipment, and facilities will be larger, and the scope of construction will be wider. Therefore, the challenge is to perform the examination by overviewing the entire Fukushima Daiichi NPS, including other construction work. For this reason, in addition to the requirements for operations and equipment related to retrieval methods (containment, criticality control, operability, maintainability, throughput, etc.), the requirements for the entire power plant (site use area, interfacing with existing systems, groundwater management, waste management, etc.) should be clarified further. The interaction among the requirements should also be considered.

- Issue identification and verification of actual site applicability and technical feasibility

As a method to systematically and comprehensively identify issues latent in the developed retrieval method, an effective means is to examine the construction sequence from preparatory work through fuel debris retrieval, maintenance and completion of fuel debris to exhaustively identify issues that may significantly affect the technical feasibility of each process work. The issues identified should be verified as to whether they can be addressed from the perspective of actual site applicability and technological feasibility while considering countermeasures.

(2) Considerations when evaluating retrieval methods

- Setting indicators/criteria for determination

When evaluating retrieval methods, in addition to evaluation to confirm that they meet the target safety level and to check the actual site applicability and technology feasibility based on the Five Guiding Principles (safe, proven, efficient, timely, and field-oriented), the results of assessment on resources, processes, availability of workers, and social receptivity should also be used as decision indexes. In addition, decision indexes should be defined from the initial stage of studying retrieval methods to clarify the criteria used in the evaluation. Information (e.g., exposure assessment reports, structure evaluations) to objectively determine whether the criteria are met should also be clarified in advance.

3.1.3.4.3 Overview of the Report of the Sub-Committee

Below shows the overview, advantages and issues of retrieval methods studied and evaluated in the Sub-Committee report, recommendations on the selection of a retrieval method, and future course of action. Note that each retrieval method outlined are only examples and are not definitive.

3.1.3.4.3.1 Overview of and advantages and issues with each retrieval method

(1) Overview of and advantages and issues with partial submersion method

a. Overview of partial submersion method

The partial submersion method is a method for retrieving fuel debris exposed in the air or immersed at a low water level. (Refer to Fig. 17 Example of partial submersion method)

For this method, TEPCO is thinking to combine the “top-access” method (which is to access inside the PCV from above by installing containment equipment on the operating floor of the building and opening the reactor well) and the “side-access” method (which is to access inside the PCV from the side by establishing containment equipment at the side of the PCV on aboveground levels). As the top-access allows a large working opening and direct access, fuel debris inside the RPV and the pedestal will be retrieved mainly by the top-access, and fuel debris outside the pedestal, which has poor top-accessibility, will be retrieved by the side-access. While so doing, to suppress radioactive dust dispersion, water will be sprayed at the fuel debris retrieving area as necessary. Consideration will be given to performing the side-access before the top-access, in order to implement safety measures inside and outside the pedestal, such as criticality control through prevention of accumulation of cutting particles during fuel debris crushing and prevention of heavy objects from falling from the RPV. Necessary containment barriers will be constructed to suppress radioactive dust dispersion and the spread of contamination during retrieval. Basically, the primary containment barrier will comprise PCVs and other structures while the secondary containment barrier will comprise reactor buildings and other structures. In addition, a gas-phase containment system will be installed at the primary and secondary containment barriers to implement active containment by means of the difference in the pressure between inside and outside the containment barriers.

In top-access fuel debris retrieval, heavy instruments such as a cell with a containment function and retrieval machinery will have to be installed on the operating floor. To support such instruments and to ensure seismic resistance, a new large-scale working platform will have to be established. The working platform will have a structure to bridge across the reactor building north and south and support the heavy instruments on the operating floor via a base-isolated layer to prevent interference with the turbine building. In addition, an additional building will be established at the southern side of the reactor building, and auxiliary systems (gas-phase systems, liquid-phase systems), water treatment system, debris/waste pre-transfer treatment equipment, etc., will be installed inside the building.

The retrieved fuel debris will be transported to the additional building connected to the reactor building, and undergo pre-transfer treatment such as placing in transfer casks and measurement of hydrogen concentration. The transfer casks will be transferred from the additional building to a pre-storage treatment facility to analyze, sort, and dry fuel debris as pre-storage treatment. They will be then placed in storage containers and stored in storage facilities.

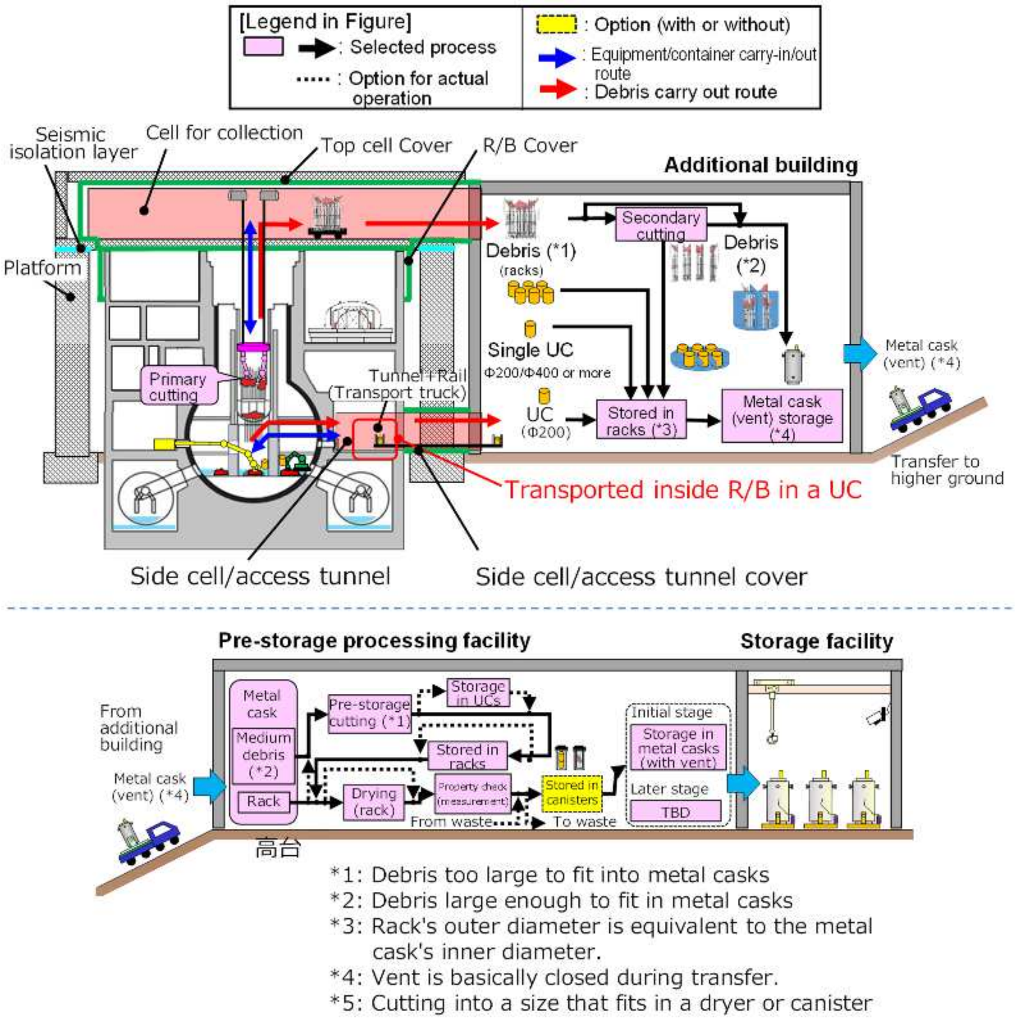

Fig. 17 Example of the partial submersion method

b. Advantages and issues with partial submersion method

For the partial submersion method stated in **a.** above, the Sub-Committee has analyzed the sequence of work processes (preparatory work, construction work, fuel debris retrieval work, transfer, storage, and maintenance) for each method, identified inherent issues, considered countermeasures, and evaluated the technical feasibility. The summary of advantages and issues of each method based on the evaluation is shown below.

<Advantages>

- The partial submersion method is performed without changing the state maintained in the air very much, and therefore poses few concerns over issues associated with change in the state.
- Fuel debris retrieval can be started earlier than the submersion method.
- It allows selecting fuel debris crushing and collection methods according to the state inside, such as selecting from multiple top-access methods and combining top-access and side-access.

<Issues>

- As the radiation dose of the work site is high, various remote control devices will be required compared to other methods. The development, design, and verification of the devices will require a long time, and it is possible that the design of a device will have to be changed after introducing the device at the work site. Considering that rescue of remote control devices takes a substantial amount of time, studies on the recovery method in a high radiation dose environment or means to prevent the inside of the cell having a high radiation dose will be required.
- As high radiation dose fuel debris and waste will be taken out from the top, the operating floor will have to have an extremely heavy cell and retrieval devices installed, and a large-scale aseismic working platform to support them will be required.

(2) Overview of, and advantages and issues with partial submersion method option (partial submersion with solidification/fill method)

a. Overview of partial submersion method option (solidification/fill method)

The partial submersion method option (solidification/fill method) is a method to physically solidify and stabilize the bottom inside and outside the pedestal, inside the RPV, the reactor well, etc., by injecting a fluid filler material that solidified after a certain period of time, and then to take out fuel debris, internal structures, etc., from a relatively small opening to be established on the operating floor using remote control devices. (Refer to Fig. 18 Example of partial submersion method option: Partial submersion with solidification/fill) Solidified parts will be retrieved by excavation, etc., and unsolidified parts using appropriate remote control jigs.

A filler material and other substances will be injected into the bottom inside the pedestal from the side and into the section deemed appropriate to be solidified in the space below the reactor well (lower part of PCV head, inside the RPV, remaining areas inside the pedestal, etc.) from the top to solidify and stabilize.

For the retrieval work, remote control jigs will be inserted from the operating floor via openings to excavate the fuel debris and the filler material down to the bottom of the pedestal, and if there are unfilled and unsolidified spaces such as the bottom outside the pedestal, casing will be installed to excavate the fuel debris and the filler material.

The places to fill and solidify are expected to be places where temporary stabilization is urgently required, places where retrieval by the excavation method is efficient, and places where effective radiation dose reduction for the operating floor due to the γ-ray shielding effect of the filler material is anticipated. There are many possibilities for areas to be solidified. They may vary depending on information obtained by internal investigations, such as the degree of damage to the existing structures and the distribution of fuel debris, and include partial filling. Potential cases are filling the whole area below the reactor well, filling only some sections inside the RPV, filling the whole area inside the RPV, and filling the whole area or only some sections at the bottom of the PCV inside the pedestal. Consideration shall be given taking into account all factors including the results of internal investigations and accessibility of excavation and retrieval.

Possible methods of retrieval during excavation of filled and solidified parts include methods to retrieve as a solid (e.g., core boring, crushing, splitting) and methods to collect excavation chips by circulating water and sending them into a filter-type collection container.

In order to install a cell with a containment function, retrieval devices and a cell cover to encase the cell on the operating floor, a new working platform to support them will be established.

Duplexed containment barriers will be constructed to suppress radioactive dust dispersion and the spread of contamination during retrieval. Similar to the partial submersion method, the primary containment barrier will comprise PCVs and other structures while the secondary containment barrier will comprise reactor buildings and other structures. However, compared with the partial submersion method, since the filler covers fuel debris and other materials, radioactive dust dispersion and spread of contamination are expected to be suppressed more effectively. In addition, a gas-phase containment system will be installed at the primary and secondary containment barriers to implement active containment by means of the difference in the pressure between inside and outside the containment barriers.

Transport and storage of the fuel debris stored in containers should be examined with reference to the proposed partial submersion method and submersion method.

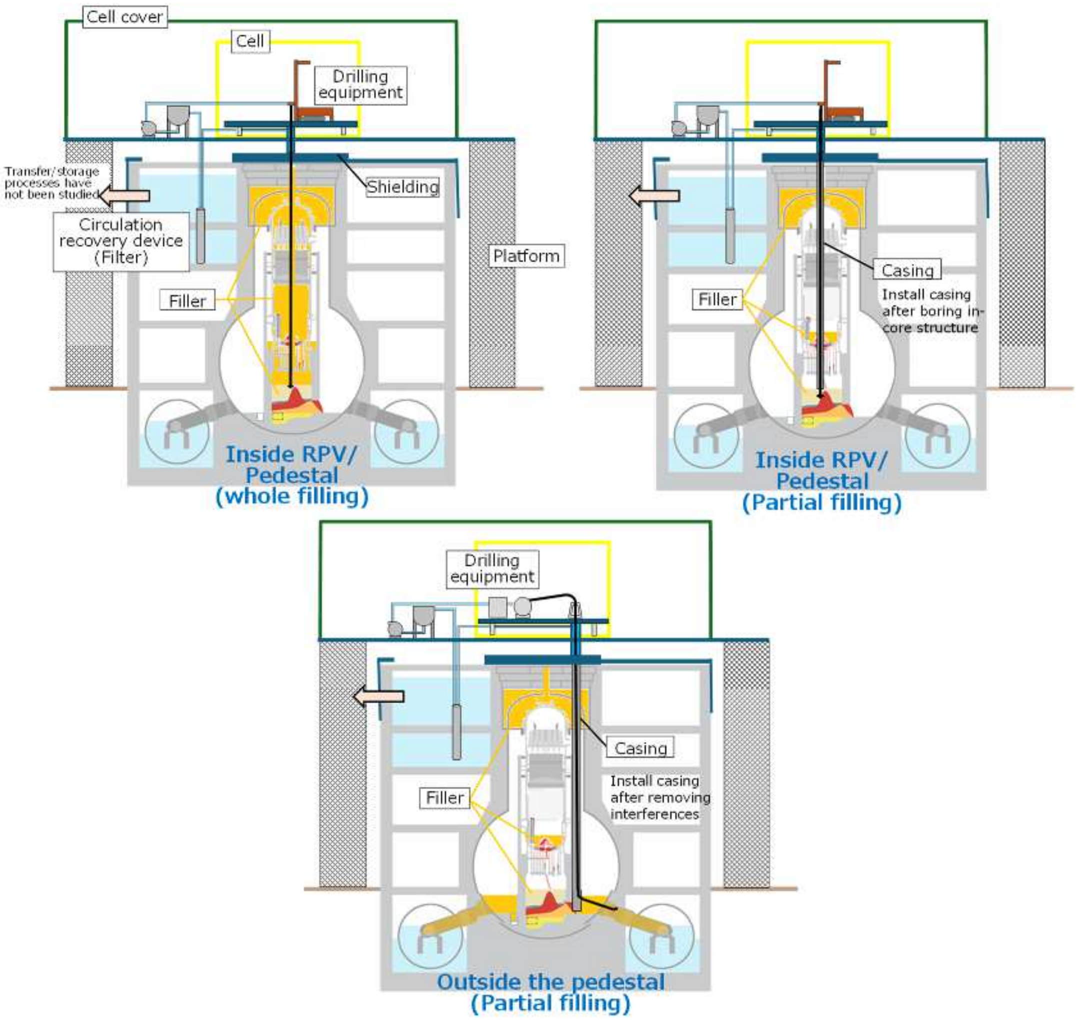

Fig. 18 Example of partial submersion method option (Filling and solidification method)

b. Advantages and issues with partial submersion method option (Filling and solidification method)

For the partial submersion with solidification/fill stated in **a.** above, similar to the partial submersion method, the Sub-Committee has identified inherent issues, considered countermeasures, and evaluated the technical feasibility. The summary of advantages and issues of each method based on the evaluation is shown below.

<Advantages>

- Fuel debris, etc., at the bottom of the RPV and pedestal can be temporarily stabilized by solidifying with a filler material. In addition, solidifying allows uniform and simple handling during retrieval.
- Radiation dose reduction for the operating floor is expected due to the shielding effect of filler material and accessing inside the reactor through a relatively small opening. By this, the size of the cell to be installed on the operating floor, the cell cover to encase it, and the working platform to support them may be made smaller. In addition, rescuing devices in

the event of a failure may be performed through direct operation by workers on the operating floor.

- Excavation devices will be remotely controlled, but their structure will be simple as they will basically only require moving in one vertical axis. In addition, the tip bit, etc., can be replaced according to what to excavate, offering flexibility.
- Compared to the partial submersion method and submersion method, the scale of installations can be smaller, and fuel debris retrieval work may be started the earliest.

<Issues>

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

(3) Overview of and advantages and issues with submersion method

a. Overview of submersion method

Submersion method involves enclosing the entire reactor building from the underground to the roof with a new structure, called shell structure, flooding the entire reactor building by filling this structure with water, and retrieving fuel debris. (Refer to Fig. 19 Example of submersion method) The shielding effect of water enables radiation dose reduction for the fuel debris retrieval work area. The shell structure will be built with a supporting frame consisting of three layers of thick steel plates, designed as containment barriers that support the entire weight of the reactor building and water and have sufficient aseismic properties.

A remote-control device will be lowered into the water from a cell installed on the operating floor to retrieve the reactor installations and fuel debris inside the RPV and inside and outside the pedestal. The outside of the pedestal will be accessed from inside the pedestal via worker access opening in the basement.

The three-layer structure will be: the inner wall in contact with water and a cell installed on the operating floor as a primary containment barrier; the shell structure interior as a secondary containment barrier; and the outer wall as a water shielding containment barrier. In addition, a gas-phase containment system is installed at the primary and secondary containment barriers to achieve active containment by means of the difference in the pressure between the inside and outside the containment barriers.

For the retrieval cell at the top of the shell structure, top-access-related installations such as fuel debris retrieval equipment, auxiliary systems (gas-phase systems, liquid-phase systems), water treatment system, debris/waste pre-transfer treatment equipment, etc., will be installed. The pre-transfer treatment of the retrieved fuel debris will be carried out underwater until it is stored in a shielded container, and then the container will be cleaned, drained, capped, and inspected in the air. To ensure a hydrogen concentration below the flammable limit for radiolysis of water contained in the transfer cask, the amount stored will be limited. The transfer casks will be transferred from the shell structure to a pre-storage treatment facility to analyze, sort, and dry fuel debris as a pre-storage treatment. They will be then placed in storage containers and stored in storage facilities.

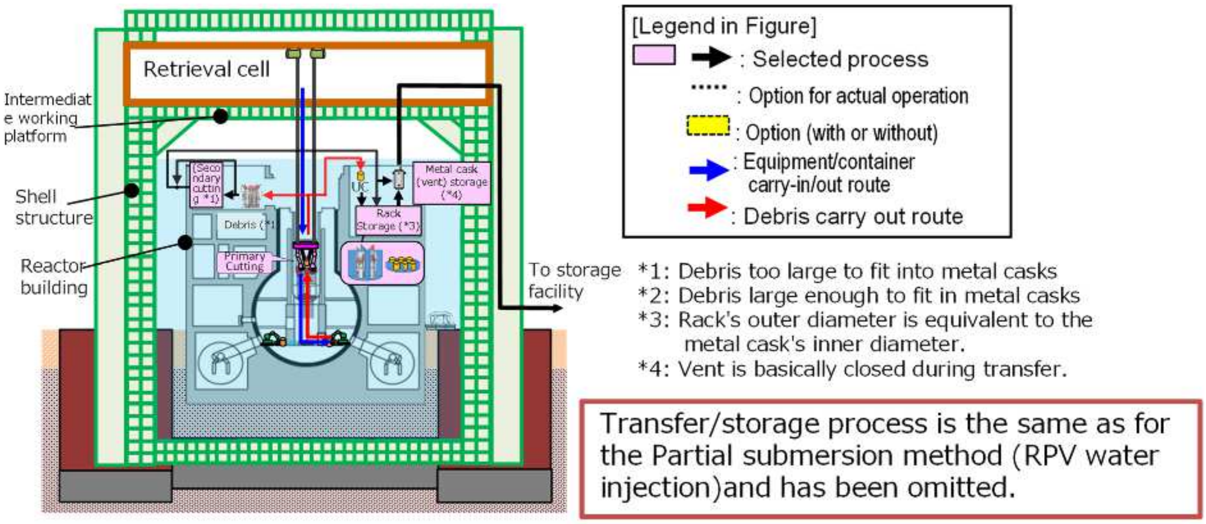

Fig. 19 Example of submersion method

b. Advantages and issues with submersion method

For the submersion method stated in **a.** above, similar to the partial submersion method, the Sub-Committee has identified inherent issues, considered countermeasures, and evaluated the technical feasibility. The summary of advantages and issues of each method based on the evaluation is shown below.

<Advantages>

- Against the strong γ-rays from inside the reactor, the radiation dose at the operating floor will be reduced by water shielding, which facilitates remote control from the top and increases the margin of exposure of workers to radiation. Along with that, radioactive dust dispersion may be suppressed.
- Sturdy containment barriers (shell structure) enable complete isolation of the entire reactor building from the outside.
- Rescue of remote-control devices in the event of failure can be done manually from the operating floor.

<Issues>

- Verification of on-site workability in the construction of a shell structure on the ground under the building (e.g., ground stability against earthquakes during construction, measures against groundwater during construction, quality assurance of production of large-scale shell structure) and securing stabilized installation transfer destinations other than the turbine building will be required.

- Elaborate criticality control will be required, in addition to management of a large amount of water held (e.g., water quality control, leak prevention, corrosion measures).
- The shell structure will be huge.
- The preparatory construction period will be the longest, and the fuel debris retrieval work starting time will be the last.

3.1.3.4.3.2 Recommendations for selecting retrieval methods

Based on the evaluation of the retrieval methods stated in the preceding paragraphs, the Sub-Committee has made recommendations as below.

① It was found that each method has its own issues, and the technologies that constitute the methods come with uncertainties (in design, basic data, technical verification, etc.). Therefore, it is preferable to study scenarios that take advantage of benefits of the retrieval methods and supplement each other's shortcomings (hereinafter referred to as "retrieval scenarios"), instead of sticking to one retrieval method.

② The submersion method would prove to provide effective radiation shielding by water, but the on-site constructability of the shell structure is uncertain, and it involves handling a substantial amount of water. Therefore, it is not advisable to select it as the retrieval method to be totally implemented at the moment. On the other hand, the advantages of handling high-dose materials in water are significant, and it is undeniable that there is a possibility of shifting from partial submersion method to a method that can utilize the function of water shielding in the future.

③ The partial submersion method would be the basic approach TEPCO may take. However, the currently proposed partial submersion method is extremely large in scale and completely relies on remote control devices, which poses major performance concerns over the consistency with yard planning at the work site, feasibility of construction sequence, remote operability, and overall operation rate.

④ The partial submersion with solidification/fill requires small-scale equipment and simple devices. It also offers temporary stabilization of fuel debris by filling and solidifying. However, it is undeniable that technical studies are still lacking, including pending selection of a filler material to satisfy these expectations, incomplete study on technology for injecting a filler material to fill and solidify necessary areas, and insufficient design study pertaining to excavation of solidified parts and handling of retrieved objects. Once the fundamental feasibility of the partial submersion with solidification/fill is established, that would drive the development of the partial submersion method utilizing the function of filling and solidification, not just the partial submersion with solidification/fill.

⑤ Whichever method will be selected, gaining a full understanding of the state inside the PCV and RPV will be a prerequisite for its design and safety assurance. In the future, it will be important to accelerate internal investigations, but the internal investigations will have to be conducted concurrently with the design study of retrieval methods, considering the limited time available for achieving the goals.

Comprehensively considering the above, the Sub-Committee suggests that it is appropriate to:

- start design studies, research and development for a combination of the partial submersion method and the partial submersion with solidification/fill;
- in parallel with this, proceed with small-scale internal investigations, by accessing from the top; and
- concurrently study methods using shielding function of water as well.

Note that future internal investigations, etc., may find new issues due to, for example, a significant difference between the actual fuel debris distribution and the distribution used as the basis of a design study. In that case, retrieval scenarios may be changed even amid the design study, and in some cases the method itself may be retroactively revised.

3.1.3.4.3.3 Future course of action

The Sub-Committee proposes the below as the future course of action.

① How to proceed with specific design studies at TEPCO

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

② How to proceed with giving shape to safety assurance

The concept of safety assurance, criteria and rationale shall be determined as early as possible, and they shall be reflected in basic designs and detailed designs taking into account the views of and suggestions from the regulator.

③ Follow up by the Sub-Committee

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

④ Dialog with municipalities and residents in the relevant area

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

3.1.3.4.4 Current state of activities taken by TEPCO based on the recommendations made by Sub-Committee

TEPCO has been working on specific design studies in accordance with the report of the Sub-Committee. Their plan is to complete specific design studies in about 1-2 years and to move onto the basic design phase using the outcome. TEPCO established a specific design study implementation plan as the state of its initiatives in and after FY 2024, and submitted it at the Sub-Committee meeting held in July 2024. The implementation plan is outlined below.

3.1.3.4.4.1 Outline of specific design study implementation plan

TEPCO has established a specific design study implementation plan assuming achievements necessary to proceed to the basic design phase. For the implementation plan, the content of implementation, study schedule, and the study system are outlined below.

(1) Content of implementation of specific design studies

① Formulation of retrieval scenarios

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

② Facility plan

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

③ Logistics and layout plans

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

④ Processes

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

⑤ Subjects of technological development

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

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

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

⑦ Approach to ensuring safety and setting criteria for determination

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

(2) Schedule of studies

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

(3) System of studies

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

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

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

As part of accident analysis activities by TEPCO itself, to clarify the events that occurred at the time of the accident, TEPCO identified 52 issues as unconfirmed and unresolved matters regarding the accident at the Fukushima Daiichi Nuclear Power Station and has made reports on the progress of investigations and studies based on the outcome of internal investigations and other findings. At the 1st progress report in December 2013, TEPCO reported its conclusions on 10 issues including the possibility of loss of cooling water at Unit 1 that was affected by the earthquake[34]. Among the 10 issues reported, two issues including determining the amount of water pumped into the reactor by fire engines were determined as requiring further studies, and the remaining 44 issues including these two were divided into 10 high priority issues and the other 34 issues. Study results were reported for the 10 high priority issues by the 4th progress report in December 2015, and for 20

[34] "First Progress Report" on the Results of investigation and review of unconfirmed and unresolved issues on the detailed development mechanism after the Fukushima Daiichi Nuclear accident, December 13, 2015

issues including “Core damage and the location of core debris” among the 34 lower priority issues by the 6th progress report in November 2022[35]. TEPCO has been conducting estimations of the state of the RPV and PCV referring to these accident analysis results and is reflecting the results on the systematic implementation of on-site investigations and the examination of fuel debris retrieval method and storage/management. Meanwhile, studies are not progressing well on the remaining 14 issues, including reaction between molten core component and concrete and release of radioactive materials from the PCV during venting. Going forward, internal investigations to be conducted in the course of the trial retrieval in Unit 2 and analysis of retrieved fuel debris are expected to provide information useful for such accident analysis activities.

The progress related to this section is provided in Attachment 10, and the details of OECD/NEA activities are provided in Chapter 4.

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

For issues that are difficult to address in engineering or far-sighted issues, the Project of Decommissioning, Contaminated Water and Treated Water Management has been promoting research and development. This R&D is being carried out in accordance with the R&D medium-and-long-term plan and the next-term R&D plan that are described in Chapter 5.2, and it is important to proceed exhaustively, systematically and efficiently while confirming that it is in line with the needs of TEPCO as the entity responsible for decommissioning. The followings are the research and development items being performed. The sections describe research and development that is common to all methods, regardless of the method to be selected, except for Section 3.1.3.6.7. Although Research and development described in Section 3.1.3.6.8 is only for partial submersion method at present, those for other methods will be initiated by identifying research issues as necessary in the future.

3.1.3.6.1 Technology for RPV internal investigation

To avoid regressing in engineering in the fuel debris retrieval method inside the RPV, verifying the distribution of fuel debris and environmental conditions such as situations and radiation doses in the RPV is useful.

So far, the Project of Decommissioning, Contaminated water and Treated water Management has examined a method to access the core via top access (investigation by drilling the upper part) and a method to access the core via side access (investigation by drilling the side). By FY 2019, the project verified the equipment function toward practical application. In the investigation method by drilling the upper part, the plan is to use AWJ (abrasive water jets) for the drilling holes (openings)

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[35] Attachment 2: [Study issue list], “The 6th Progress Report” on the Results of investigation and review of unconfirmed and unresolved issues on the detailed development mechanism after the Fukushima Daiichi Nuclear accident, November 10, 2022[36] Publication of the 2022 Performance Report on the “Development of Fuel Debris Drying Technology”

of the in-core structures (dryer, steam-water separator, and shroud head). However, issues such as the impact on internal investigations and the increase in waste have been pointed out because a large amount of abrasive enters the PCV and RPV due to the AWJ cutting.

For this reason, from FY 2020, cutting techniques that reduce secondary waste (abrasives, etc.) were examined. As a result, AWJ with small nozzles and laser cutting were selected as candidate techniques. The remote workability from the operating floor using this cutting equipment was tested and verified by FY 2023.

Regarding the investigation by drilling the upper part, it is necessary to specify the details of the engineering work plan, including interference with fuel removal work from spent fuel pool, investigation of the site condition where an ROV for the RPV internal investigation is installed, and improvement of the site environment. In addition, in FY 2024, a study on the access-from-top/side investigation method was started as a method that may allow early checking of the level of damage to the steam dryer, steam-water separator, shroud, etc., in the RPV. In this method, investigation equipment is to be installed at the dryer separator pit (DSP), and holes will be drilled on the DSP plug, PCV, and RPV to survey inside the RPV.

Considering that it is important to promote the development of a method capable of conducting RPV internal investigations at an earlier stage, an internal investigation method via lower access has been studied since FY 2020. In this method, an investigation device is inserted into the PCV by using an established access route for PCV internal investigation, and then to the RPV through the opening that is assumed to exist at the bottom of the RPV. As a result of the study, the following methods were developed: for Unit 1, a small drone is inserted into the pedestal through a CRD opening for investigation, and for Units 2 and 3, a telescopic device mounted on a robot arm is inserted into the pedestal for investigation. In FY 2024, regarding the lower access investigation method assuming Unit 3 in which many obstacles were found at the lower section inside the pedestal, a study was started including the development of new accessing devices.

TEPCO is studying a simple investigation method in which a fiberscope with a small diameter and high radiation resistance is inserted into existing instrumentation pipes (small-diameter pipes) to access and investigate the inside of the RPV, and is planning to conduct surveillance for Unit 2 in FY 2024.

As an extension of this study, concerning the technical issues with internal investigation using the existing piping accessible inside the shroud (passing of clogged sections such as check valves and T-shaped pipe fittings in the middle of piping, etc.), the Project of Decommissioning, Contaminated Water and Treated Water Management started developing elemental technologies to solve the issues in FY 2022, and identified the core spray (CS) system, main steam (MS) system, and primary loop recirculation (PLR) system as the practical application candidates and developed devices with necessary functions by FY 2023. From FY 2024, the Project plans to solve issues found in and before FY 2023 and check the actual site applicability through mock-up tests, targeting the CS system (Unit 2) and the MS system (Unit 3) for which early practical application can be expected.

Since each unit has many areas where direct visual information of RPV internals is unavailable, the challenge is gaining the information inside the RPV as early as possible by promoting engineering leveraging technical development in the Project of Decommissioning, Contaminated water and Treated water Management and the developed technologies. The direction of the fuel debris retrieval strategy will be verified based on the acquired information to avoid regressing in engineering and to increase the certainty of the method to be selected.

3.1.3.6.2 Technology for work environmental improvement in reactor building

In accordance with the Mid-and-Long-term Roadmap and TEPCO's Mid-and-Long-term Decommissioning Action Plan, the removal of obstacles and radiation dose reduction in the reactor buildings are in progress as improvements of the work environment in work areas/access routes. In future work related to fuel debris retrieval, the issue in environmental improvement is reducing exposure during work by establishing safe and reasonable methods to remove obstacles such as the high radiation dose and highly contaminated installations and through radiation dose reduction in work areas. The Project of Decommissioning, Contaminated Water and Treated Water Management Research and Development has promoted R&D on technologies to improve the environment in the reactor buildings 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. Moreover, the need will arise to handle nuclear fuel materials containing alpha-ray emitting nuclides with a large dose contribution in the case of internal exposure. Therefore, when considering measures to improve the environment, it is essential to prevent excessive exposure on the part of workers and to reduce exposure by implementing radiation protection measures appropriately based on the work environment, such as structures, system equipment, radiation sources, and doses, as well as operation modes, such as decontamination, shielding, and removal. Regarding protection from external radiation exposure, the radiation exposure dose is evaluated considering the radiation sources, the radiation dose rate, and work hours in the work area. Then, based on the three principles, namely “time, distance, and shielding,” it will be necessary to implement radiation exposure reduction measures as low as reasonably achievable. For protection from internal exposure, in addition to system measures such as suppressing the dispersion of radioactive dust and prevention of the spread of contamination, it is essential to select protective measures according to the contamination state in the work area and to strive to prevent inhalation ingestion and body contamination. With these ideas in mind, an appropriate combination of measures such as decontamination, shielding, and remote technology should be pursued.

In particular, the following are important perspectives to consider in fuel debris retrieval.

- Work environment in the reactor building should be sufficiently secured to access into the PCV from the penetration X-6 and the operating floor, etc.
- As the reactor building still has areas where the extent of damage due to the accident remains unknown in the high radiation dose environment, sufficient investigations on the

radiation dose distribution and state of contamination, including the contribution from the surroundings of the target areas, will be conducted to identify the source locations and intensity as much as possible and to build work plans.

- 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, operational needs will be clarified, and measures will be discussed to reduce the total radiation exposure dose to as low as reasonably achievable and to accomplish operations with respect to work hours in accordance with dose limits and the work hours required to accomplish operations.
- The development of remote technology will be promoted to remove obstacles that are relatively difficult to remove, such as equipment in high places and heavy objects.

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. A prototype was built in FY 2022, and development has been underway since FY 2023 to advance functions for practical applications. In FY 2024, the actual site applicability will be evaluated for the study items. Long-term operation is expected to help build a system that can accumulate proven knowledge. In order to remove heavy objects, system equipment in high places, and other obstacles that are relatively difficult to remove, the development of remote technologies for environmental improvement and removing obstacles under high radiation doses began in FY 2020. As a result, the specifications of a remote-control device in accordance with the required functions for the obstacles selected to be removed were proposed and ended in FY 2022. While TEPCO's engineering promoted development in order to actualize the proposal based on this achievement, regarding the removal of high radiation dose PCV-penetrating pipes, etc., that may have contaminated fluid or hydrogen inside, various difficult-to-resolve issues were identified, including how to address their tendency to aggregate and how to secure the visibility for remote monitoring in an environment with many obstacles. Accordingly, from FY 2024, technology development will be conducted on the remote monitoring and removal work systems for removing PCV-penetrating pipes, etc.

3.1.3.6.3 Development of analytical technology for radiation exposure dose assessment

In the event of intake of alpha-ray emitting nuclide or other nuclides into worker's body, the effective radiation dose should be properly assessed using external counting (lung monitor) and bioassays. For this reason, the following is important:

- Select alpha-ray emitting nuclides that are important for exposure assessment in advance, and incorporate them into the control of airborne concentrations, standards for wearing protective equipment, and equipment calibration management.
- Control the surface contamination density in the work environment and the bodies of workers entering/leaving contaminated areas for the early detection of the spread of contamination beyond the area division and to prevent the intake of re-suspended dust from loose contamination.

Relatively high α-contamination has been observed in some parts of the reactor building, and the frequency of operations in the reactor building has increased as decommissioning work has progressed. As restoration work by human workers in response to problems has also occurred, it is necessary to proceed with more attention to the intake than before. In preparation for full-scale fuel debris retrieval in the future, the challenges are to improve protection functions against the intake as well as to promptly assess the amount of radioactivity of the radioactive materials taken in and evaluate the radiation dose in order to more accurately consider responses and measures in the event of such intake.

The intake of alpha-ray emitting nuclides must be evaluated as early as possible through bioassay and other methods because of the difficulty of measuring α-rays and the large contribution to internal radiation exposure dose. In recent years, medical interventions such as medication administration have been implemented for internal exposure to plutonium, and more complex actions to intake events have become a challenge. Furthermore, the particularity in the work environment for decommissioning the Fukushima Daiichi NPS should be taken into consideration as there are significant differences from existing facilities in Japan and overseas in terms of the nuclide composition and concentration of the radioactive materials handled, the operational conditions to be controlled, and the number of personnel involved.

In light of the above, in FY 2021, the Project of Decommissioning, Contaminated Water and Treated Water Management began R&D activities to protect against intake and assess the radiation dose in the event of intake, and technical development has moved forward that includes studying the concept of an internal radiation exposure dose assessment program, investigating and examining the acceleration of bioassay methods, and optimizing protective equipment. Based on these outcome, since FY 2023, the development of internal exposure dose evaluation programs has been promoted by the development of technologies related to the measurement and evaluation of internal exposure doses, such as the advancement of bioassay methods and the examination of skin contamination and wound contamination measurement, and the development of internal exposure dose evaluation systems and standards.

3.1.3.6.4 Liquid treatment system (alpha-ray emitting nuclide removal technology)

Fuel debris retrieval may cause mixing and leaching of granular particulate or soluble alpha-ray emitting nuclides in higher concentrations of contaminated water than the current condition because fuel debris is cut or fabricated in a wet or underwater environment. In decommissioning the Fukushima Daiichi NPS, removing alpha-ray emitting nuclides is a particularly important issue. While water treatment facilities (SARRY, ALPS, etc.) to remove radioactive materials from contaminated water are currently in operation, it is necessary to establish a technology that can remove alpha-ray emitting nuclides from contaminated water and reduce the concentration to a predetermined level even when the concentration of alpha-ray emitting nuclides increases. Therefore, the Project of Decommissioning, Contaminated Water and Treated Water Management technologies have been engaged in technical research and development to remove particles containing radionuclides, remove soluble alpha-ray emitting nuclides in an environment simulating practical application, and treat secondary waste. However, the quality of contaminated water during fuel debris retrieval is unclear until the retrieval begins. Thus, the design of the retrieval facilities will need to set facility specifications conservatively to compensate for such uncertainties, including the presence of colloidal alpha-ray emitting nuclides that are difficult to remove. Therefore, it is considered useful to expand knowledge of the retrieval methods proposed in previous research and development activities and continue to develop technologies by conducting further tests using contaminated stagnant water in existing buildings to realize more rational designs. In addition, further research on secondary waste treatment technology needs to be conducted in coordination with subsequent sorting, transfer, and storage operations. The ongoing efforts since FY2023 include developing removal technologies that can accommodate colloidal alpha-ray emitting nuclides in addition to soluble alpha-ray emitting nuclides, preparing tests using contaminated stagnant water in buildings, and developing more rational secondary waste treatment technologies.

Although the basic design and detailed design of the retrieval facilities will be carried out in preparation for further expansion of the retrieval scale, it would be more rational if the research and development results could be incorporated sequentially at each design stage. Engineering should be promoted considering this point.

3.1.3.6.5 Technologies for containment, transfer and storage of fuel debris

Before initiating the 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 storage of retrieved fuel debris (pebble or powder) furnished with safety functions such as maintaining subcriticality, containment functions, countermeasures against hydrogen generation, and cooling. Accordingly, the examination of the following is underway until the end of FY 2023. [36] [37]

- Development of basic specifications for the container (storage cans)32, such as height in consideration of handling of it, internal diameter, quality of materials and lid structure in

[36] Publication of the 2022 Performance Report on the “Development of Fuel Debris Drying Technology” (https://irid.or.jp/wp-content/uploads/2023/06/2022013syuunoukankansouF202306.pdf)

[37] Publication of the 2022 Performance Report on the “Development of Handling Pulverized, Slurry and Sludge Fuel Debris” (https://irid.or.jp/wp-content/uploads/2023/06/2022014syuunoukankonajyouF202306.pdf)

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 transfer conditions with consideration for the accumulation of hydrogen gas in transferring casks.
- Development of efficient drying technology applicable to fuel debris in unit cans32, and establishment of a drying system and drying process conditions using this drying technology
- Table-top study of the behavior of powdery fuel debris in containers and the preparation of testing for its verification

Moreover, in reference to the results of these studies, TEPCO continues their activities to materialize canisters used for storage and the first storage facilities (receiving/delivery cell, storage casks, etc.) needed for the gradual expansion of fuel debris retrieval in coordination with other associated projects. In addition, study on transfer/storage process, survey of storage technologies/types, narrowing down of these candidates, the investigations of treatment required before storage fuel debris, and survey of method and route of transfer of fuel debris to the storage site are ongoing toward the further expansion of the retrieval scale. These studies have focused on pebble or grain state of fuel debris. Retrieving the powder fuel debris generated by fuel debris working (cutting and machining) are considered to be retrieved in a powder state in the gas management systems, or slurry or sludge state in cooling water circulation ones. Therefore, technical issues for the safe, proven, and efficient storage of powder or sludge/slurry fuel debris have been identified in the Project of Decommissioning, Contaminated Water and Treated Water Management in FY2020. Based on these results, since FY2021, desktop studies on the method of drying slurry/sludge fuel debris, the characteristics of hydrogen gas generation and its release behavior from them, and their behavior during fuel debris handling from transfer to storage operation have been in progress. Since FY2023, based on the study results in the Project of Decommissioning, Contaminated Water and Treated Water Management and new findings on fuel debris properties and conditions in PCVs, the results of desktop studies on the characteristics of hydrogen gas generation and its release behavior from them have been checked through element tests, etc. Concurrently, checking the service life of filters installed on the container lids through element tests, etc., was started. It is necessary to steadily advance these activities in order to accumulate and share information that will contribute to the establishment of processes for the safe, proven, and efficient storage of slurry/sludge fuel debris and the design of equipment and systems necessary for composing such process.

At present, since the information and knowledge on the properties of fuel debris are limited, design of equipment and installations by TEPCO and the studies by the Project of Decommissioning, Contaminated Water and Treated Water Management are proceeding, based on conservative assumptions of the properties of fuel debris. In the design of equipment and installations for the containing, transferring, and storage of fuel debris for further expansion of the retrieval scale, it is important to proceed in a streamlined manner by utilizing a variety of measurement data that have been collected and accumulated during the trial retrieval and gradual expansion of fuel debris retrieval, 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 transfer of fuel debris to storage. In developing the specific equipment and installations for handling and storing retrieved fuel debris, it is also necessary to consider satisfying the safeguard requirements.

Unit cans and containers in which fuel debris is stored should be handled by remote control devices in a safe and reliable manner. Therefore, it is useful to perform mock-up testing of possible tasks using an actual or similar remote-control devices in the initial stage of detailed design. Moreover, to prevent design change/modification, it is also considered to be a valuable approach to determine the specifications, layout and size of equipment and installations required for containing, transferring, and storing fuel debris, as well as the flow line of fuel debris based on the knowledge gained through mock-up tests.

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.

3.1.3.6.6 Data acquisition of dust dispersion rate

For the further expansion of the retrieval scale, it is necessary to develop fuel debris retrieval methods and safety assessment techniques for accident events. In safety assessment, in addition to understanding the relocation from the point of retrieval to the air and the amount, it is necessary to assess the relocation behavior of the dust generated by fuel debris fabrication, cutting, etc., during fuel debris retrieval, including dispersion, deposition, and resuspension as a basis. In the acquisition of dust dispersion rate data, with a focus on the above points, knowledge about dust dispersion, such as dust generation and relocation, has been acquired through tests simulating fuel debris retrieval environments to gain knowledge on dust dispersion rates.

To develop this safety assessment technique, the objective of this study is to understand the basic behavior of dust dispersion generated during fuel debris retrieval. Data on the dust dispersion rate in dry conditions was acquired by 2022. Since FY2023, the acquisition of data on dust dispersion rates for multiple retrieval methods in a wet environment inside PCVs, which is assumed during fuel debris retrieval, has been in progress. Actual retrieval of fuel debris is performed under a wet environment, and dust dispersion is considered to be more suppressed than under dry conditions. In the future, the factors contributing to the suppression will be identified, including the study of measurement and analysis methods under wet conditions, analysis using data under dry and wet conditions will be advanced, and the method of applying the acquired data to safety assessment will be examined. The acquired data are being organized systematically to utilize as a technical basis for safety assessment during fuel debris retrieval in the future decommissioning work of the Fukushima Daiichi NPS.

3.1.3.6.7 Fuel debris retrieval method

For the fuel debris retrieval method for the further expansion of the retrieval scale, on the assumption that the fuel debris retrieval work will be a remote operation under an environment with high radiation dose, high contamination, and high uncertainty, the issue is developing the technology for the devices, equipment, and systems required for establishing access routes to the PCV and fuel debris retrieval. In response to these issues, the Mid-and-Long-term Roadmap (September 26, 2017) indicated a fuel debris retrieval policy focused on the partial submersion method. Accordingly, as subsequent R&D activities, the Project of Decommissioning, Contaminated Water and Treated Water Management is developing retrieval methods via side and top access for the partial submersion method and elemental technologies common to the side and top access methods. Elemental technologies for the side access retrieval method have been developed, such as a fuel debris retrieval system (suction, gripping, etc.), a fuel debris cutting/dust collection system, technologies to prevent the spread of contamination to the S/C, cell structures for access route construction, carry-in and installation technologies, technologies to connect with the PCV, technologies to remove obstacles, and remote-control support systems. As for the retrieval method via top access, initially, there were discussions on retrieving fuel debris by shredding it in the reactor and carrying it out. However, a method of cutting the in-core structures and fuel debris into large units and carrying them out has been under study since FY 2019 to increase throughput. The following have been developed as elemental technologies: methods and devices for cutting into large units, large transport devices, isolation mechanisms between the operating floor and the additional building to prevent the spread of contamination, and large transport containers. The development of remote decontamination and maintenance technologies for contaminated equipment and the development of dust dispersion control materials during fuel debris fabrication have been promoted as elemental technologies common to the side and top access methods.

From FY 2023, as a response to the issues identified in the results obtained in the development of the retrieval method via the top access so far, the system development for the upper part of the operating floor, such as large transport equipment considering the containment performance, and technology development such as for filling, stabilizing, and cutting damaged in-core structures are being promoted. In addition, to address new issues, since heavy objects may fall to the bottom of the pedestal during retrieval via top access due to cut pieces and vibration during fabrication, technology development for fall prevention is in progress to prevent re-criticality due to falls, dust dispersion, or equipment damage. Moreover, TEPCO has started specific engineering study based on the recommendations in the report of “Sub-Committee for the evaluation of fuel debris retrieval methods”, and development of retrieval scenarios and their technical feasibilities are being examined, as shown in Section 3.1.3.4. For issues that are determined to have a high need for new development and high technical difficulty, the Project of Decommissioning, Contaminated Water and Treated Water Management will proceed with the necessary technological development.

3.1.3.7 Issues in examining safeguards strategies

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

3.1.4 Summary of key technical issues

The key technical issues and future plans described in this section are summarized as shown in Fig. 20.

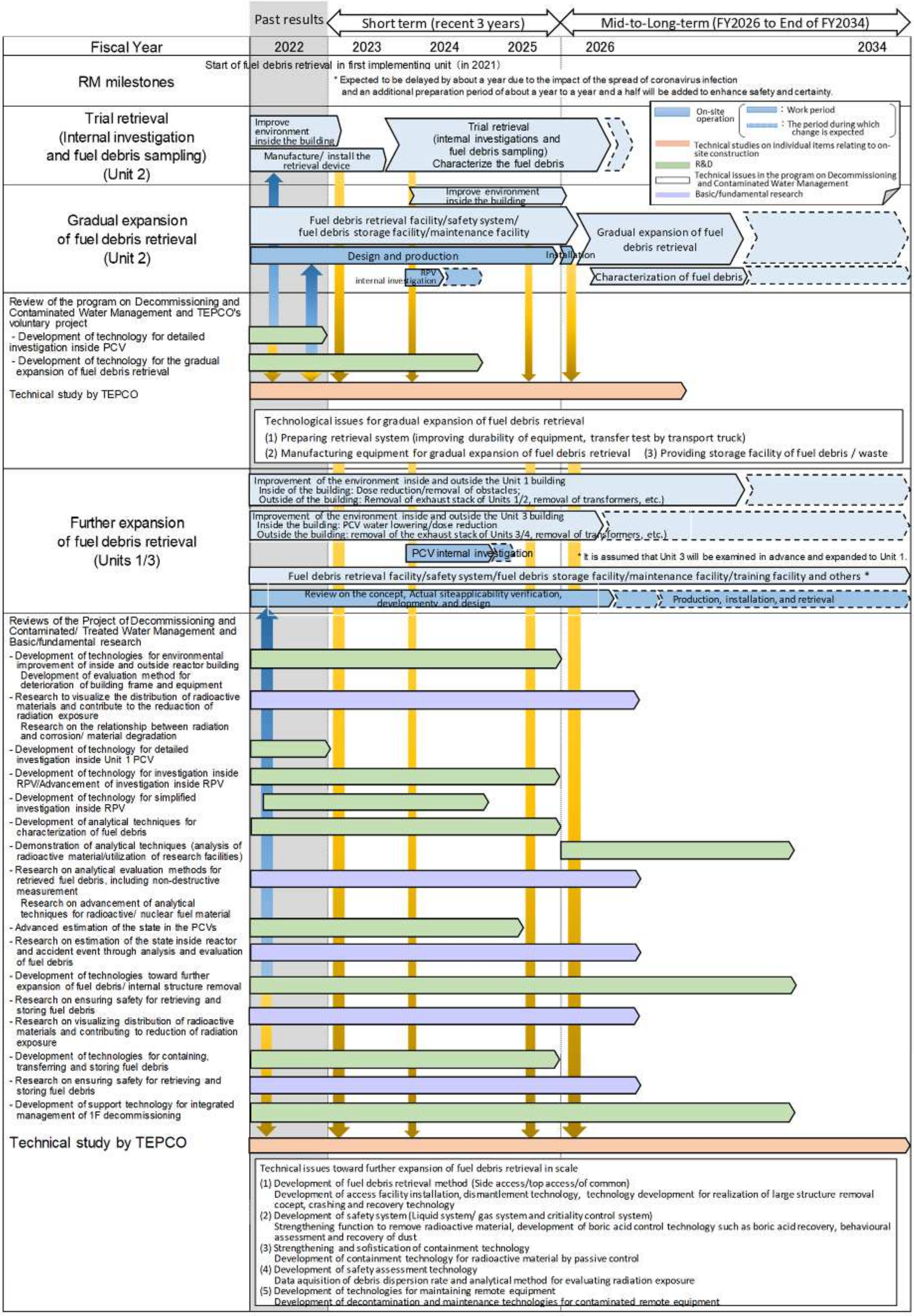

Fig. 20 Key technical issues and future plans on fuel debris retrieval (progress schedule)

3.2 Waste management

3.2.1 Target

① The Solid Waste Storage Management Plan (hereinafter referred to as the "Storage Management Plan") is developed and revised with updating the estimated amount of solid waste[38] to be generated in the next 10 years, as well as appropriate storage/management should be implemented including waste prevention, volume reduction, and monitoring of storage/management conditions based on it.

② Develop and update the analysis plan necessary to advance the consideration of storage/management, processing, recycling and disposal, and proceed steadily with analysis based on it.

③ Based on the prospects of processing/disposal methods of solid waste and technology related to its safety (hereinafter referred to as "Technical Prospects") presented in FY 2021, the creation of options for storage/management, processing, recycling and disposal measures and their comparison and evaluation should be conducted with promoting characterization. Studies on detailed waste management processes of the whole solid waste (management from generation to recycling and disposal of solid waste) proceed for presenting appropriate measures. For that, first evaluate the flow of integrated measures for individual solid waste from characterization to recycling and disposal (hereinafter referred to as "individual waste stream") in the overall solid waste management, and accumulate the individual waste stream option proposals that have been recognized as safe and feasible. Then, integrate all individual waste stream option proposals together and form entire waste stream (hereinafter referred to as "waste stream").

3.2.2 Progress

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 through storage/management, processing, recycling and disposal. The terms for solid waste management prepared based on the IAEA's Glossary of Terms related to radioactive waste management[39] are shown in Attachment 5, and classification and disposal of radioactive waste in Japan and abroad are shown in Attachment 6.

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[38] In the Mid-and-Long-term Roadmap, "solid waste" is defined as "some of the rubbles and other materials generated after the accident may not be treated as waste or radioactive waste due to recycling at the site, etc., as described below, but these, including secondary waste generated by water treatment and radioactive solid waste stored at the Fukushima Daiichi NPS before the accident, are hereinafter referred to as "solid waste".

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

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 following "Basic Policies on Solid Waste" summarized in the Mid-and-Long-term Roadmap are promoted.

<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/managed 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 confirm required R&D tasks after cooperating with each R&D field in characterization and processing/disposal and overviewing the overall management of solid waste.

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.

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 storage/management, processing, recycling and 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 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 detailed management of solid waste to present appropriate measures as a whole.

Until FY 2021, IRID took the lead in the Project of Decommissioning, Contaminated Water and Treated Water Management related to solid waste, with the JAEA as a key player. However, the JAEA is taking the main role in the projects by itself which are started from FY 2022.

a. Current status of storage/management in Fukushima Daiichi NPS

Table 3 shows the current storage/management status for solid waste. To store/manage 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, all the 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 recycling/reuse. Facilities needed to achieve this goal are under development (Attachment 13) and the processing plan[40] and transfer plan[41] related to this were examined.

Amid the advancement of construction and operation of waste disposal facilities, the waste volume reduction and disposal facility encountered a defective air conditioning balance, and the additional solid waste incineration facility building had a fire alarm activated in February 2024. To promote volume reduction and incineration for storage as planned, necessary measures need to be considered and implemented, and reflected in future facility plans.

To date, waste has been stored/managed by classification based on the surface radiation dose rate as an index because a large amount of rubble is contaminated by fallout. From now on, for more appropriate storage/management, the radioactivity concentration will be assessed through analysis of each waste product with a view to promoting recycling on-site.

The Technical Prospects have provided the examples of foreign 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. 21)), and TEPCO has also been implementing initiatives corresponding to this concept.

Among the targets of recycling/reuse, concrete rubble is crushed and recycled as roadbed material on the premises of Fukushima Daiichi NPS after confirming that the surface dose rate is equivalent to the background radiation dose. In addition, melting is under consideration as a

[40] Verification of whether the necessary volume reduction will be completed by estimating the operation and processing periods based on the completion time of the construction of each facility for volume reduction.
[41] Assessment of the impact on receiving operations in terms of the impact of the completion time of the solid waste storage.

decontamination method for recycling metal. The Project of Decommissioning, Contaminated Water and Treated Water Management is in progress to clarify the nuclide distribution behavior during melting and decontamination and examine inspection methods after melting processing 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, ALPS slurry generated by the multi-nuclide removal equipment, etc., and the waste sludge generated at the decontamination equipment have high water content and flowability. For safer storage/management, ALPS slurry will be examined for performing stabilization (dehydration) treatment based on the issues related to storage risk reduction and volume reduction at the Study group on Monitoring and Assessment of Specified Nuclear Facilities and the Technical Meeting on the Examination of the Implementation Plan of the Measures for the Specified Reactor Facilities. 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 (The plan of starting collection of waste sludge was rescheduled from FY 2025 to FY 2027. [42]). In the Measures for Mid-term Risk Reduction at TEPCO's Fukushima Daiichi NPS, a policy for solidifying dehydrated and recovered materials and sorption associated with water treatment waste (unstable) will be developed by FY 2025. The “elimination of outdoor storage and conducting appropriate storage” and the “start of solidification processing” are shown as the conditions to be realized (FY 2033).

Such solid waste requiring proper storage/management in the Fukushima Daiichi NPS will continue to be generated with some exceptions. The Storage Management Plan published in November 2023 describes a considerable amount of waste is expected to be generated in future preparatory work for fuel debris retrieval, etc. The amount of waste generated is estimated to be at least 300,000 m^3, including specifically that from dismantling the buildings around Unit 1 to 4 and resin and other wastes generated before the earthquake, on the assumption that there is uncertainty due to the fact that the fuel debris retrieval method has not been determined. In the future, the amount of waste generated will be scrutinized in anticipation of the volume reduction effects of incineration/crushing, etc. Solid waste will be also generated from fuel debris retrieval. It is also necessary to consider how to deal with this solid waste in the future.

[42] Collection of waste sludge is difficult to start in FY 2025, considering the lengthening design period associated with the expansion of equipment in size as a measure for radioactive dust containment, the need for considering measures to improve reliability in the future, as well as the process to manufacture and install collection equipment thereafter. It is expected to be started in FY 2027 at the earliest.

Table 3 Status of solid waste storage/management

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

(As of July 31, 2024)

Classification	Stored volume (m^3) / Storage capacity (m^3) (Percentage)
Outdoor storage (surface radiation dose rate ≤ 0.1 mSv/h)	322,000 / 397,900 (81%)
Outdoor sheet covered storage (surface radiation dose rate 0.1 - 1 mSv/h)	33,300 / 55,300 (60%)
Soil-covered temporary storage facilities, outdoor container storage (surface radiation dose rate 1 - 30 mSv/h)	16,400 / 17,200 (95%)
Containers* (in solid waste storage building)	28,500 / 39,600 (71%)
Total	400,200 / 509,900 (78%)

Fallen trees

Classification	Stored volume (m^3) / Storage capacity (m^3) (Percentage)
Outdoor storage (trunks, roots, branches, leaves)	43,200 / 134,000 (32%)
Temporary storage pool (branches, leaves)	37,300 / 41,600 (90%)
Total	80,500 / 175,600 (46%)

Used protective clothing, etc.

Classification	Stored volume (m^3) / Storage capacity (m^3) (Percentage)
Temporary storage	15,500 / 25,300 (61%)

* 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 secondary waste generated by water treatment

(As of August 1, 2024)

Sorption vessels, etc.

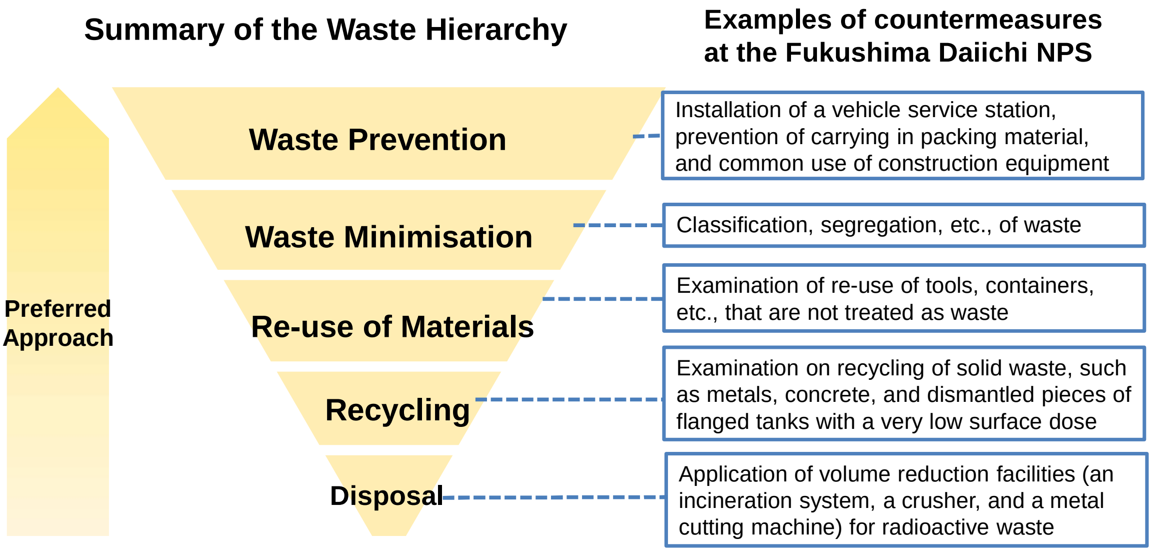
Place stored			Storage volume		Stored volume/capacity (Percentage)
Outdoor temporary storage area of used sorption vessels	Cesium sorption apparatus		779	Number of vessels and filters	5,790 / 6,692 (87%)
	2nd Cesium sorption apparatus		263	Number of vessels and filters	
	3rd Cesium sorption apparatus		21	Number of vessels and filters	
	HICs from multi-nuclide removal system		4,380	Number of containers	
	Used vessels from high-performance multi-nuclide removal system	High performance	90	Number of vessels	
	Used columns from multi-nuclide removal system	Existing	17	Number of Columns	
	Used vessels and filters from mobile treatment systems		240	Number of vessels	

Waste sludge

Storage place	Stored volume (m^3) / storage capacity (m^3) (Percentage)
Sludge storage facility (indoor)	423 / 700 (60%)

Concentrated liquid waste

Storage method	Stored volume (m^3) / storage capacity (m^3) (Percentage)
Concentrated liquid waste storage tanks (outdoor)	9,517 / 10,300 (92%)



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

Fig. 21 Summary of waste hierarchy at the NDA, and countermeasures at the Fukushima Daiichi NPS

b. 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. The outcome of the analysis methods for simplified and sped-up data acquisition, which have been studied, had its validity confirmed for use as standard analysis methods at the Radioactive Material Analysis and Research Facility Laboratory-1 of JAEA, using simulated samples. Applying the same analysis methods to rubble samples collected from Fukushima Daiichi NPS resulted in confirming that the results obtained are equivalent to those of the validity evaluation test, and demonstrating the applicability to real samples. Moreover, to obtain analytical data on high activity waste, the sorption sampled from the cesium sorption vessel (KURION and SARRY) at the Fukushima Daiichi NPS site has been transported to facilities for analysis in the Ibaraki area, and studies for analysis methods are accordingly in progress.

For storage/management, nuclide distribution behavior when melting and decontaminating contaminated metals for volume reduction and reuse technology of metal waste and the inspection method after melting processing is being studied.

As for the processing technology, the prospects of the practical application of normal-temperature processing technology were confirmed through full-scale tests, the mechanism of quick setting of Portland cement that occurred in said tests with the normal-temperature processing technology of ALPS carbonate slurry was clarified, and further examinations are underway on the inspection methods for verifying the possibility of solidification and evaluation methods of the stability of solidified waste (leaching characteristics, long-term alteration phenomenon, radiological impact, etc.) produced by various processing technologies. To contribute to the expansion of technological options (such as expanding the scope of application of normal-temperature processing technologies), confirmation is underway on waste with a significant weight reduction rate and for which mineralization is possible based on basic tests of pyrolysis considered as a candidate of interim processing technologies. At the same time, efforts are made to confirm the applicability through a full-scale test and to stabilize the treatment residue that was generated. To develop a policy for solidifying ALPS slurry, etc., TEPCO has updated its analysis plan[43] and is putting priority on arranging information about the characteristics of waste required in developing the policy. TEPCO is also working on confirming the applicability of bulk solidification technologies for a large amount of miscellaneous rubble that contains hazardous materials, etc., and the technology to process ALPS carbonate slurry dehydrates and the entire container storing the dehydrates. These efforts are a preliminary study to flexibly and rationally address issues anticipated in the immediate decommissioning work.

Concerning disposal technology, key scenarios that may significantly affect the feasibility of radioactive waste disposal are identified to understand the needs required in disposal concepts based on said scenarios, etc. Disposal concept options are also established as measures to address the needs, and efforts are underway to advance the technology for developing said options.

3.2.3 Key issues and technical strategies

The Mid-and-Long-term Roadmap stated that the characterization of solid waste would be promoted, and the specifications of waste form and their production methods will be determined in Phase 3. Therefore, in coordination among the areas of characterization, storage/management, processing, recycling and disposal, the following study will be conducted to present appropriate overall measures for detailed solid waste management approaches while reviewing the necessary R&D tasks. In conducting the study, it is important to summarize the results and the status of studies of past R&D in each field from characterization to disposal (Attachment 14).

- The first step is to identify options for each area in the individual waste stream by examining draft options in the areas of storage/management, processing, recycling and disposal (Fig. 22).

[43] The Analysis Plan of Solid Waste for Decommissioning of TEPCO’s Fukushima Daiichi NPS

- Then, using the property data, etc., that are becoming clear and repeating examinations by mutually feeding back research results in each field, the characteristics of the draft individual waste stream options with recognized safety and feasibility will be evaluated, thereby accumulating the draft options (Fig. 22 and Fig. 24). This examination will also identify and summarize issues in the R&D tasks of each field, as well as issues, etc., related to the management of solid waste.
- All draft individual waste stream options will be integrated, and then, evaluated and examined the results, and narrowed down to establish a waste stream, thereby presenting appropriate overall measures on solid waste management.

Institutions concerned, led by NDF, are promoting technical studies on integrated measures from characterization to storage/management, processing, recycling and disposal of solid waste based on their respective roles.

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 institutions concerned 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. An 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 supporting them, should also be considered.

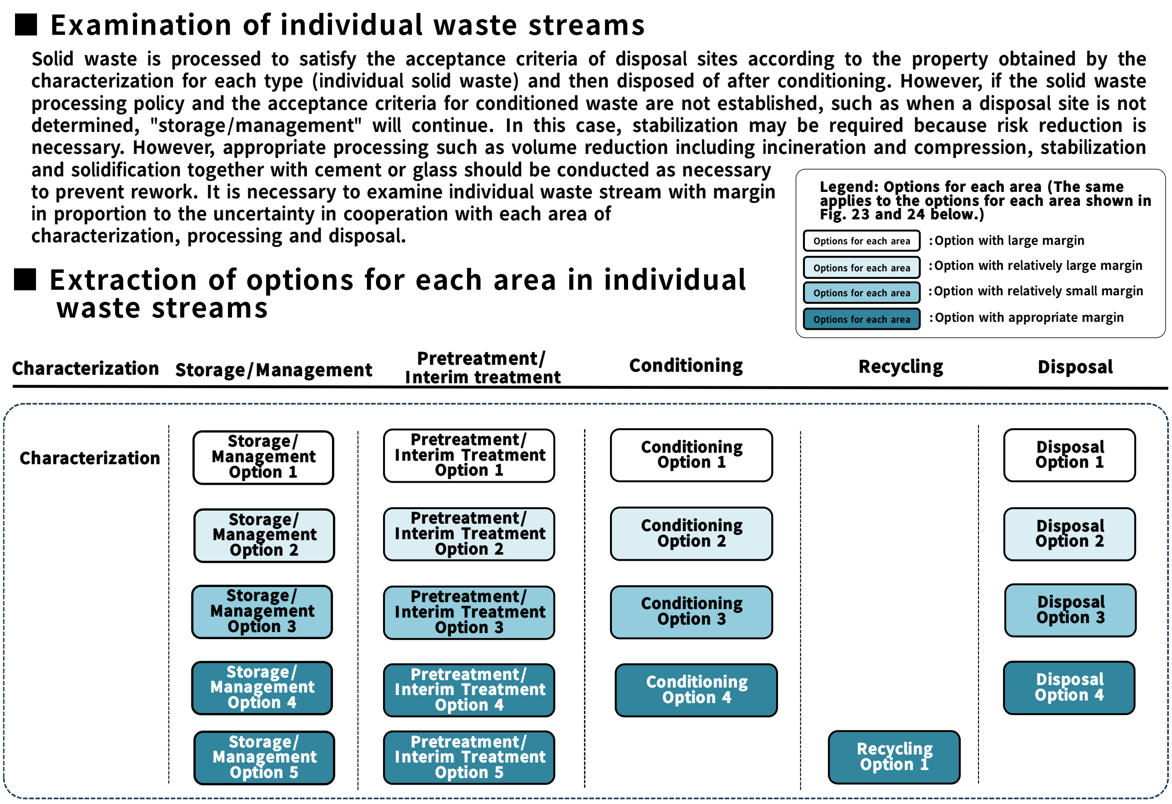


Fig. 22 Needs for examination of individual waste stream and identification of options for each area of waste management

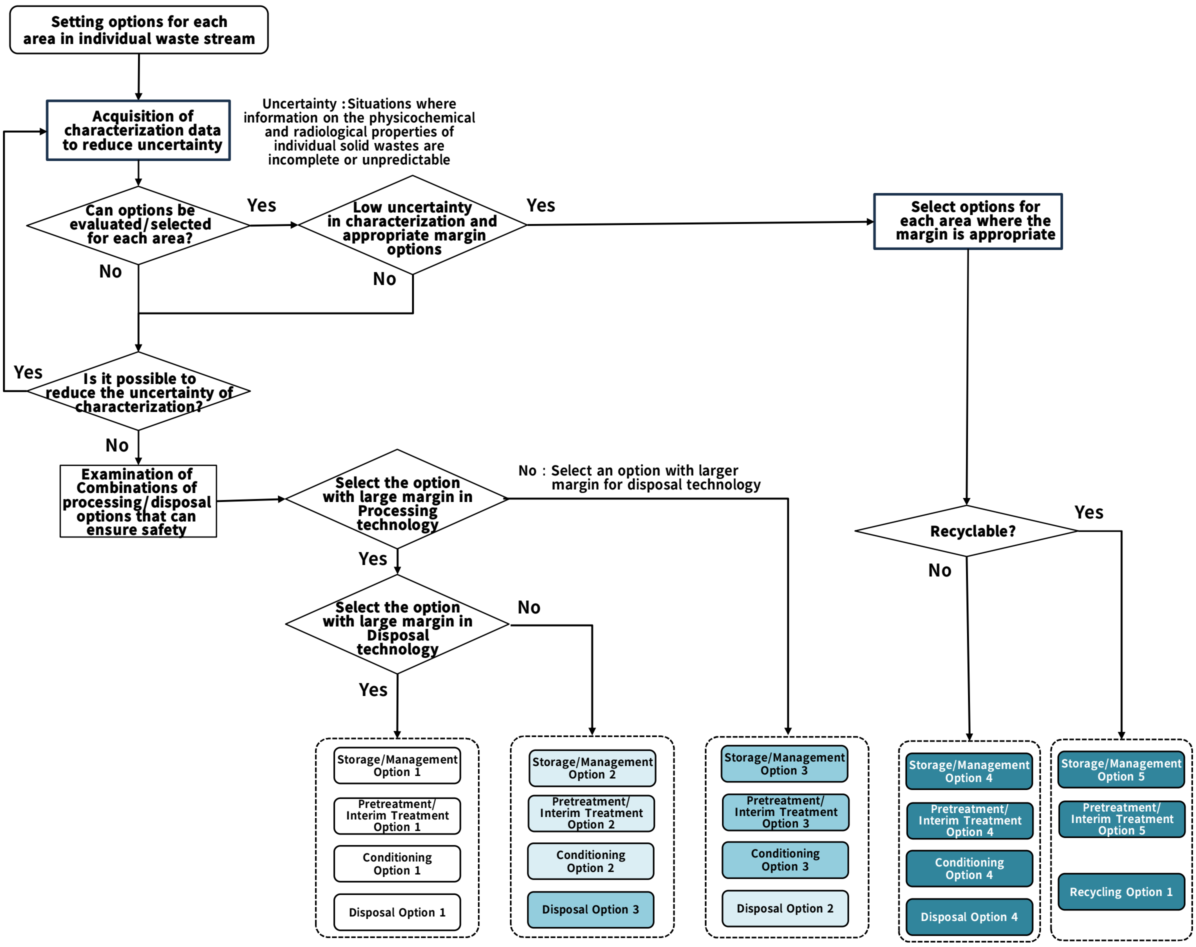


Fig. 23 Concept of option setting for each area of waste management in individual waste stream

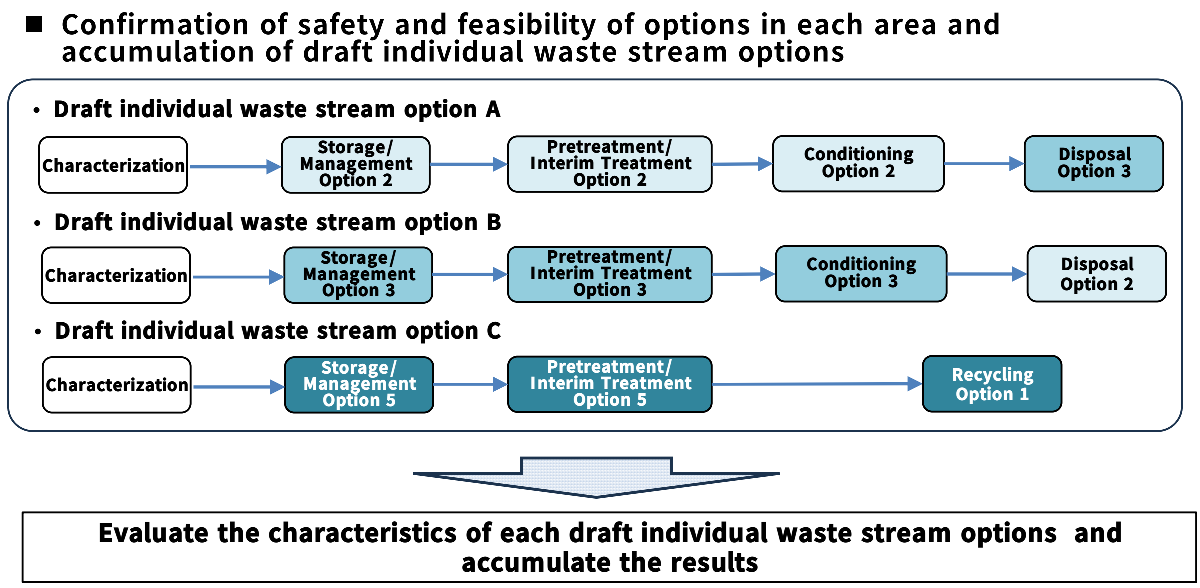


Fig. 24 Evaluation and accumulation of draft individual waste stream options

3.2.3.1 Characterization

a. Acquisition and management of analysis data

While accumulating analytical data, inventory for solid waste will be continuously improved, which is the basic information for solid waste management, including processing/disposal. In this case, efforts will 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.

Although the analysis work itself is not difficult, low-activity waste has the feature of enormous volume. And the limited number of analysis data obtained for high-activity waste due to the difficulty of sampling. Considering their features, analysis of such waste makes it important to take an approach that ensures the required accuracy efficiently. For these issues, efforts to establish an efficient analysis project approach that combines the DQO process[44] with statistical methods are underway and will continue.

In addition, the development of technologies necessary for the analysis of samples collected from cesium sorption apparatus, waste generated from fuel debris retrieval, and difficult-to-measure nuclides will be promoted.

b. Developing a framework for improving analysis capabilities and steady implementation of analyses

Efforts are being made to improve facilities, develop human resources for analysis, and pass on and strengthen analysis techniques capabilities to promote characterization steadily. Capacity of analysis has been enhanced with the completion of Radioactive Material Analysis and Research Facility Laboratory-1 of JAEA in June 2022. With that capacity in mind, analyses contributing to solving issues in the decommissioning process will be performed systematically, considering the priority of samples.

The Project of Decommissioning, Contaminated Water and Treated Water Management is promoting the development of mid-to-long-term analysis strategies; annual analysis planning; data acquisition and analysis; the incorporation of the acquired data into an examination of processing/disposal methods and an evaluation of the outcome; the development of the next mid-to-long-term analysis plans based on the evaluation results; and the establishment of a flow. As acquired data should be used for overall waste management, TEPCO should provide comprehensive management of solid waste characterization, including adjustment of the analysis supply chain[45].

In March 2023, TEPCO developed an analysis plan for the characterization and optimization of storage/management to examine solid waste processing and disposal methods, as well as

[44] Method for planning the sampling of analytical samples for decision making developed by the U.S. Environmental Protection Agency.
[45] The entire process of securing facilities for sampling and analysis, transporting samples, etc.

recycling measures. The plan was updated in March 2024 to present priority analysis targets and processes, as well as the nuclides to be analyzed. Examples include the examination of model cases on dismantling, the development of a method for managing rubble radioactivity concentration, and the development of a policy for solidifying secondary waste generated by water treatment, etc. Based on the plan, the following will be addressed in cooperation with the JAEA:

- Incorporate into detailed analysis work,
- Review the analysis plan,
- Identify the details of necessary technical development tasks, and
- Establish the operational structure of the analysis supply chain early.

Radioactive Material Analysis and Research Facility Laboratory-1 of JAEA started analysis work using radioactive materials in October 2022. The simplified and speed-up analysis techniques that have been developed as standard analysis methods completed their demonstration process by the end of FY 2023, and have entered into full-scale use from FY 2024. Moreover, TEPCO's new facility for analysis is scheduled to be operational in the second half of the 2020s. An analysis supply chain will be developed and operated systematically with due consideration for the appropriate role allocation of the solid waste-related facility for analysis, including the Ibaraki area, based on the above analysis plan and emerging analysis needs in the decommissioning process.

3.2.3.2 Storage/management

Storage/management of solid waste should be appropriately implemented for the risk depending on the 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.

a. Transition to management by classification of radioactivity concentration

Currently, waste is stored/managed by classification based on the surface radiation dose rate because a large amount of rubble is contaminated by fallout. In preparation for the expected increase in the amount of solid waste generated with the progress of decommissioning, it will transit to the management of solid waste based on the concentration of radioactivity and examine the rational classification of waste and recycling on-site.

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

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

b. Efforts to eliminate temporary outdoor storage

The Mid-and-Long-term Roadmap calls for eliminating temporary outdoor storage of all solid waste, excluding secondary waste generated by water treatment and waste subject to recycling and reuse, by the end of FY 2028. To achieve this goal, it is necessary to develop necessary facilities and installations systematically including incineration/volume reduction facilities and solid waste storage, and promote steadily consolidate storage of solid waste inside buildings. In addition, taking into account the views[46] of the Study group on Monitoring and Assessment of Specified Nuclear Facilities and the Technical Meeting on the Examination of the Implementation Plan of the Measures for the Specified Reactor Facilities, regarding the practicality and rationality of storage of low-level concrete and other waste, it is important to examine the storage/management methods which are safe, reasonable and feasible, such as classification according to the characteristics of the main nuclides with views to long-term processing/disposal method and recycling measures.

c. Storage/management of ALPS slurry

Although there is a delay in installing the ALPS slurry stabilization/treatment system, the immediate storage capacity has been secured. The upper limit of the integrated absorbed dose (5,000 kGy) will be evaluated to exceed before the commencement of the stabilization process, and the HICs that needed to be transferred continuously increased. To ensure storage capacity for HIC and transfer for the time being and to transit to a more stable state, stabilization/treatment system installation and processing will proceed in a planned manner.

d. Storage/management of solid waste generated from fuel debris retrieval

With regard to high-activity waste such as waste generated from fuel debris retrieval, the issues and countermeasures assuming further expansion of the retrieval scale have been clarified according to the results of Project of Decommissioning, Contaminated Water and Treated Water Management up to FY 2021. Going forward, reviews will be performed along with

[46] NRA, Material 3-1: “Approach to Solid Radioactive Material Target in Medium-term Risk Reduction Target Map”, The 107th Committee on Oversight and Evaluation of Specified Nuclear Facilities, April 14, 2023

examining the fuel debris retrieval methods. Measures will be taken to ensure the storage/management of solid waste expected to be generated during fuel debris retrieval (trial retrieval, gradual expansion of fuel debris retrieval) before full-scale retrieval.

According to the preparatory works for fuel debris retrieval, it was estimated that at least 300,000 m^3 of waste would be generated, including that from dismantling the buildings around Units 1 to 4, and resin and other waste generated before the earthquake, regardless of the fuel debris retrieval method[47]. It is not expected that this amount of waste can be reduced in volume by incineration and volume reduction facilities. Although further examination is required, solid waste will continue to be generated during decommissioning work in the future, so only increasing storage capacity for solid waste will eventually reach the limit. First, it is essential to steadily continue measures for volume reduction implemented so far (Fig. 21) and examine further possibilities for volume reduction by referring to advanced cases overseas.

3.2.3.3 Processing/Disposal

Findings will be widely acquired by mutually feeding back research results in each field on individual waste streams, and the characteristics of draft individual waste stream options with recognized safety and feasibility will be evaluated and the results will be accumulated. The draft individual waste stream options will be integrated, and then, evaluated and examined the results, and narrowed down to proceed with examinations to establish an appropriate waste stream. To this end, the R&D of processing and disposal technologies required for the series of studies, as shown in Fig. 25, will be continued.

a. Processing technology

Regarding the normal-temperature and thermal processing technology for which R&D has been promoted:

- Evaluation of individual waste streams not yet considered for applicability,
- Evaluation of the stability, etc., of the solidified waste to be produced,

and other activities to address the above pending issues will continue.

As for normal-temperature processing technology, consideration will be given to the transformation of solidified waste as well as test methods to verify the possibility of solidification. Measures need to be examined to prevent the quick setting of Portland cement that occurred in a full-scale test of the normal-temperature processing of ALPS carbonate slurry. 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.

[47] TEPCO, Storage Management Plan for TEPCO’s Fukushima Daiichi Nuclear Power Station, November edition of 2023

Interim processing technologies are being developed, as a method that eliminates the need for rework when stabilization is required during storage, for the operational waste and secondary waste generated by water treatment which were affected by the earthquake disaster. The interim processing technologies require examinations on how to remove materials including in-core adhered materials generated from the pyrolysis processing of spent resin, impacted by seawater as a result of the accident, as well as the impact on the salinity-based solidification of residues.

Securing storage capacity is an issue for ALPS slurry constantly generated from water treatment. Thus, in light of the point at issue regarding the dehydrate technologies for ALPS slurry in the Study group on Monitoring and Assessment of Specified Nuclear Facilities and the Technical Meeting on the Examination of the Implementation Plan of the Measures for the Specified Reactor Facilities, the issues related to dehydration should be considered sufficiently to discuss requirements in selecting treatment technologies to be applied, with priority.

In addition to measures for the issue of establishing a medium-to-long-term waste stream, a study will be conducted as follows to address anticipated issues in the immediate decommissioning work flexibly and reasonably.

- As measures for a large amount of miscellaneous rubble, which is difficult to segregate and may contain hazardous materials etc., the potential of bulk solidification technologies for without the segregation will be examined. Collecting information on the segregation-based approach will also continue for consideration.
- The potential of technologies to process dehydrated ALPS slurry together with the container will be considered, simplifying the preprocess when processing dehydrated ALPS slurry produced in the slurry stabilization processing system where early installation is required, and eliminating the need for development associated with removal from containers.

b. Disposal technology

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

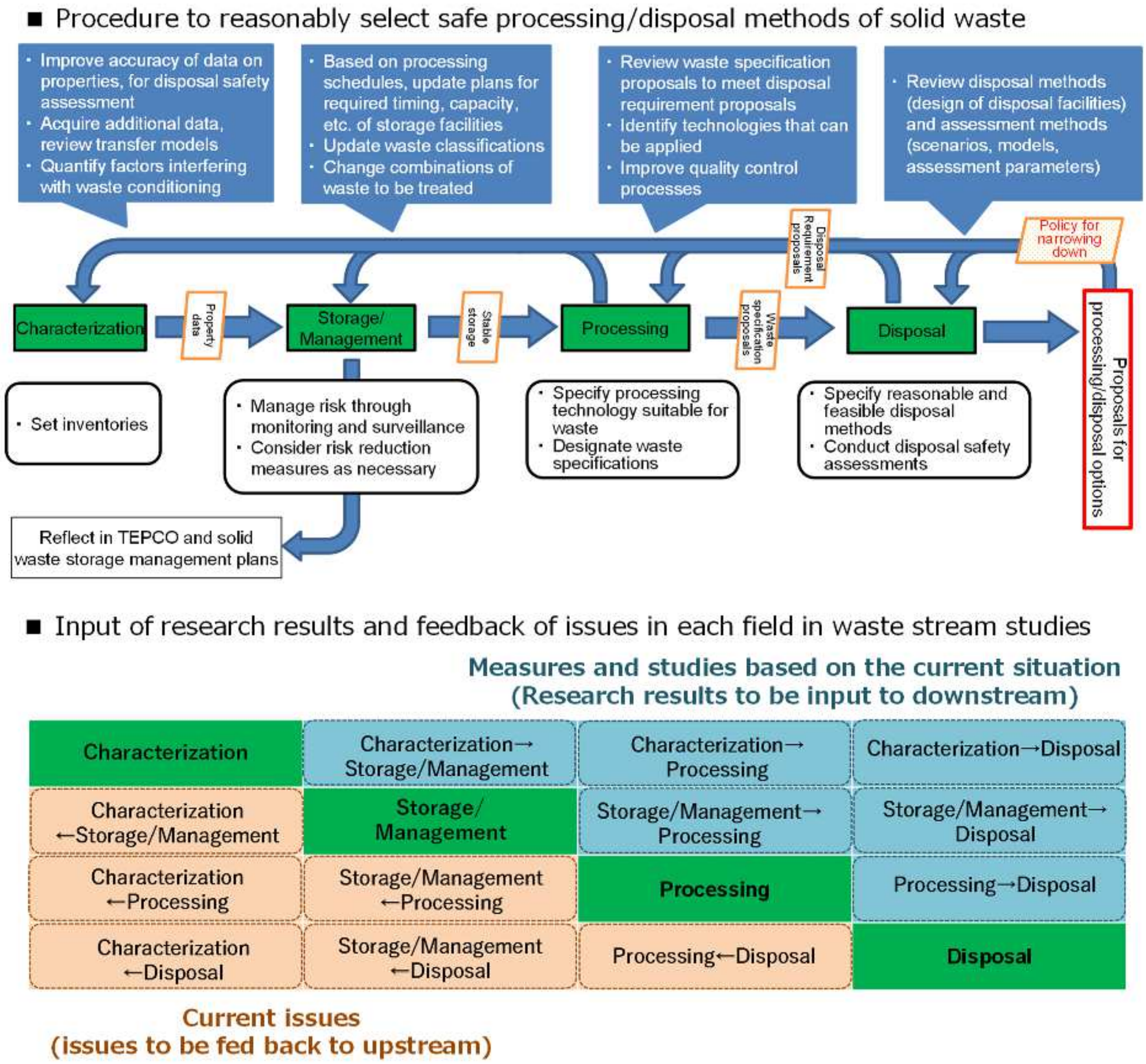


Fig. 25 Procedure to reasonably select safe processing/disposal methods of solid waste

3.2.4 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 promoted to present appropriate overall measures for detailed 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,

- Widely acquire findings by individual waste stream by accumulating trial examples of appropriate individual waste stream settings under the assumption of ensuring safety,

- Then, consideration will be given to specify appropriate overall picture covering the waste stream, in which all the draft individual waste stream options are integrated, and then, evaluated and examined the results, and narrowed down, allowing clarification of approaches toward such purposes.

In examining these, it is important to flexibly consider 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, in finalizing the processing/disposal methods for the overall picture of waste, it will be important to share the examination process for overall optimization, such as by sharing the awareness of problems with local communities and society.

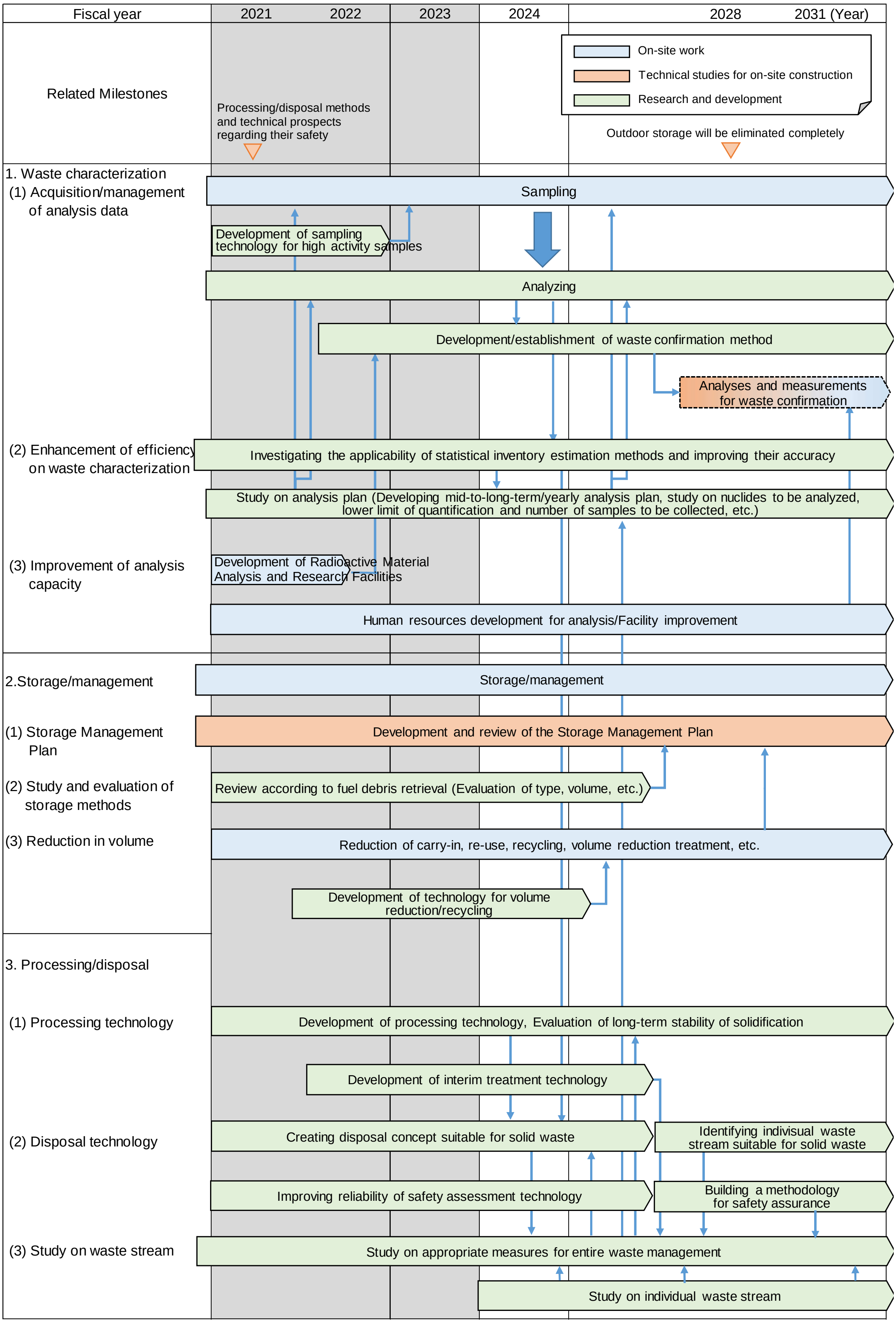


Fig. 26 Key technical issues and future plans on waste management (progress schedule)

3.3 Contaminated water and treated water management

3.3.1 Target

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), the target is to control the amount of contaminated water generated to less than 100 m^3/day or less with the average rainfall by the end of 2025, and about 50 to 70 m^3/day by the end of FY 2028, while continuing the operation of the constructed water-level management system. Moreover, to ensure the stable implementation of contaminated water management, measures for mitigating large-scale natural disaster risks, such as tsunamis and storm rainfall, will be implemented in a planned manner.

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 To discharge ALPS-treated water[48] safely and reliably to secure the site and other resources and steadily advance the entire decommissioning process.

3.3.2 Progress

As for the contaminated water issues, efforts have been made from the initial stage based upon the three principles (“Removing” the contamination source, “Redirecting” fresh water from the contaminant source, and “Retaining” contaminated water from leakage). Fig. 27 shows the outline of contaminated water management[49]. Stagnant water in buildings, that is, contaminated water with a mixture of cooling water that has come into contact with the fuel debris and groundwater and rainwater that leaked into the buildings, is liquid containing a considerable amount of radioactive materials (inventory). From the perspective of measures to reduce the risk from radioactive materials, the Requiring Level for Safety Management is at a high level.

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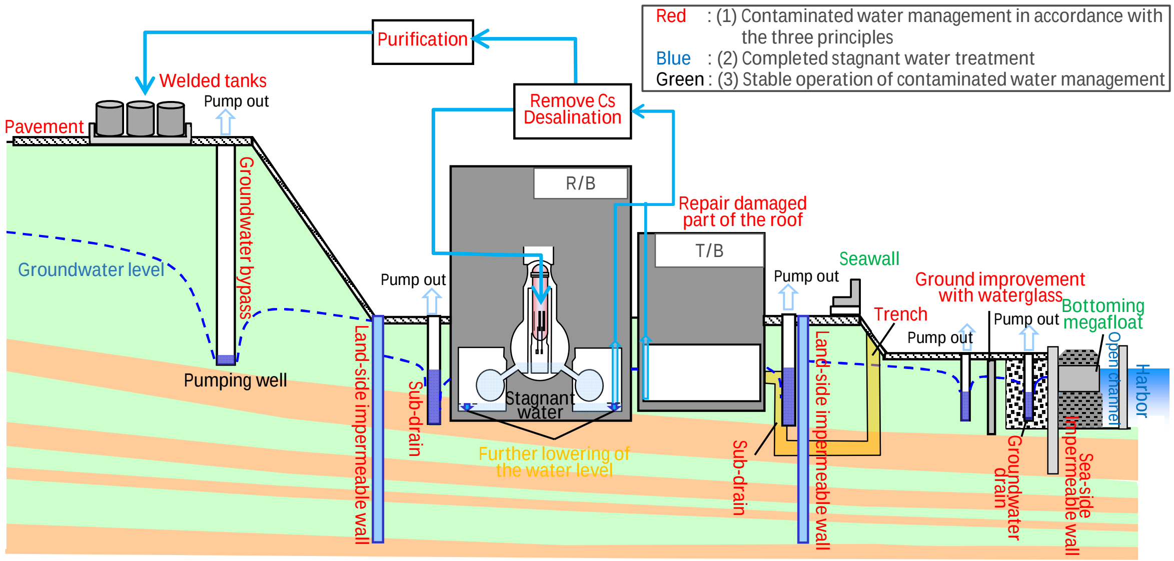
[48] Water that has been purified by multinuclide removal equipment systems (ALPS：Advanced Liquid Processing System), etc., to a level that is definitely below the regulatory standard for safety of radioactive materials other than tritium

[49] Material 2-1: “Outline of decommissioning, contaminated water and treated water management”, The 114th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, March 28, 2023



(Source : TEPCO material edited by NDF)

Fig. 27 Outline of contaminated water management

Said stagnant water in buildings is present in the reactor buildings of Units 1 to 3 where circulating water injection is ongoing, and in the process main building (hereinafter referred to as "PMB") and high-temperature incinerator building (hereinafter referred to as "HTI") storing contaminated water temporarily for purification treatment. The inventory has been significantly reduced (the milestone to "reduce the amount of stagnant water in the reactor buildings to about half of the level at the end of 2020" was achieved in FY 2022).

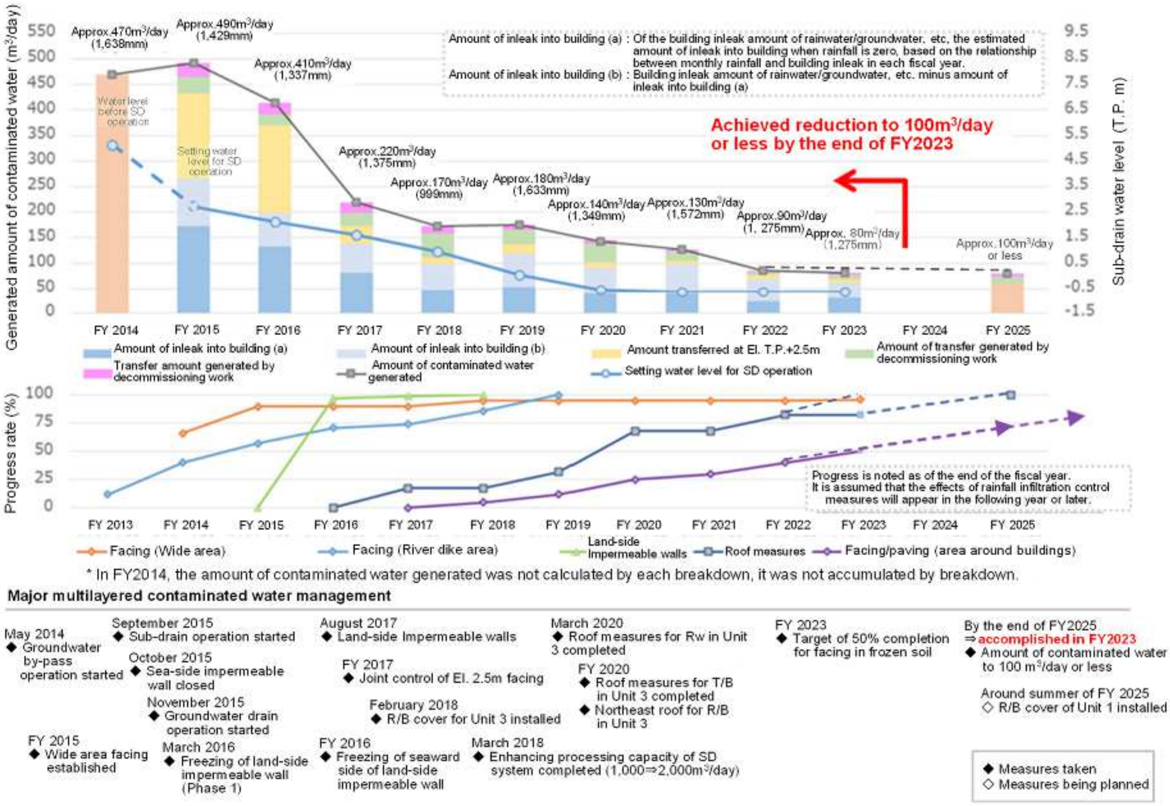
Currently, the following four measures are primarily being implemented as contaminated/treated water management:

a. Efforts to reduce the amount of contaminated water generation

The primary factor behind the increase in contaminated water is the groundwater and rainwater that leak into buildings, and measures are underway to limit these. 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, along with the prevention of rainwater infiltration by repairing damaged roofs and facings on site. (Entire vicinity area of Units 1 to 4 buildings: Completed approximately 50% out of approximately 60,000 m^2 in February 2024.) This has led to a controlled trend in the amount of contaminated water generated during rainfall. As a result, even if FY2023 saw rainfall-adjusted contaminated water generation of approximately 90 m^3/day (adjusted to an average rainfall-equivalent level because the annual rainfall was approximately 200 mm less than the approximately 1,470 mm average year level), achieving the Mid-and-Long-term Roadmap's goal of "approximately 100 m^3/day or less by the end of 2025" two years ahead of time.

With the aim to limit the amount of contaminated water generated to about 50 to 70 m^3/day by around the end of FY 2028, examinations are underway for local water sealing in the exterior wall of the buildings (water seal at the end of the gap between buildings[50]). The plan is to trial-operate at Units 5 and 6 in FY 2023, and expand the application to Unit 3 and others in FY 2024.

Fig. 28 shows the progress of contaminated water management and changes[51] in the amount of contaminated water generated.



(Source: TEPCO)

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

b. Efforts to complete stagnant water treatment in buildings

With the objective of reducing the risk of off-system leakage of stagnant water in the reactor building, efforts have been made to reduce the stagnant water inventory in the buildings (lowering the level of stagnant water in the buildings), the concentration of radioactive materials contained in stagnant water, and the amount of contaminated water generated. As a result, in addition to completing the exposing of the building floors in FY 2020 except for the reactor buildings in Units 1 to 3, the PMB, and the HTI, FY 2022 saw the achievement of a milestone in the Mid-and-Long-

[50]Water seal at the end of the gap between buildings (the gap between the exterior walls formed when constructing buildings next to each other around the reactor building, in which penetration sites of piping are present).

[51] Material 3-1: "Groundwater level in the vicinity of the reactor buildings, Status of contaminated water generation" The 125th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, contaminated water and treated water; April 25, 2024

term Roadmap: to reduce the amount of stagnant water in the reactor buildings in FY 2022 to 2024 to about half of the level at the end of 2020. Currently, the following measures continue to be implemented:

- Study on a method to recover the sludge located on the floor in the turbine buildings in Units 1 to 4 where the exposing of the floor was completed.
- Preparation for recovering the zeolite sandbags located on the lowest floor to complete the stagnant water treatment in the PMB and the HTI.

c. Efforts for stable operation of contaminated water management

As measures to reduce tsunami-associated risks, the construction of the Kuril Trench tsunami seawalls was completed in September 2020, the measures for closing building openings were completed in January 2022, and work to install the Japan Trench tsunami seawalls was completed in March 2024. Efforts are ongoing to maintain and reinforce the land-side impermeable walls, relocate the sub-drain and other water collection systems from the revetment side to higher ground, and transfer waste sludge to higher ground, among other endeavors. As for a measure against heavy rain, the Drainage Channel D has been in service since August 2022 to eliminate the risk of inundation in the vicinity of Units 1 to 4, and the drainage function of the existing drainage channels has been enhanced systematically.

Although the importance of multilayered measures such as land-side impermeable walls has not changed, in light of the damaged installations and other factors, the management structure is being established, combining preventive maintenance and condition-based maintenance.

d. Efforts toward discharging ALPS-treated water into the sea

To discharge ALPS-treated water into the sea, TEPCO completed its installation of ALPS-treated water dilution/discharge facilities and related installations in June 2023, underwent a pre-service inspection by the Nuclear Regulation Authority, and received a certificate of completion in July 2023. Previous efforts toward discharging ALPS-treated water into the sea are described in Attachment 15.

At the meeting of the Inter-Ministerial Council concerning Decommissioning, Contaminated Water, and Treated Water Management (6th) and the meeting of the Inter-Ministerial Council concerning the Continuous Implementation of the Basic Policy on Handling of ALPS Treated Water (6th) held on 22 August 2023, the entire government confirmed the status of efforts to date on safety assurance and reputational measures related to the disposal of ALPS-treated water, and the ALPS-treated water started to be discharged to the sea on August 24, based on the proposed exact timing of the discharge of the water into the sea[52].

[52]Prime Minister’s Office of Japan website, https://www.kantei.go.jp/jp/singi/hairo_osensui/dai6/siryou2.pdf

Since the first discharge in August 2023, a total of 8 discharges have been performed in about a year. Table 4 shows the results[53]. The total amount of ALPS-treated water discharged to date was about 63,000 m^3, and the amount of tritium discharged was about 10 trillion Bq.

Table 4 Result of ALPS-treated water discharge

Fiscal year	Time of discharge	Period	Pre-dilution tritium concentration	Concentration of radionuclides other than tritium (Total notification concentration ratio)	Post-dilution tritium concentration	Amount of discharge	Total amount of tritium
FY2023	First	Aug 24 to Sep 11 2023	140 K Bq/L	0.28 (≤1)	220 Bq/L	7,788m^3	Approx. 1.1 tn Bq
	Second	Oct 5 to Oct 23 2023	140 K Bq/L	0.25 (≤1)	189 Bq/L	7,810m^3	Approx. 1.1 tn Bq
	Third	Nov 2 to Nov 20 2023	130 K Bq/L	0.25 (≤1)	200 Bq/L	7,753m^3	Approx. 1.0 tn Bq
	Fourth	Feb 28 to Mar 17 2024	170 K Bq/L	0.34 (≤1)	254 Bq/L	7,794m^3	Approx. 1.3 tn Bq
FY2024	First	Apr 19 to May 7 2024	190 K Bq/L	0.31 (≤1)	266 Bq/L	7,851m^3	Approx. 1.5 tn Bq
	Second	May 17 to June 4 2024	170 K Bq/L	0.17 (≤1)	234 Bq/L	7,892m^3	Approx. 1.3 tn Bq
	Third	Jun 28 to Jul 16 2024	170 K Bq/L	0.18 (≤1)	276 Bq/L	7,486m^3	Approx. 1.3 tn Bq
	Fourth	Aug 7 to Aug 25 2024	200 K Bq/L	0.12 (≤1)	267 Bq/L	7,897m^3	Approx. 1.6 tn Bq

The tritium concentration is confirmed pre-dilution and ahead of the discharge of ALPS-treated water into the sea. At the same time, in analyses to confirm that non-tritium radioactive materials have been purified until they are reliably under safety regulation standards, not only TEPCO but also third parties conduct analyses as per the “Summary of Immediate Measures”[54] based on the government’s “Basic Policy on Handling of ALPS Treated Water,”[55] thereby conducting highly objective and transparent measurements. More specifically, as the red area in Fig. 29 shows, a cross-checking-capable system is made available by commissioning analyses to KAKEN as an analytical laboratory independent from TEPCO, in addition to Tokyo Power Technology to which analyses are commissioned by TEPCO. As an effort based on government policies, the JAEA Okuma Analysis and Research Center also analyzes the treated water, from the standpoint of a third party with expertise in analyzing radioactive materials. Each laboratory analyzes the concentration of tritium and that of the nuclides to be measured and evaluated in the pre-diluted ALPS-treated water, and the results are promptly and transparently disclosed on TEPCO’s treated water portal site[56]. The number of nuclides to be measured and evaluated was 29 until

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[53] TEPCO; Reference: “Completion of the 4th discharge of ALPS treated water at Fukushima Daiichi Nuclear Power Station in FY2024,” August 26, 2024

[54] Material 3: “Summary of Immediate Measures Associated with Handling of ALPS Treated Water at the TEPCO Fukushima Daiichi Nuclear Power Station (draft)”, The Meeting of the Inter-Ministerial Council concerning the Continuous Implementation of the Basic Policy on Handling of ALPS Treated Water (2nd),” August 24, 2021

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

[56] Treated water portal website, https://www.tepco.co.jp/decommission/progress/watertreatment/

the 3rd discharge in FY 2024 as shown in Table A15-2 in the attachment, but it was increased to 30 in total from the 4th discharge in FY 2024 as cadmium-113m was added in response to the detection of cadmium-113m in significant amounts during the analysis of contaminated water prior to ALPS treatment conducted in February 2024. Note that TEPCO has been voluntarily assaying cadmium-113m and other nuclides prior to discharge into the sea, confirming that the concentration of cadmium-113m is less than 1/500 of the regulatory concentration limit every time, and there is no problem with the safety of the ALPS-treated water that was discharged.

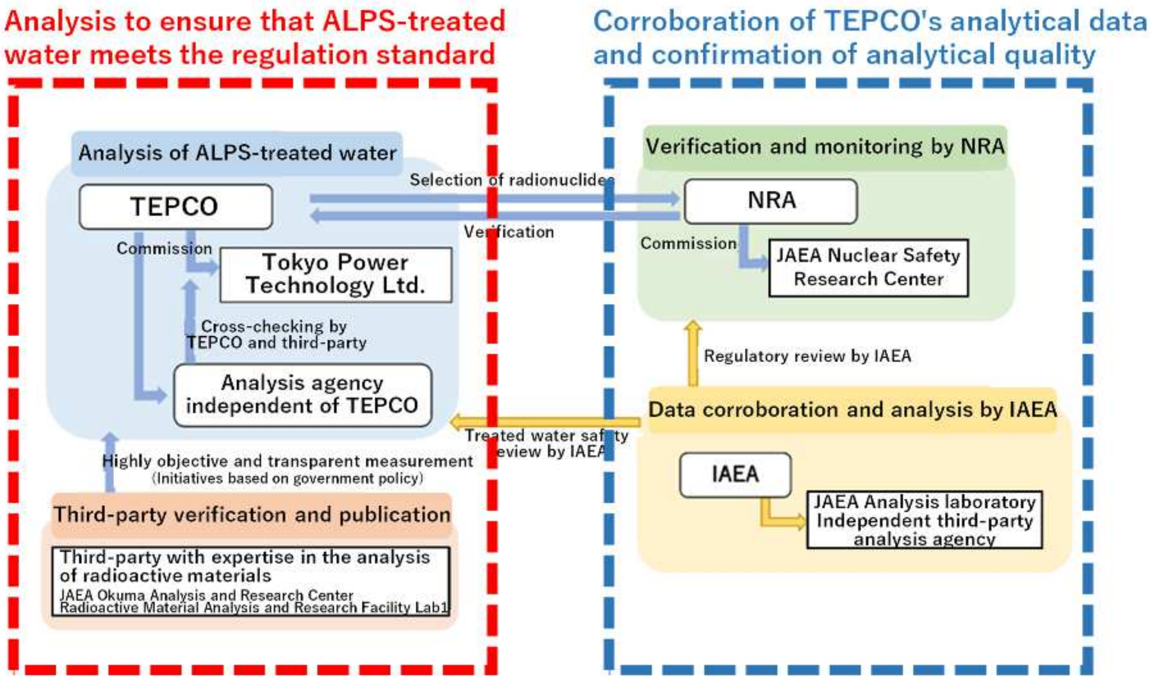


Fig. 29 ALPS-treated water analysis and evaluation structure [57] (NRA material edited by NDF)

(Source: TEPCO)

Fig. 30 shows the outline of ALPS-treated water dilution/discharge facilities. In the first three discharges in FY2023, the validity of the calculated values[58] was confirmed through the following two phases for the post-dilution tritium concentrations of the treated water:

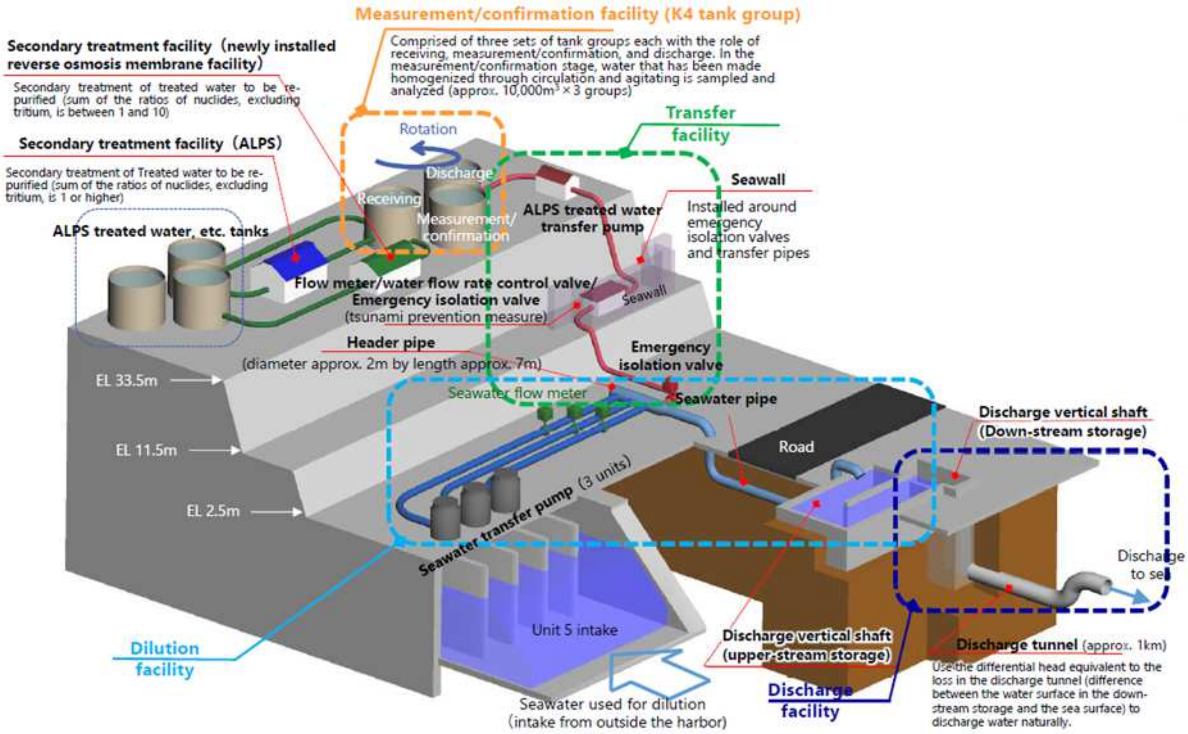
- Temporarily retain the post-dilution treated water in the discharge pit (upstream tank) for a tritium concentration measurement before release, and release it after confirming that the water has been diluted as planned (phase one).

[57] Material 1-1: Attachment 2 ALPS-treated water analysis structure, The 101st S Committee on Oversight and Evaluation of Specified Nuclear Facilities, July 25, 2022

[58] Post-Dilution Concentration = Pre-Dilution Concentration × Treated Water Flow Rate / (Treated Water Flow Rate + Seawater Flow Rate)

- For the post-dilution tritium concentration during discharge, collect water daily from the downstream of the seawater piping header to measure the concentration of tritium and confirm that the water has been diluted as planned (phase two).

The three discharge results allowed for confirming that the dilution-mixing with the seawater piping header was performed as designed and that the calculated and measured tritium concentration values following dilution/discharge showed no significant difference. The phase one confirmation was thus temporarily ended after the 4th discharge in FY2023, arrangements were made to make phase one confirmations in alignment with a simple (annual) inspection of the seawater transfer pumps to confirm that no change has occurred in the condition of the installations[59].



(Source : TEPCO)

Fig. 30 Overview of ALPS-treated water dilution and discharge facility

For marine monitoring, as per the Comprehensive Monitoring Plan[60] of the government, Japan's Ministry of the Environment, the NRA, Fukushima Prefecture, TEPCO, etc. are collaborating to sample seawater, seabed soil, and marine organisms from the sea area near Fukushima Daiichi to the open sea area within a 300 km radius to measure the radioactive

[59] Material 3-1: "Status of Discharge of ALPS-Treated Water into the Sea," The 121st Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, contaminated water and treated water, December 21, 2023

[60] The Monitoring Coordination Council (16th), handout, "Comprehensive Monitoring Plan" (revised on March 21, 2024)

material concentration. Regarding the tritium concentrations in the seawater at 10 locations in the vicinity of the NPS (within 3 km from the harbor) and at four points within a 10 km × 10 km range from the front of the NPS shown in Fig. 31, monitoring to promptly obtain results by raising the detection limit to about 10 Bq/L (prompt measurement) has been conducted, and enhanced monitoring with increased measurement frequency is applied at the 10 locations within 3 km of the harbor in particular during discharge and for one week after discharge is completed.

Table 5 shows the results of prompt seawater tritium concentration measurements from eight discharges conducted to date[61].

Each surveillance point has, as operational indicators, levels for judging discharge suspensions and surveillance levels. All points have seen their values stay below the detection limit or at more than one digit below the indicator, showing that the discharge into the sea thus far has been safely performed as planned.

In October 2023, the IAEA Task Force conducted the first safety review mission on the ALPS-treated water following the discharge into the sea, and its report was disclosed on January 30, 2024[62.] The report concludes the Task Force has confirmed that equipment and facilities are installed and operated in approaches that conform with the implementation plan and related international safety standards.

Regarding TEPCO's organization and system related to the discharge of ALPS-treated water into the sea, thus far the ALPS-treated water Program Department has handled processes from planning to equipment installation and operation. To safely and steadily, as well as to systematically and rationally discharge ALPS-treated water into the sea over a long period, the Water Treatment Center consolidating the groups for planning, design, construction, and maintenance of the entire water treatment process has been freshly established in July 2024.

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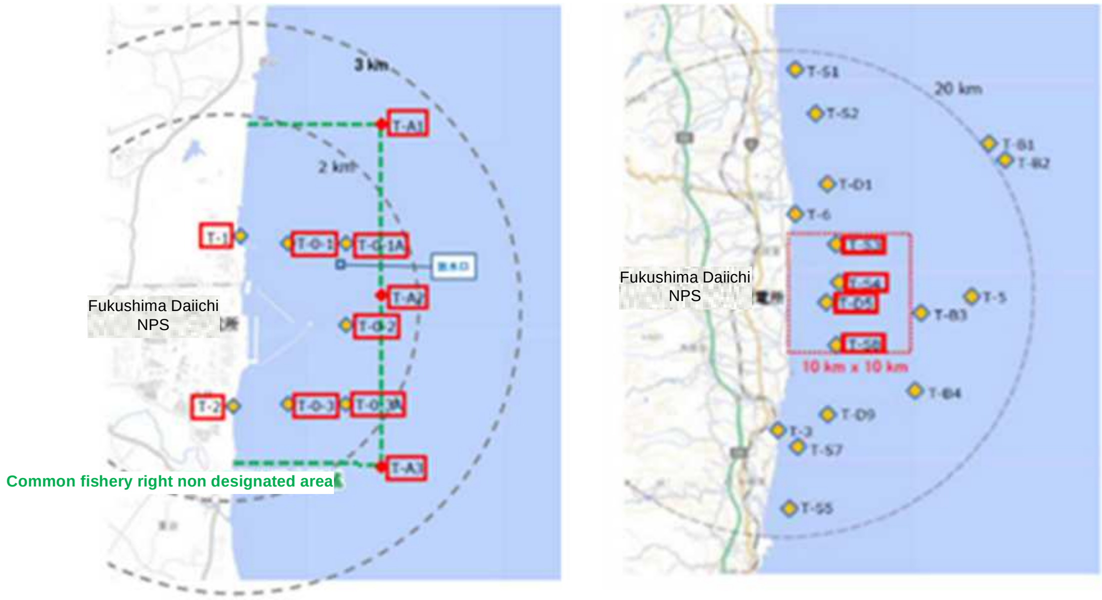
[61] Treated water portal site
https://www.tepco.co.jp/decommission/progress/watertreatment/performance_of_discharges/

[62] IAEA Review of Safety Related Aspects of Handling ALPS-Treated Water at TEPCO's Fukushima Daiichi Nuclear Power Station, Report 1: First Review Mission to Japan after the Start of ALPS Treated Water Discharge (October 2023), January 2024



(a) Vicinity of power station (within 3 km outside the harbor)

(b) 10 km square in front of the NPS

Fig. 31 Sampling points of prompt measurements (seawater)

Table 5 Results of prompt measurement of tritium concentration in seawater

Measurement point			Within 3km from the NPS (10 locations)	Within a 10km square from the front of the NPS (Four locations)
Operational indicator	Level for judging discharge suspension		700 Bq/L	30 Bq/L
	Surveillance level		350 Bq/L	20 Bq/L
Result of prompt measurement	FY2023	First	Max. 10 Bq/L	Below detection limit
		Second	Max. 22 Bq/L	Below detection limit
		Third	Max. 11 Bq/L	Below detection limit
		Fourth	Max. 16 Bq/L	Below detection limit
	FY2024	First	Max. 29 Bq/L	Below detection limit
		Second	Max. 7.7 Bq/L	Below detection limit
		Third	Max. 18 Bq/L	Below detection limit
		Fourth	Max. 9.0 Bq/L	Below detection limit

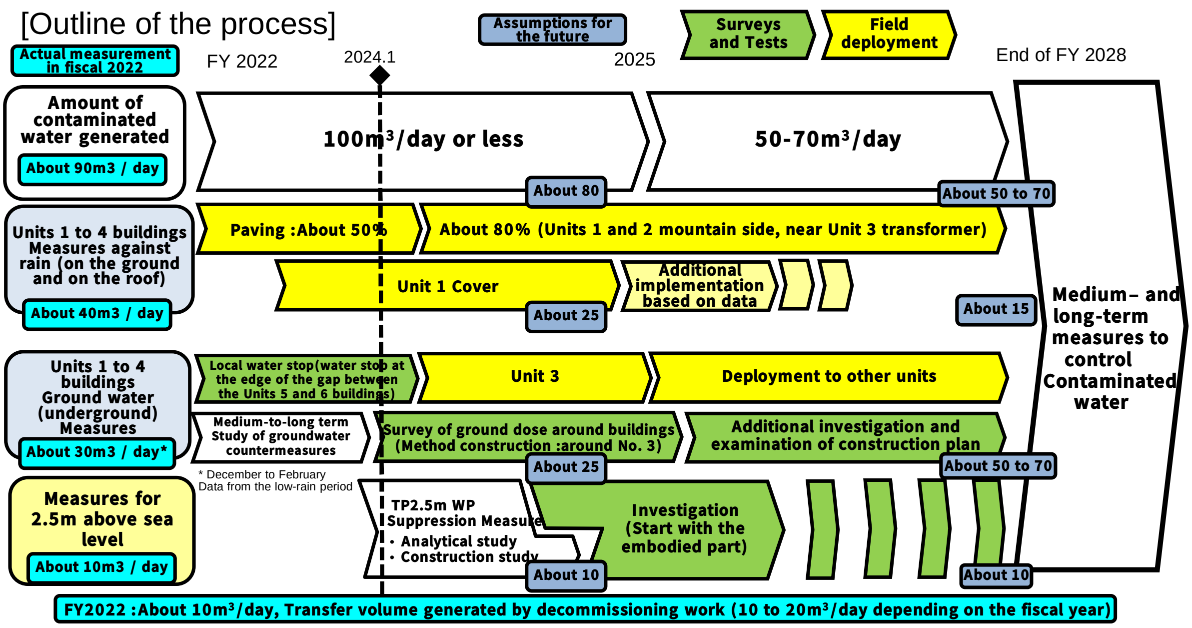
3.3.3 Key issues and technical strategies

3.3.3.1 Control of contaminated water generation amount

Fig. 32 shows the outline for measures to control the amount of contaminated water generation[63].

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

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



(Source: TEPCO)

Fig. 32 Outline for measures to control the amount of contaminated water generation

[63] Material 2: "The Present State of Measures to Control Contaminated Water," The 27th Committee on Countermeasures for Contaminated Water Treatment, January 30, 2024

Here, the penetration in exterior walls and gaps (50 to 100 mm) between buildings, which are likely the main factors of groundwater inflow into buildings, has a depth distribution as shown in Fig. 33. Especially in the gaps between buildings, there are nearly 200 sites of penetration at T.P. -0.65 m (Fig. 34)[63], the current sub-drain water level (L value). If the water level is lowered to the assumed future groundwater level (about T.P. -1 m), the number of penetration sites will be reduced by almost half, which is expected to reduce the inflow to buildings. However, there will still be nearly 100 penetration sites below T.P. -1 m.

To limit groundwater inflow from the penetration sites of these gaps, the plan is to establish a water seal part by boring holes at the ends of the gaps between buildings and filling them with mortar, etc. (Fig. 35) [63]. In FY 2023, test construction was started at the end of the inter-building gap between Unit 5 turbine building (T/B) and reactor building (R/B). As a result, it was found that boring can be performed within the target precision range, and the water sealing material could be filled up to the target height. In addition, as a result of comparing the inflow to the buildings before and after filling the water sealing material, as shown in Fig. 36, the amount was reduced from 30 to 50 m^3/day to 15 to 25 m^3/day for Unit 5 T/B and from 5 m^3/day to 1 m^3/day for Unit 5 R/B[64]. Note that the result for Unit 5 T/B includes inflow from sections to which water sealing hasn't been applied (Fig. 36 open circles).

Based on these, the plan is to check the construction method, workability, etc., for the inter-building gap between Unit 4 R/B and the waste underground storage building (FSTR), expand it to Unit 3 by FY 2025, and thereafter advance water seal work for the end of the inter-building gaps at other units aiming at achieving the end-of-FY 2028 goals (around 50 to 70m^3/day).

In examining the medium-to long-term contaminated water management, with study on the fuel debris retrieval methods underway for decommissioning, examinations need to be made considering the interference with retrieval tasks and related facilities, and specific study should be developed, while ensuring consistency with the progress of the entire decommissioning process, including the efforts to be made to summarize actual site applicability, technical feasibility, the consistency with the work plan, issues, and other factors (described in 3.3.3.3).

[64] Material 3-1-2: "Groundwater level around the building and generation of contaminated water", The 125th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, contaminated water and treated water, April 25, 2024

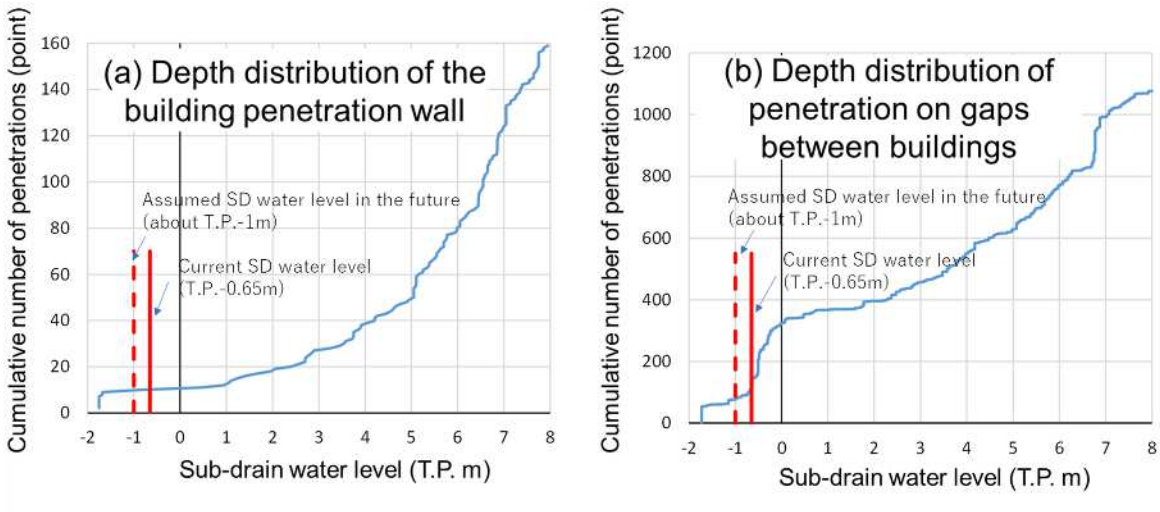


Fig. 33 Depth distribution of the building penetrations (TEPCO material edited by NDF)

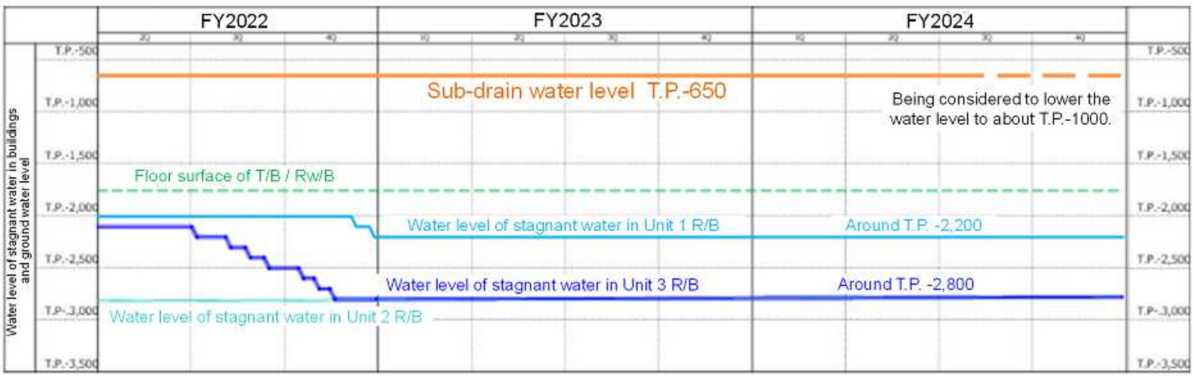


Fig. 34 Lowering of sub-drain and building water levels (TEPCO material edited by NDF)

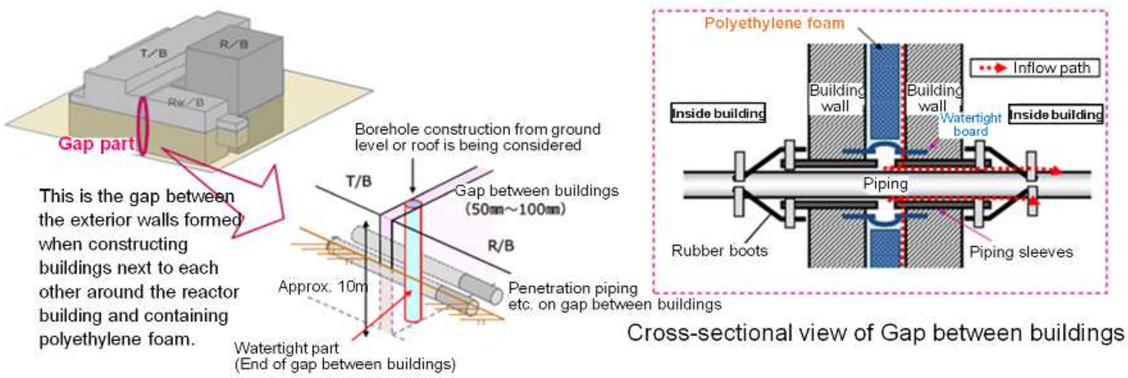


Fig. 35 Conceptual drawing of water sealing at the edge of the gap between buildings

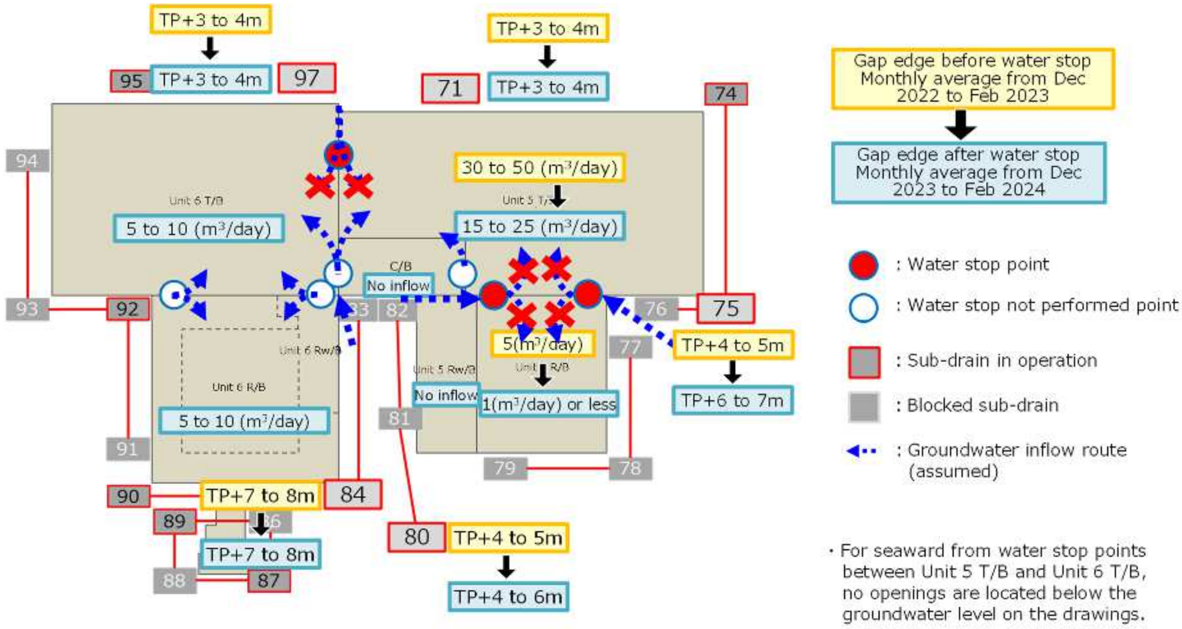


Fig. 36 Comparison of inflow into the building before and after the water stop at the edge of the gap of Unit 5

3.3.3.2 Treatment of stagnant water in buildings

a. Further reduction of stagnant water

Due to the presence of high-radiation dose sludge containing Cs and α-nuclides near the floor of the reactor building, there will be the following concerns when lowering the water level of the building excessively to reduce the stagnant water inventory in the building.

- Reduced shielding effect causes increased radiation dose and dust dispersion in the reactor buildings, deteriorating the work environment.
- If contaminated water with a radioactivity concentration several orders of magnitude higher than usual flows into a Cs sorption apparatus such as KURION and SARRY, the purification performance is significantly degraded.

Despite successfully reducing the amount of stagnant water in the reactor building to about half the level (approx. 3,000 m^3) at the end of 2020, further reduction requires examinations in integration with the fuel debris retrieval method. For example, even in the case of partial submersion method, the target for reducing the amount of stagnant water in the buildings differs depending on whether the inside of the building is to be dried up or the stagnant water is to be circulated and poured. Therefore, it is important to specify the ideal way of the stagnant water management in conjunction with the examination of the retrieval methods for further expansion of the retrieval scale for fuel debris.

b. Stagnant water treatment in the process main building and high-temperature incinerator building

Stagnant water is also stored in the basement floors of the process main building (PMB) and high-temperature incinerator building (HTI). A plan is to lower the water level to expose the floor surface of these buildings from FY 2024. The following actions are essential to achieving this.

- Recover zeolite sandbags with high-radiation doses placed on the basement floors of the PMB and HTI[65].
- Install temporary storage facilities for stagnant water instead of storage on the basement floor of the PMB and HTI[66].

The basement floors of both the PMB and the HTI contain high-radiation dose zeolite sandbags, which were placed shortly after the accident to improve the stagnant water quality (the maximum surface dose: approximately 4,400 mSv/h). Activated charcoal sandbags were also observed in the stair hall. Although the stagnant water is also a source of high radiation doses, exposing these basement floors will eliminate water shielding for zeolite sandbags with higher radiation doses, resulting in an expected significant rise in the radiation dose in the opening of the ground floors.

The currently considered work plan to recover zeolite sandbags is shown below. Fig. 37 shows an overview of the recovery task.

① Place a recovery ROV[67] at the basement floor, perform suction of zeolite, and transfer it to the collection spot.

② Transfer the zeolite and other collected materials to the ground floor with a container sealing task ROV. Desalinate and dehydrate them in the building, seal them in metal storage containers, and transfer them to temporary storage facilities.

Collection work will be highly challenging as it requires collecting high radiation dose objects in basement floors with narrow passages through remote operation. Therefore, the work needs to carefully proceed in steps, making improvements based on knowledge obtained through mock-up tests. As an example, a full-scale mock-up test found a reduction in visibility due to sludge being blown up and turbidity. It is necessary to reflect the findings in the actual collection work. The procedure can be applied to subsequent container sealing tasks and the recovery of high-radiation dose sludge deposited on the floor surface of the reactor building to be planned, providing critical knowledge for the future progress of decommissioning work.

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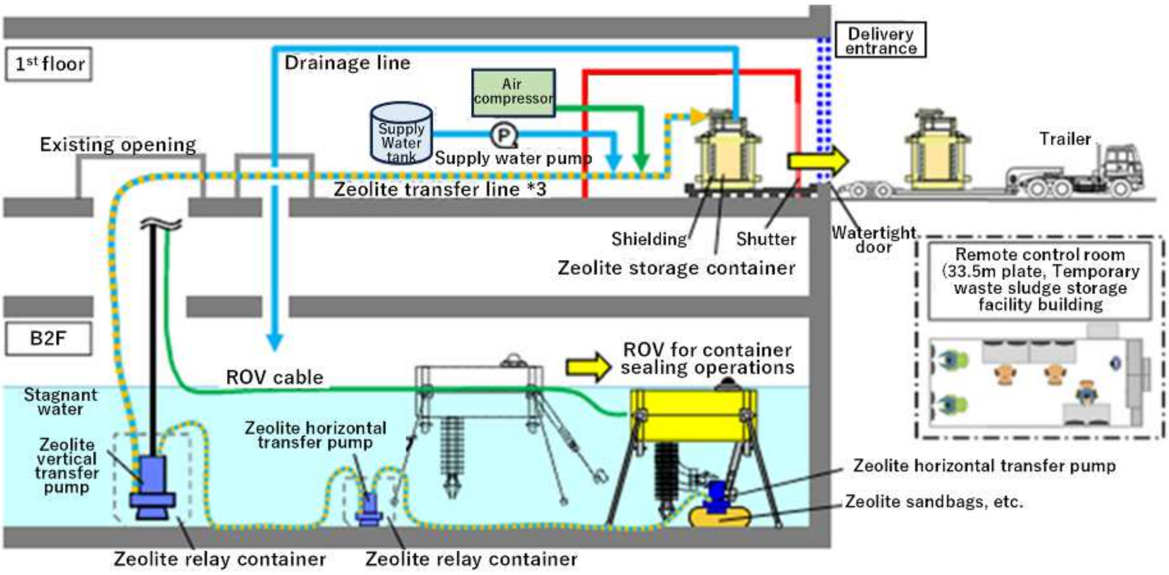
[65] Material 2-2: “Status of zeolite sandbags disposal study”, The 5th Technical Meeting on the Examination of the Implementation Plan of the Measures for the Specified Reactor Facilities, February 1, 2023

[66] Material 3-1: “Application for Approval to amend the implementation plan for installation of temporary storage facility for stagnant water in buildings”, The 14th Technical Meeting on the Examination of the Implementation Plan of the Measures for the Specified Reactor Facilities, November 2, 2023

[67] ROV: Remotely Operated Vehicle



(Source : TEPCO material edited by NDF)

Fig. 37 Overview of the zeolite sandbag recovery task[65]

Because lowering the water level in the PMB and the HTI to expose the floors will prevent the storage of stagnant water in these buildings, designing and producing temporary storage equipment for stagnant water is in progress. This will take over the following functions that the PMB and HTI have performed:

- Stagnant water buffer function for the stable operation of cesium sorption apparatus (SARRY, etc.)
- Concentration averaging of the stagnant water in each building, and sludge settling separation

The temporary storage installations for stagnant water will be installed on the fourth floor of the PMB. The basement floor of the PMB after installation will be used only when the in-leak volume increases during heavy rain and other situations. The temporary storage installations for stagnant water will combine the following two types of tanks to take over the above functions:

- Receiving tank (capacity: approximately 15 m^3): Receive stagnant water and separate sludge by settling
- Temporary storage tank (capacity: approximately 24 m^3): Store the supernatant water that was settled and separated in the receiving tank and homogenize water concentration

The sludge separated and collected with the receiving tank is planned to be discharged for the time being to a limited area of the PMB basement floor, and the water is planned to be collected through a floor funnel (drain outlet on the floor) to temporary stagnant water storage equipment, thereby only storing the drained sludge. Equipment to directly collect sludge from the receiving tank will be installed in the future to eliminate sludge storage in the PMB basement floor and further reduce risks.

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

a. Examination of water treatment systems to prevent the dispersion of α-nuclides and for fuel debris retrieval

Since the effective dose factors of α-nuclides are remarkably high when inhaled or ingested[68], special management and countermeasures are required if α-nuclides spread to water treatment systems or stagnant water in buildings. Thus, keeping the spread of α-nuclides to a range as limited as possible is an issue.

Previous analyses of stagnant water in buildings have confirmed that α-nuclides primarily exist as granular particles[69]. A total α-concentration of 10 Bq/L or below is currently maintained at the cesium sorption apparatus (SARRY/SARRY II) outlet, and the spread of contamination by α-nuclides to the downstream side has been suppressed. In the future, with the increase in the accumulated sludge at the bottom of the building through fuel debris retrieval and other tasks, more sludge may be mixed into the contaminated water, causing the total α-concentration at the water treatment system inlet to rise. To address such concerns, installing filtering systems (α-nuclides removal equipment) in the subsequent stage of the cesium sorption apparatus is under consideration.[70]

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

b. Medium-and-long term measures for contaminated water management systems

To maintain the effectiveness of contaminated water management over a medium-to-long term, implementing periodical and reliable inspections and updating equipment for land-side impermeable walls, sub-drain installations and existing water treatment systems (SARRY, ALPS, etc.) is an issue. For this purpose, it is necessary to anticipate various risks, such as the deterioration of system functions caused by aging and the damage to piping caused by material degradation and natural disasters, to procure and arrange backup and alternative items for the

[68] Japan Radioisotope Association, Attached Table 2, Collection of Isotope Laws and Regulations (I) 2005 Edition, Science and Technology Agency Notification No. 5 (Item to Establish the Quantity and Other Factors of Radiation-Releasing Radioisotopes), October 2005

[69] Material 3-1: "Progress of the Treatment of Stagnant Water in Buildings, etc.," The 100th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, contaminated water and treated water, March 31, 2022

[70] Material 3-1-2: "Progress of the Treatment of Stagnant Water in Buildings, etc.," The 110th Committee on Oversight and Evaluation of Specified Nuclear Facilities, December 18, 2023

enhanced structure for monitoring, early recovery, and stable operation, and to promote maintenance/management and system updates in a planned manner.

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

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

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

The discharge plan is devised with an approach to basically discharge treated water from those with lower tritium concentration, those already stored and for which secondary treatment is expected to be unnecessary, and from storage tanks closer to measurement/confirmation facilities, in a sequential manner for the time being to promote smooth discharges.

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

Formulation of a discharge plan is necessary to develop a plan in accordance with a site use plan, while considering the concentration and decay of tritium contained in treated water in tanks. Regarding the usage plan for the time being regarding the previous tank site, the E area (where the flange tank is dismantled) and its surrounding area are expected as the location to construct facilities related to fuel debris retrieval. It is important to ongoingly examine, draft, and publish a medium-to-long term discharge plan and a site usage plan so that facilities and equipment necessary for decommissioning work including fuel debris retrieval and removal of fuel in SFP can be constructed systematically.

The analysis of ALPS-treated water, as mentioned earlier, is advanced under a cross-check system consisting of TEPCO (Tokyo Power Technology), as well as KAKEN and the JAEA Okuma Analysis and Research Center as analysis organizations independent from TEPCO. No analysis result inconsistency has occurred thus far. In January 2024, the IAEA concluded in a report on the "Second Interlaboratory Comparison on the Determination of Radionuclides in ALPS Treated Water"[71] that TEPCO is capable of undertaking accurate and precise measurements related to the discharge of ALPS treated water, and that the company has a sustainable and robust analytical system in place to support the ongoing technical needs at Fukushima Daiichi NPS during the discharge of ALPS treated water.

In addition to the nuclides to be measured and evaluated (30 nuclides excluding tritium), TEPCO, KAKEN, and JAEA have performed analyses/evaluations and disclosed the results regarding (38) nuclides for which TEPCO has voluntarily confirmed their lack of significant presence[72]. These nuclides need to be periodically reevaluated for their changes resulting from the decay of the radioactive materials and measurement results, and have examinations on the need of analyses/evaluations continued, as well as it is also important to seek public understanding for the reduction of the target nuclides through easy-to-understand explanations based on scientific grounds.

The IAEA is committed to continuously reviewing the safety assurance measures taken by the government and TEPCO before, during and after the discharge, and a system has been established in which IAEA personnel are stationed at the Fukushima Daiichi NPS before and after the discharge to continue the confirmation. It is important for the government and TEPCO to continue sharing the necessary information with the IAEA, and provide explanations to Japan and the international community based on scientific evidence with a high degree of transparency.

NDF will provide technical and professional support for TEPCO's planning and operation of countermeasures on contaminated and treated water, while promoting the distribution of accurate information and increasing understanding in line with the interests of those who will receive the information, through meetings and conferences with relevant domestic and overseas organizations. NDF will also ensure that measures to minimize reputational damage are implemented and that action is taken with adequate and sufficient compensation in the event of reputational damage.

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[71] IAEA Review of Safety Related Aspects of Handling ALPS-Treated Water at TEPCO's Fukushima Daiichi Nuclear Power Station， Second Interlaboratory Comparison on the Determination of Radionuclides in ALPS Treated Water， January 2024

[72] Treated water Portal site https://www.tepco.co.jp/decommission/progress/watertreatment/measurementfacility/

3.3.4 Key technical issues and future plans

The key technical issues and future plans related to measures for contaminated water, treated water, and natural disasters described in this section are summarized as shown in Fig. 38.

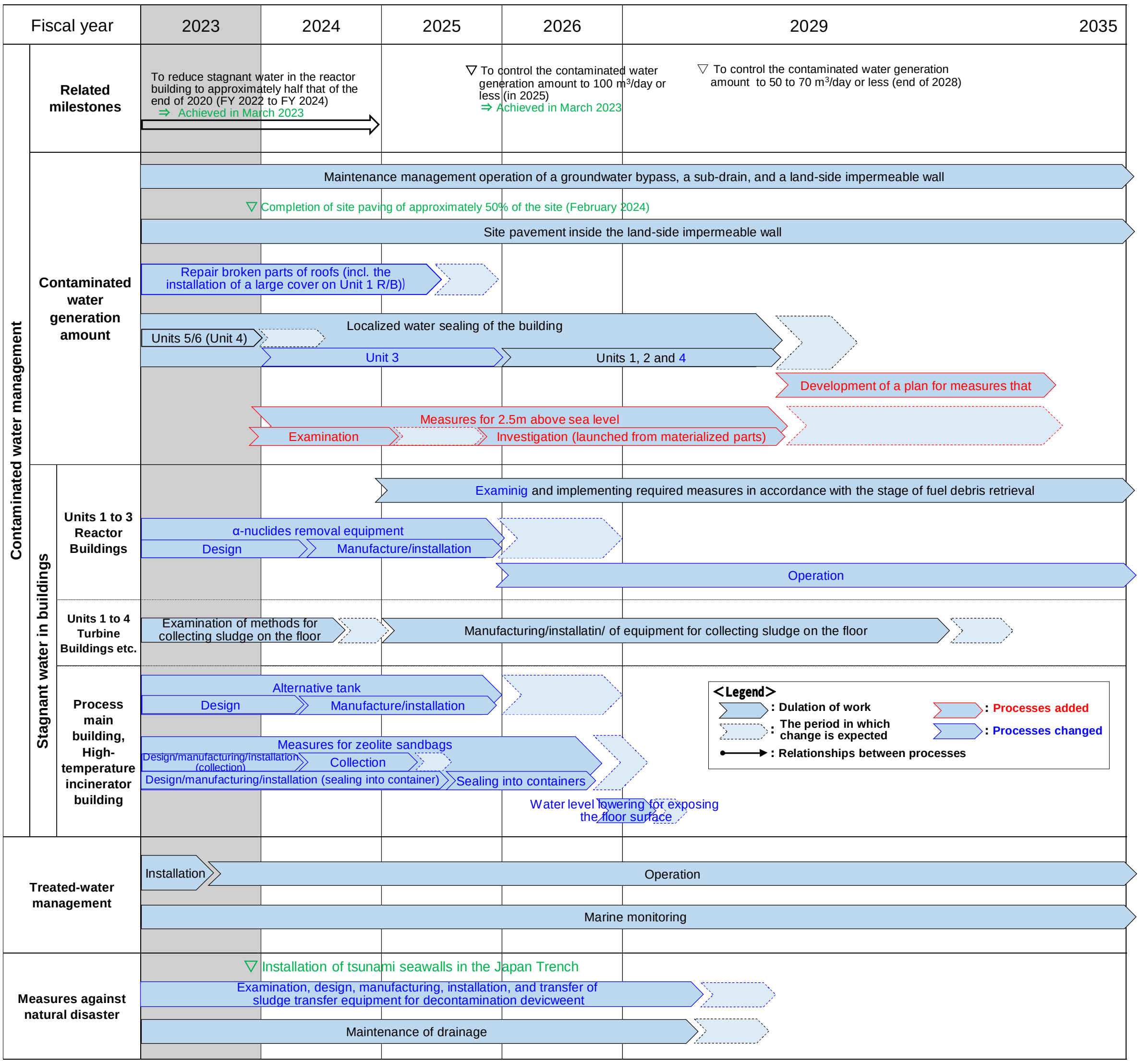


Fig. 38 Key technical issues and future plans on contaminated water/treated water management and natural disaster preparedness (progress schedule)

3.4 Fuel removal from spent fuel pools

3.4.1 Target

① To complete fuel removal from the spent fuel pools of all Units from 1 to 6 by the end of 2031.

② As the return of residents and reconstruction in the surrounding area gradually advances, to carry out a risk assessment and ensure safety, including preventing the dispersion of radioactive materials, and to start removal of fuel in SFPs in FY 2027 to FY 2028 for Unit 1 and FY 2024 to FY 2026 for Unit 2.

③ The fuel in Units 1 to 4, which were affected by seawater and rubble, is retrieved from the SFPs and transferred to the Common Spent Fuel Storage Pool, etc., where it is appropriately stored to be in a stable management state. In order to secure the Common Spent Fuel Storage Pool capacity, the fuel stored there is transferred to and stored in the dry cask at the Temporary Cask Custody Area.

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.

3.4.2 Progress

Based on the work plan outlined in the Mid-and-Long-term Roadmap and the Mid-and-Long-term Decommissioning Action Plan, efforts are underway to complete the removal of fuel from the spent fuel pools in all units, Units 1 to 6, by the end of 2031. Fig. 39 shows a layout drawing of the Common Spent Fuel Storage Pool, the Dry Cask at the Temporary Cask Custody Area, and the overall workflow. Fig. 40 shows the available capacity. Securing the available capacity of the Common Spent Fuel Storage Pool is required to remove all the fuel in SFPs, including Units 5 and 6, and store them in the Common Spent Fuel Storage Pool. To this end, expanding the storage capacity of the dry cask at the Temporary Cask Custody Area and systematic off-site transportation of new fuel are underway to transfer some fuel from the Common Spent Fuel Storage Pool. Such efforts will be made to complete fuel removal in all units in 2031. Regarding the transfer of new fuel off-site, priority will be given to the transfer of spent fuel from Unit 6, which is planned to begin in FY2025 or later. The radiation dose measurement/cleaning of new fuel removed from Unit 4, which is currently stored in Unit 6, was completed in March 2022.

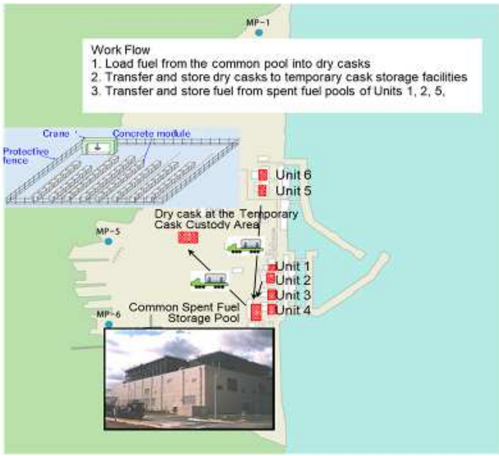


Fig. 39 Layout drawing of the Common Spent Fuel Storage Pool and Dry Cask at the Temporary Cask Custody Area and the workflow

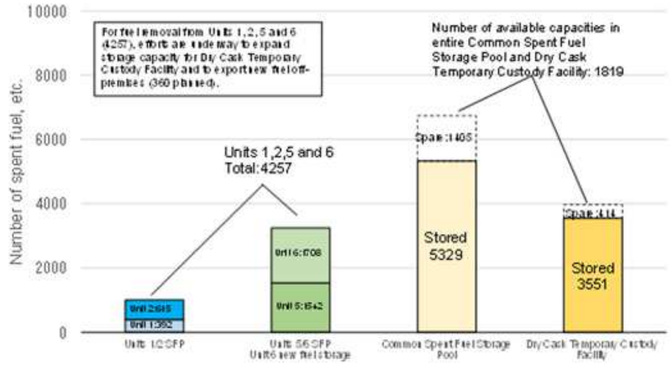


Fig. 40 Storage status of spent fuel (As of June 2024)

a. Unit 1

Due to the hydrogen explosion, roof sheets and building materials, such as steel frames, which constituted the upper part of the building, an overhead crane, and other elements collapsed and produced rubble on the operating floor (Fig. 41). While the residents were returning, from the perspective of the further reduction of the radioactive dust dispersion risk, the whole operating floor was covered with a large cover, and the removal method was changed to one in which rubble removal and fuel removal from SFP would be carried out inside the cover in December 2019. Fig. 42 shows a conceptual drawing of this method.

In preparation for the installation of the large cover and the subsequent rubble removal, the following measures have been completed.

- Curing of spent fuel pool (completed in June 2020)
- Installation of supports for the overhead crane and fuel handling machine (completed in November 2020)
- Removal of interfering existing building covers (remaining parts) (completed in June 2021)

Subsequently, the area around the reactor building has been improved. Still, delays in removing standby gas treatment system (hereinafter referred to as “SGTS”) piping (removal of high radiation dose pipes by remote control) caused delays in the preparatory work. Also, after that, places with a high radiation dose were found on the wall at the south side of the reactor building, which necessitated implementing additional decontamination, performing shielding work and increasing the number of workdays, and large cover installation work is taking time. Work is currently underway to assemble a large cover box ring in the off-site yard in parallel to installing a frame for a large cover on the reactor building of Unit 1. Based on these, the Mid-and-Long-term Decommissioning Action Plan 2024 states that the large cover installation work is to be completed by around the summer of 2025, but the Unit 1 fuel removal is still planned to be started in FY 2027 to 2028.

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

Condition of the collapsed south-side roof

Fig. 41 State of the collapsed rubble on the Unit 1 operating floor

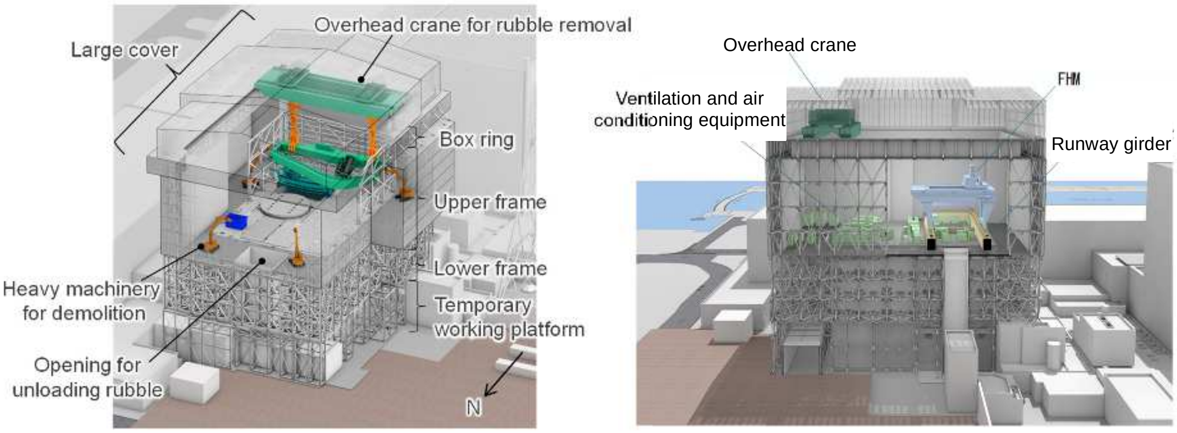
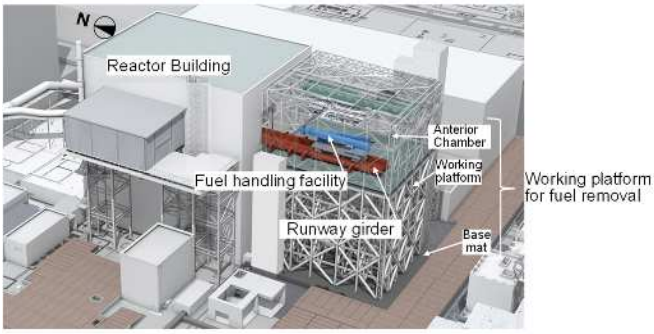


Fig. 42 Fuel removal method from Unit 1 SFP

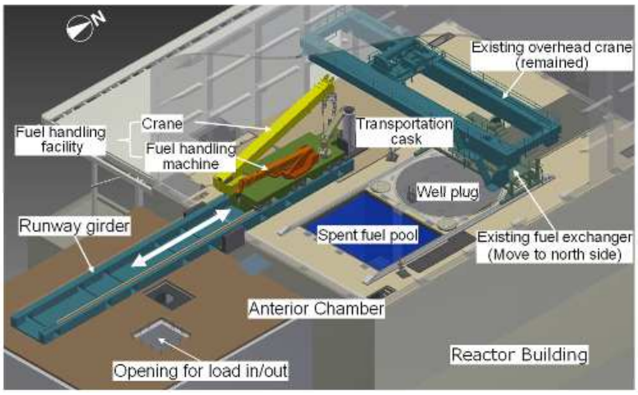
b. Unit 2

From the perspective of the further reduction of the radioactive dust dispersion risk, a method was adopted in which the upper part of the operating floor will not be dismantled and in which there is access from the working platform for fuel removal to be installed on the south side of the reactor building. Fig. 43 shows a conceptual drawing of this method.

At the south side of the reactor building, the installation of the fuel removal working platform and front chamber was completed in June 2024, and access routes are currently being established. Production of fuel handling equipment has also been completed, and its function test is being carried out at the factory. In addition, within the operating floor, decontamination and shielding work was completed in April 2024 after removing obstacles from the spent fuel handling equipment operation room located on the south side of the spent fuel pool, and with that a series of work toward radiation dose reduction has been completed. Fuel removal is expected to start in FY 2025 with reliable management of schedules for fuel removal, including regulatory responses. Also, regarding the fuel removal, for the purpose of prompt equipment problem-related responses, TEPCO employees are to be stationed at the factory in order to master the operation and functions of Japan's first boom-type fuel handling equipment.



Fuel removal method (conceptual drawing)



Fuel handling facility (conceptual drawing)

Fig. 43 Fuel removal method from Unit 2 SFP

c. Units 5 and 6

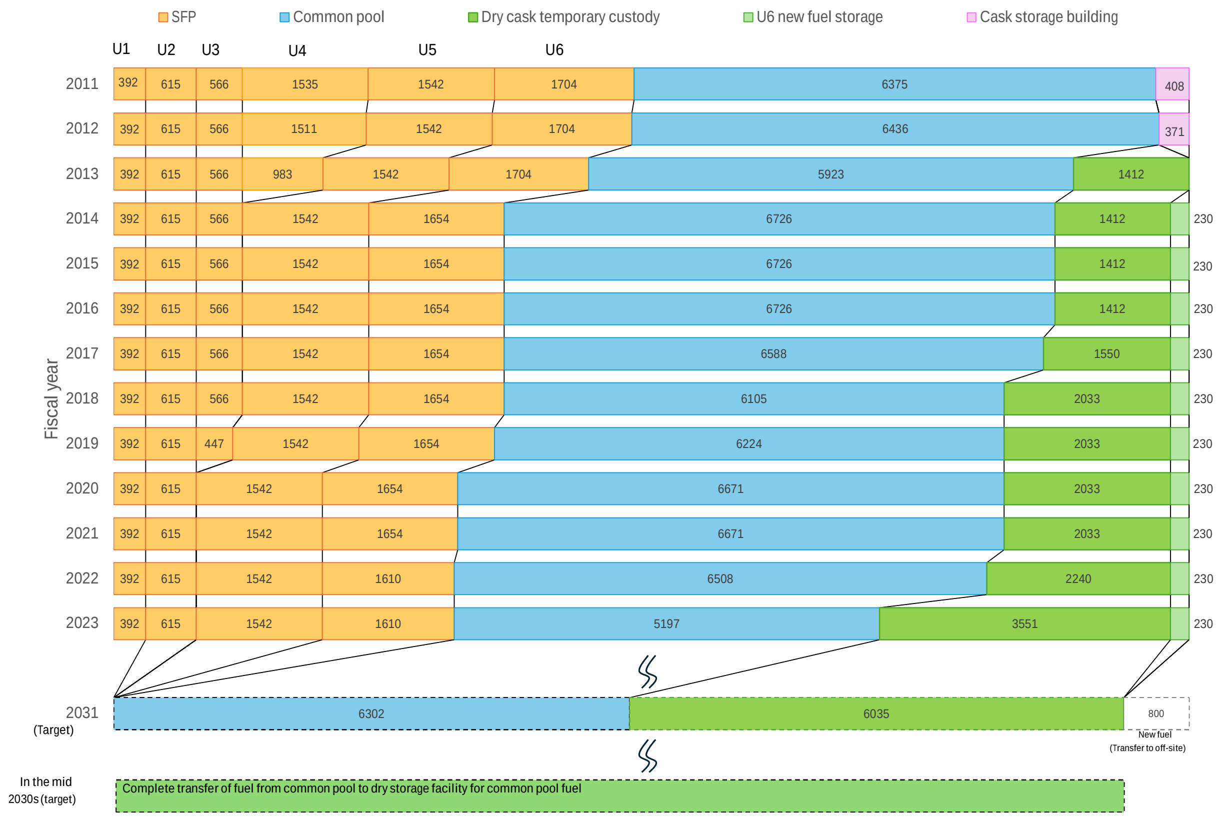
TEPCO is committed to implementing fuel removal tasks within a range that makes no impact on Units 1 and 2's tasks. For Unit 6, transfers from the spent fuel pool to the Common Spent Fuel Storage Pool started in August 2022. To further secure the available capacity of the Common Spent Fuel Storage Pool, fuel was transferred from the Pool to the dry cask at the Temporary Cask Custody Area. However, the impact of rubble, etc., that became mixed while transferring the fuel in the Unit 3 SFP to the Common Spent Fuel Storage Pool resulted in an inability to ensure airtightness of the dry cask. A review was thus made of the work content before and after fuel-loading, causing the process to be delayed. The transfer of Unit 6 spent fuel using a dry cask, and its storage were all completed in February 2024, securing the available capacity of the Common Spent Fuel Storage Pool. The transfer of spent fuel from the Unit 6 spent fuel pool to the Common Spent Fuel Storage Pool accordingly resumed in May 2024, which is planned to be completed in the first half of 2025. As soon as preparations are set, the transfer from the Unit 5 spent fuel pool to the Common Spent Fuel Storage Pool is to start.

d. Removing high radiation dose equipment

In addition to fuel, other high radiation dose equipment is also stored in the spent fuel pool of each unit, such as control rods, channel boxes, and filters. Although cooling is not necessary, shielding is required, and there is still the risk that the source in the pool will be exposed if the pool water leaks. Therefore, to reduce risk, efforts are underway to remove the high radiation dose equipment following the fuel in the pool. With the fuel handling equipment on the spent fuel pool side and the site bunker on the receiving side ready, the removal of high radiation dose equipment from the spent fuel pool of Unit 3 began in March 2023. Subsequently, multiple problems occurred in the fuel handling equipment[73], such as malfunction of the crane main winding hose winder and leakage of working fluid from the vicinity of the main winding hydraulic hose reel. After that, responses to the defects were completed and the removal of high radiation dose equipment was resumed in March 2024.

e. Transition of the fuel storage status

The transition of fuel from immediately after the accident is shown in Fig. 44:



* Dry cask at the temporary cask custody area: Started operation in 2013 Unit 4: Removal from spent fuel pool completed in 2014 Unit 3: Removal from spent fuel pool completed in 2021
Cask storage building (Cask storage building located beside the shallow draft quay before the accident): Stored dry casks were transferred to the Dry cask at the temporary cask custody area in FY 2013. New fuel as of 2031 (800 units) will be transported out of the site. 95 casks will be stored in the Dry cask at the temporary cask custody area.

Fig. 44 Number of fuel of Fukushima Daiichi NPS at the end of each fiscal year

3.4.3 Key issues and technical strategies

3.4.3.1 Fuel removal from SFPs

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

[73] Cranes, etc., used in fuel removal will be reused for the removal of high radiation dose equipment from the spent fuel pool.

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

a. Unit 1

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 the SFP. Therefore, in the ongoing examination of how to remove the overhead crane, it is assumed that safety assessments will be performed, and it is important to carry out a comprehensive examination in light of rationality and impact on other operations by:[74]

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

As for how to remove the overhead crane, because the information on the condition of the lower part of the roof slab is currently limited, a detailed investigation will be conducted after the removal of the slab. There is a risk that the process of dismantling the crane may be delayed depending on the investigation results. Therefore, work procedures should be developed after identifying the required tasks, such as surveys and verification. Then, the overhead crane should be investigated promptly as soon as the investigation becomes possible in order to incorporate them into safety assessments and rubble retrieval plans, including risk cases.

Regarding the contamination state of the well-plugs of Units 1 to 3, the Study Committee on Accident Analysis of the Fukushima Daiichi NPS pointed out that, due to their high level of contamination, the well-plugs have important implications for safety and decommissioning work.[75] Although the well-plugs of Unit 1 have been evaluated by the above-mentioned Study Committee to be about two orders of magnitude less contaminated than several dozen PBq of Units 2 and 3, as those in Unit 1 become deformed and unstable due to the impact of the explosion at the accident, measures to deal with this are being considered. A comprehensive decision should be made on how to handle these well-plugs based on the study results and by

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

[75] NRA, Material 3: (pages 81 to 83): "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), March 5, 2021

taking into consideration the impact on fuel removal from SFPs and fuel debris retrieval in the subsequent stage and performing thorough safety assessments.

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

b. Unit 2

The plan is to remove fuel from the SFP by using a fuel handling machine composed of a boom-type crane system, which has never been used for nuclear facilities in Japan. Given that this fuel handling machine will be used for the first time for such a purpose, it is essential to identify risks associated with operational and equipment problems in advance and take countermeasures without fail. In particular, the following actions should be taken steadily[76].

- Function test and verification of operation procedure by actual workers
- Feedback to operation procedure and modification of the system, as necessary, based on the results of the test and verification

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

As the fuel handling machine will travel between the operating floor and the front chamber, work procedures to prevent contamination of the front chamber and workers should be established and thoroughly implemented, and efforts should be made to minimize risks associated with presumable machine problems to be encountered.

Given that there is a damaged fuel assembly[77] in the SFP, it is also crucial to assess the situation of the fuel, establish a procedure to safely remove it, and implement thorough risk management before the operation to move it starts.

c. Removing high-radiation dose equipment

As removing high-radiation dose equipment is an issue in light of risk reduction in the event of pool water leakage, efforts are being made toward removal. Once removing high-radiation dose equipment is completed, it is possible to exclude pool water from management by draining it, leading to smooth fuel debris retrieval in the later stages because of the increased flexibility of use of the operating floor.

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

[77] There was an incident in which a fuel assembly was dropped, resulting in damage to all the bottom end caps of a coupled fuel rod and splitting it into the upper and lower parts, although without damaging the cladding tubes. Subsequently, the split fuel rod was repaired with stainless steel wire and other materials to return it to a single assembly.

It is effective for removing high-radiation dose equipment to utilize the devices used for fuel and rubble removal. From the viewpoint of maintenance and management of existing equipment, removal should be started as soon as preparations are made, such as securing a storage place. The fuel removal system for Unit 1, which will be installed in the future, should also be designed and maintained in anticipation of the removal of high-radiation dose equipment. Moreover, because of the limits to the capacity of existing site bunkers for storing high-radiation dose equipment for Unit 3, where removal has started, studies are being made on the construction of new site bunkers. Regarding storage, whether dry or wet storage is suitable should be determined. However, since the possibility of pool water in the existing site bunkers leaking before new site bunkers are installed cannot be ruled out, it is important to enhance monitoring and formulate measures against leakage.

When draining the pool water, the radiation dose and dust dispersion from the pool after drainage should be evaluated to confirm safety in advance.

3.4.3.2 Decision on future treatment and storage methods

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

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

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

Currently, technical feasibility studies are ongoing on several types of concrete casks. With respect to concrete casks, in particular, there is concern about the risk of deterioration of the sealing function of canisters caused by stress corrosion cracks (SCCs) due to salt adhesion. Thus, countermeasures need to be established. If concrete casks are to be used, it is essential to set an engineering schedule that clarifies the necessary items to be verified, such as demonstration tests, for smooth operation commencement and to proceed systematically.

Meanwhile, the advantage of metal casks is their proven track records in storing intact fuel in Japan and overseas. However, there are limited cases of storing damaged fuel overseas and no cases in Japan.

Regardless of the type of dry storage facility to be selected, the challenge is the storage of damaged fuel, etc., present in the SFPs.

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

Examples of commonly used metal and concrete casks are shown in Fig. 45 for reference. Concrete cask types used in the US include the underground storage type, which is designed to reduce air radiation dose rates and increase earthquake resistance, and the aboveground installation type, which is contained in special storage equipment. In the US, the mainstream method is dry storage with concrete casks, with over 3,300 concrete casks (containing about 143,000 fuel assemblies) already in use. In selecting the storage method, consideration should be given to factors such as earthquake resistance and site boundary radiation doses, in addition to ensuring technical feasibility concerning the above issues.

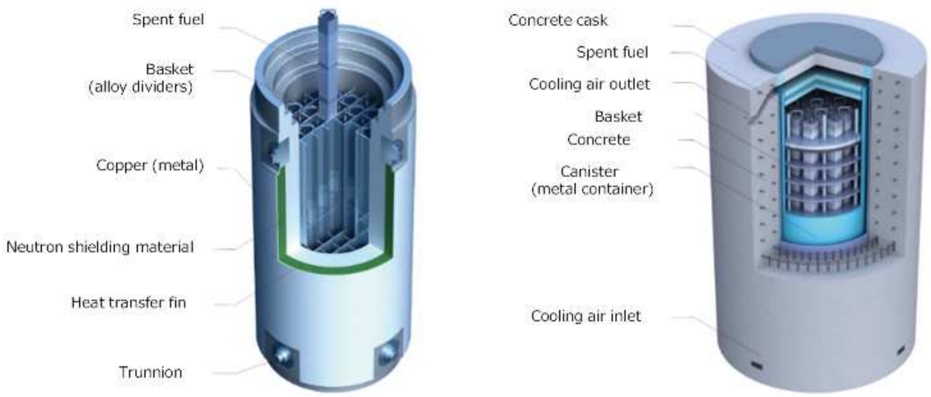

Fig. 45 Metal cask (Example) Concrete cask (Example)[78]

[78] Source：https://www.fepc.or.jp/sp/chozo/result.html

Vertical Ground-mount Storage Type

Air supplied from the bottom of the cask, exhausted from the top

Fig. 46 Concrete casks Vertical Ground-mount Storage Type

Underground Vertical Storage Type

Intake and exhaust are in the upper part near the ground surface.

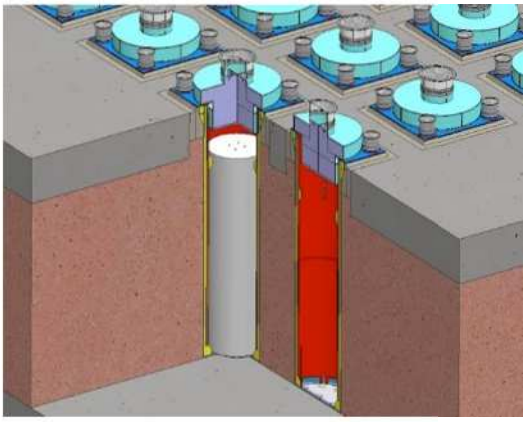

Fig. 47 Concrete casks Underground Vertical Storage Type

[79] Source: https://www.nacintl.com/solutions/storage-technologies
https://www.nacintl.com/images/pdf/NAC-Product_Flyer-Magnastor_GEV_DIGITAL_220706.pdf

[80] Source: https://holtecinternational.com/2018/03/12/the-celebrated-history-of-storing-used-fuel-below-ground/
https://holtecinternational.com/products-and-services/nuclear-fuel-and-waste-management/dry-cask-and-storage-transport/hi-storm/hi-storm-100u/

Horizontal Ground-mount Type, can be operated in 1- or 2-story buildings

Air supplied from the bottom of the storage facility and exhausted from the top

Fig. 48 Concrete casks   Horizontal Ground-mount Type

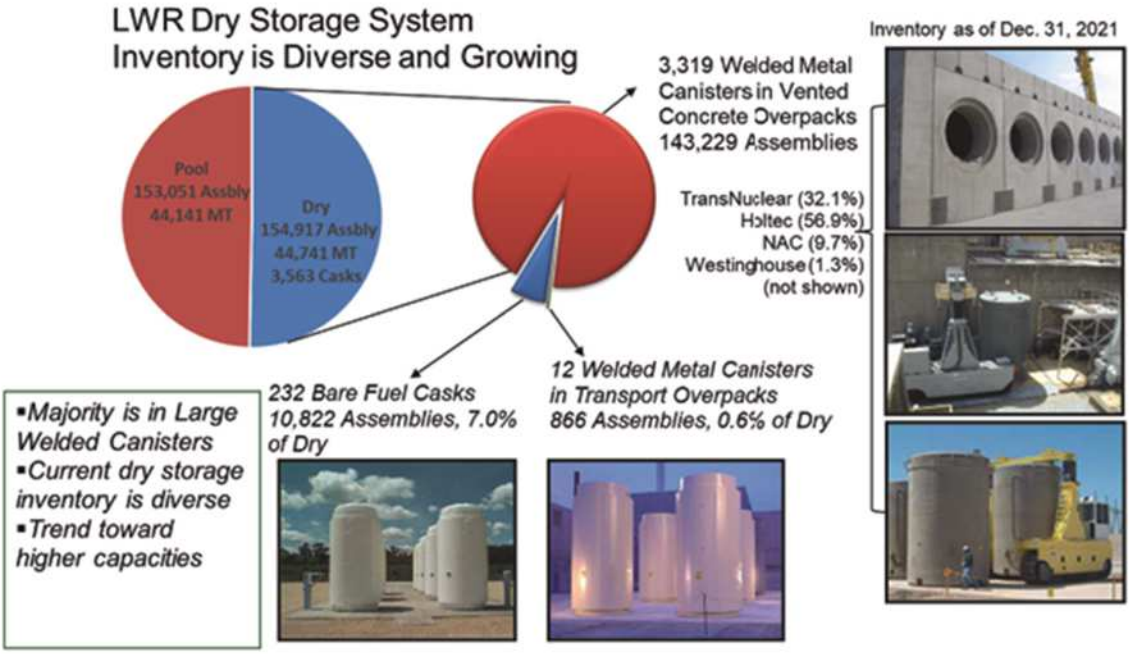

Fig. 49 Dry Storage Performance in the U.S.[82]

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[81] Source: https://www.orano.group/usa/en/our-portfolio-expertise/used-fuel-management/used-fuel-storage/nuhoms-matrix-storage-module

[82] Source: https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-33938.pdf

3.4.4 Summary of key technical issues

The key technical issues and future plans described in this section are summarized as shown in Fig. 50.

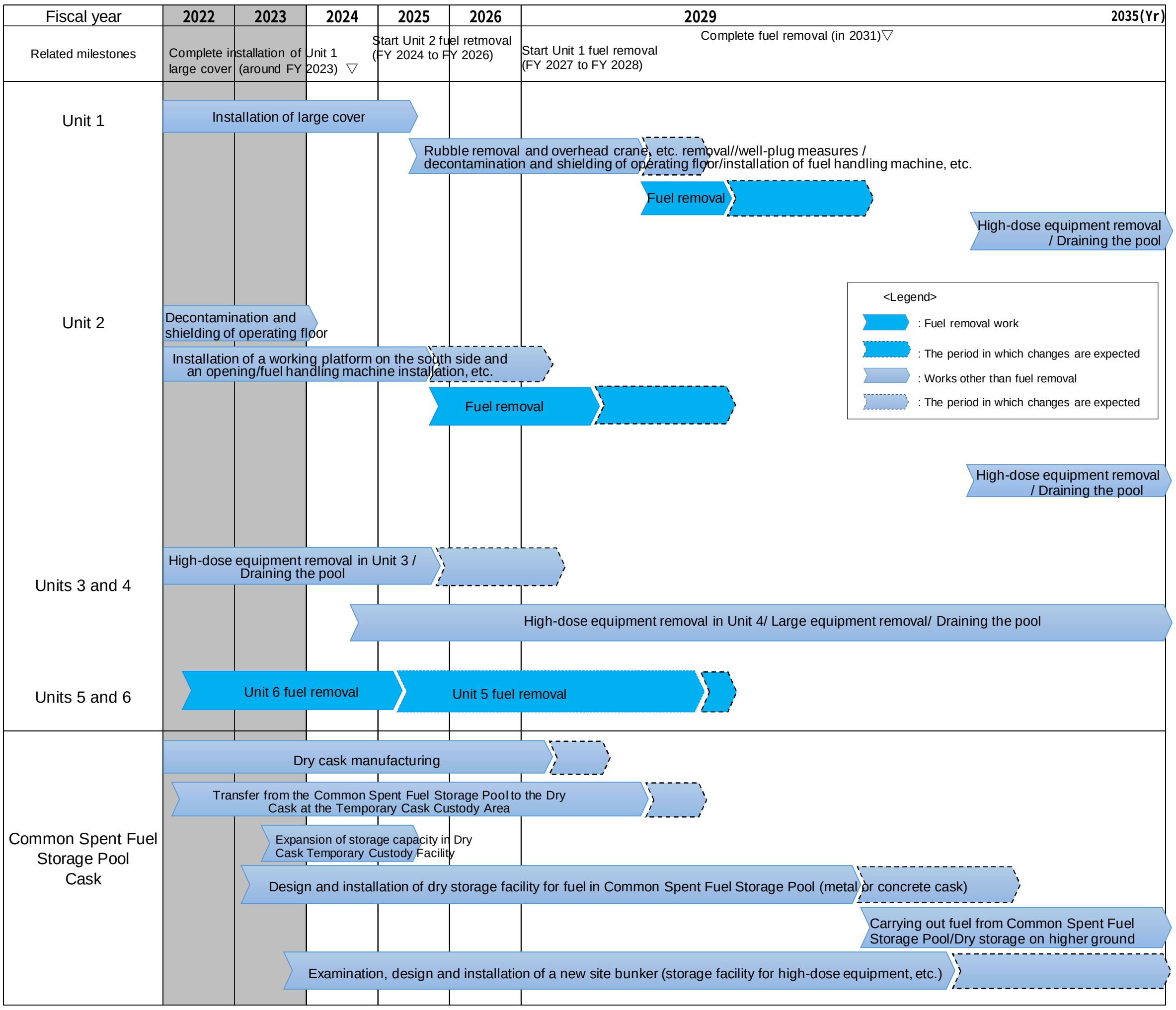

Fig. 50 Key technical issues and future plans for fuel removal from SFPs (Progress schedule)

4. Analysis strategy for promoting decommissioning

4.1 Overview of analysis on decommissioning

4.1.1 Purpose and significance of analysis on decommissioning

The accident at the Fukushima Daiichi NPS was the first core meltdown accident at BWRs in the world, and many records, including temperature records, are unavailable due to the loss of power at the time of the accident. In addition, many uncertainties remain regarding the state inside the reactors, the state of the fuel debris, fission product release paths, etc., due to the unclear operational status of the safety equipment and seawater injection to bring the accident under control. Therefore, the analysis is being conducted for the purpose of handling fuel debris and solid waste generated by the accident safely and appropriately storing/managing them.

It is considered that fuel debris would be heterogeneous in various physical properties, such as chemical composition, microstructure, and density, because there is uncertainty in its formation process as described above, and it is not under human control. Concerning the design of safety measures for decommissioning the Fukushima Daiichi NPS, safety assessment and safety measures for criticality control and transport are conservatively studied with the 4 to 5 mass% U-235 content of the fuel before the accident. In addition to the U-235 content decreasing as a result of nuclear fission in the reactor, the severe accident analysis and the videos of PCV internal investigations suggest that the U-235 content is likely to have been decreased by melting and mixing with the surrounding structural materials. However, the fact that the data used for the assessment is unknown leads to the inclusion of excessive margins in safety measures. If the range of such uncertainty is reduced by analyzing collected samples, it will lead to the optimization of safety margins in handling fuel debris, safety assessments, and safety measures, which will improve the promptness and rationality of decommissioning.

Conducting proper storage/management and examining processing/disposal methods for solid waste, it is essential to assess the physical and chemical properties of solid waste to improve its safety during storage, and steadily advance analysis to acquire property data, such as nuclide composition and radioactivity concentration, which will contribute to examining a processing and disposal strategy. Therefore, based on the characteristics of solid wastes, which have diverse properties and are large in quantity, it is necessary to establish facilities for analysis, develop analytical personnel, and conduct analysis using analytical and evaluation methods for efficient characterization. As the project will enter Phase 3, where the properties of solid waste will be analyzed, and the specifications of waste form and their production methods will be determined as stated in the Mid-and-Long-term Roadmap, reliable analysis of solid waste becomes an important issue to steadily proceed with the overall solid waste countermeasures, including such determinations. Therefore, it is imperative to develop a structure for systematic analysis based on the results of previous efforts.

A plan is to collect and contain fuel debris and solid waste in containers for storage/management, so they are not released into the environment. On the other hand, to safely discharge ALPS-treated water into the sea, an analysis must confirm that the sum of the ratios to regulatory concentrations limits of nuclides other than tritium contained in ALPS-treated water before dilution is less than 1, etc. It is also important to continue monitoring activities for environmental samples in the sea area to observe the diffusion status of tritium and other nuclides. As a measure to strengthen marine monitoring by TEPCO, the monitoring of seawater, seaweed, and fish within a 20 km radius outside the port and along the coast of the Fukushima Daiichi NPS started in April 2022.

TEPCO analyzes ALPS-treated water before and after dilution prior to discharge and has confirmed with respect to the past discharges into the sea that tritium concentrations are less than the discharge limit of 1,500 Bq/L and that the sum of the ratios to regulatory concentrations limits of nuclides other than tritium is less than 1. In addition, third-party analysis of ALPS-treated water is conducted by the JAEA before and after dilution prior to discharge and has confirmed that the aforementioned limits are not exceeded. According to the marine monitoring by TEPCO, the tritium concentration in the seawater is ranging from 0.43 to 29 Bq/L at the points close to the discharge outlet (200 to 2,100 m away) and below the lower detection limits in other areas. After the start of discharges, sea water analysis by the Ministry of the Environment and Fukushima Prefecture, and marine product analysis by the Fisheries Agency, have also confirmed that concentrations in seawater are equivalent to those before the discharges, ranging from 0.06 to 0.63 Bq/L, and that all values remain below the lower detection limits.

4.1.2 Full picture of the analysis

In the decommissioning work of the Fukushima Daiichi Nuclear Power Station, analyses covering a wide range of analysis targets, purposes, and dose rates must be performed as shown in Fig. 51. It is essential to obtain appropriate analytical results in the light of the above-mentioned objectives for proceeding with decommissioning the Fukushima Daiichi NPS safely and steadily. It is effective to improve the analysis methods and systems, the quality of the analysis results, and the size and quantity of samples, as shown in Fig. 52, and efforts are being made to achieve this.

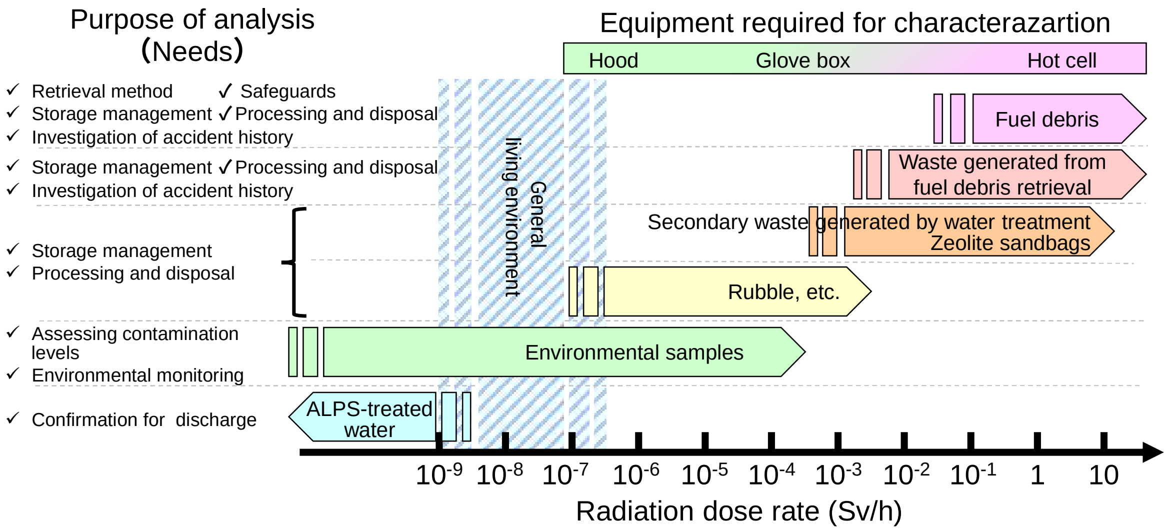

Fig. 51 Relationship between the purpose of the analysis, equipment required for characterization, and radiation dose rates of the analysis targets

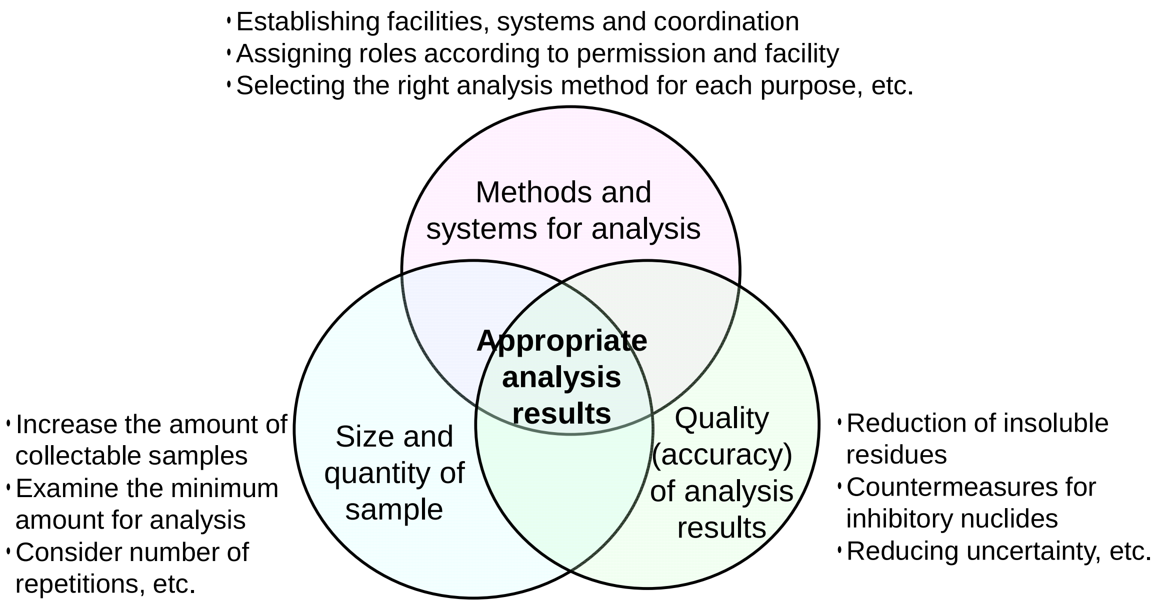

Fig. 52 Three elements of the fuel debris analysis strategy for the decommissioning of the Fukushima Daiichi NPS

4.2 Current status and strategies for analysis

4.2.1 Measures to strengthen analytical structure and analysis method

4.2.1.1 Measures to strengthen analytical structure

While the government of Japan has taken the lead in developing a Mid-and-Long-term Roadmap, TEPCO, the JAEA, NDF, and other related organizations have been working together to establish an analysis system, such as developing facilities for analysis, collaborating with domestic hot laboratory organizations, developing analysis and evaluation methods, and exchanging human resources. As the project will enter Phase 3, which begins with the fuel debris retrieval in the first implementing unit, an urgent task is to accelerate further the development of the analysis structure, which has been promoted so far.

TEPCO, the JAEA, NDF, and other related organizations are steadily advancing efforts to strengthen their analytical systems by examining analytical plans, developing analytical and evaluation methods, securing facilities for analysis and analytical personnel, while also working to strengthen cooperation among relevant organizations. The Agency for Natural Resources and Energy has compiled measures for the development of such an analysis structure and published and reported them at the Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water and the NRA meetings (refer to Attachment 16 for the action plan for each relevant organization) [83,84]. Immediate efforts will continue to be steadily implemented, and necessary measures will be taken in the light of the situation.

4.2.1.2 Update of the analysis plans

TEPCO assumes that as the decommissioning work progresses, the type and quantity of the analysis targets will increase, and the demand for analysis will expand accordingly.[85] As the demand expands for the analysis of lower concentration areas such as ALPS-treated water and environmental samples, the small amount of radioactive elements contained in the sample makes it necessary to improve detection accuracy. On the other hand, with the growing demand for analysis of high-radiation dose areas such as fuel debris and high-activity waste, it is necessary to expand radiation protection functions including shielding and containment and to diversify analysis items such as element distribution and structural analysis. Systematic preparations must be made to respond to such changes in demand flexibly and not to stagnate decommissioning work due to analyses. In particular, objects with high-radiation dose rates, such as fuel debris and secondary waste generated by water treatment, require hot cells with shielding and containment capabilities as an analytical system, but the numbers are limited. To make effective use of the available hot cells, it is important to balance the desired information to be acquired for the analysis targets and their quantity, detection accuracy, frequency of analysis, etc., and develop plans that considers periodic maintenance and other management of analysis facilities.

The NRA has updated the target map for reducing mid-term risks with the aim of establishing a medium- to long-term vision toward decommissioning and associated objectives. In light of the importance of transition to stable storage of radioactive materials, the updated document identifies

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[83] Material 3-4: “The immediate measures to the development of analytical systems for Decommissioning of TEPCO’s Fukushima Daiichi NPS”, The 112th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, March 30, 2023
[84] Material 1: “Policy initiatives to strengthen the analytical systems for Decommissioning of TEPCO’s Fukushima Daiichi NPS”, The 1st NRA committee FY2023, April 5, 2023
[85] Material 1-3-2: “Activity Status to Establish Analysis Structure”, The 104th Committee on Oversight and Evaluation of Specified Nuclear Facilities, December 19, 2022

waste generated by water treatment, rubble, and building dismantling waste, etc. as priority areas for risk reduction measures in connection with solid radioactive materials. It also refers to the analysis that needs to be completed as an essential factor in achieving the vision[86].

In response to that, TEPCO identified waste with high priority for analysis based on the progress of analysis and risks associated with storage and management, and formulated the characterization policy and analysis plan in 2023 according to the characteristics of each waste.[87] Table 6 provides the objective for analysis planning. Subsequently, reflecting the policy and plan presented at the Technical Meeting on the Examination of the Implementation Plan of the Measures for the Specified Reactor Facilities, etc., TEPCO conducted analysis for establishing solidification policy for secondary waste generated by water treatment, etc., analysis for developing management methods for radioactive concentration of rubble, and analysis for dismantling model case study on building dismantling waste, etc., as well as reviewed analysis priorities and updated the number of analyses based on the sampling conditions, etc.[88] In the future, TEPCO will implement the initiatives in the plan and, based on the progress and performance made, will constantly review its analysis plan.

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[86] Material 4-1: "Measures for Mid-term Risk Reduction at TEPCO's Fukushima Daiichi NPS (March 2024 edition)", The 112th Committee on Oversight and Evaluation of Specified Nuclear Facilities, April 26, 2024

[87] Material 3-4: "The analysis plan of solid waste for Decommissioning of TEPCO's Fukushima Daiichi NPS", The 112th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, March 30, 2023

[88] Material 3-4: "Update of the analysis plan of solid waste for Decommissioning of TEPCO's Fukushima Daiichi NPS (FY 2024)", The 124th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, March 28, 2024

Table 6 Objective for analysis planning

Response to decommissioning progress	Details
Transition to waste management based on radioactivity concentration	・Transition to management of radioactivity concentration for all waste considering the following : ✓Obtaining data that contributes to the study of rational safety measures, etc. according to the characteristics of each waste. ✓Accumulation and management of data for disposal and re-use (radioactivity concentration control for a wider range of radionuclides)
Safe and stable storage management	・By assessing the behavior of waste during storage and examining the appropriate safety measures, the physical and chemical characteristics of waste is identified to study storage methods that can maintain containment over a long period of time.
Response to the high degree difficulty of sampling and analysis	・Developing technology and human resources to handle sampling associated with debris retrieval and samples with high analytical difficulty, etc. .
Systematic sampling and analysis	・Systematic sampling and analysis with due consideration for the representativeness ・Rational characterization based on the characteristics of each waste

(Source: TEPCO)

The JAEA, in cooperation with Nippon Nuclear Fuel Development Co., Ltd. (hereinafter referred to as “NFD”) and MHI Nuclear Development Corporation (hereinafter referred to as “NDC”), have been analyzing deposits, adhered materials obtained from PCV internal investigations[89,90], and solid waste[91], etc. As a result, some properties of fuel debris and waste have been clarified. Based on past experience and the results to date, the JAEA is reviewing the analysis target items and analysis flow of fuel debris necessary to solve issues from the viewpoint of the need to promote decommissioning work safely and steadily[92]. In addition to the JAEA review, fuel debris analysis plans will be developed with the assistance of the analysis support team described below.

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[89] IRID, Subsidy for the Project of Decommissioning and Contaminated Water Management, Outcome for research in FY 2021 (Development of analysis and estimation technologies for characterization of fuel debris), (2022)

[90] Material 3-4: “Recent results on waste characterization – Characterization of major risk sources”, The 108th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, November 25, 2022

[91] IRID, 2021 Final report, “Subsidy for the Project of Decommissioning and Contaminated Water Management (Research and Development for processing/disposal of solid waste)” starting in FY2021, September 2022

[92] JAEA, JAEA-Review 2020-004, “Fuel debris analysis of TEPCO’s Fukushima Daiichi NPS”, Working group on fuel debris and other research strategies, 2020

4.2.1.3 Development of analysis and evaluation methods

Solid waste is characterized by a variety of nuclide compositions and radioactivity concentrations and a large amount of material. Therefore, unlike the development of waste identification methods in conventional power reactors, it is necessary to develop waste identification methods specific to the solid waste at the Fukushima Daiichi NPS, such as data acquisition, storage, organization, and application of statistical methods to establish the Scaling Factor method and other evaluation methods. In particular, inventories necessary for discussing a processing and disposal strategy must be characterized promptly and efficiently. For this reason, efforts will be made to develop analytical methods for the purpose of obtaining data easily and quickly, to standardize analytical methods accelerated by streamlining and automating pretreatment of samples[93], and to develop analytical methods for handling various sample forms and the difficult-to-measure nuclides. In addition, together with this effort, the Project of Decommissioning, Contaminated Water and Treated Water Management, and other projects are engaged in establishing methods for characterization with less analytical data, such as data analysis planning using the DQO process and Bayesian statistics and statistical inventory estimation methods. In the future, in developing analytical methods, verification will be conducted at the JAEA's Radioactive Material Analysis and Research Facility Laboratory-1 to establish analytical methods and perform characterization based on the analysis plan incorporating TEPCO's needs.[94] In addition, since molten fuel and structural materials will be mixed in the solid waste during fuel debris retrieval, it is expected that the workability will be improved if it is possible to promptly confirm whether uranium is contained in the materials adhered to damaged supports, pipes, and other structures. Therefore, technology development utilizing laser-induced breakdown spectroscopy (hereinafter referred to as "LIBS") is in progress as a technology development of simple (in-situ) analysis.

4.2.1.4 Securing facilities for analysis

As an essential facility for the decommissioning of the Fukushima Daiichi NPS, the JAEA develops and operates the Radioactive Material Analysis and Research Facilities adjacent to the Fukushima Daiichi NPS under the supplementary budget of the government (FY2012).[95, 96] Upon commencing its operation, they will be designated as facilities in the peripheral monitoring area of the Fukushima Daiichi NPS, which has the advantage that off-site transportation is not required. Leveraging this, it is effective to promptly identify the basic physical properties and incorporate

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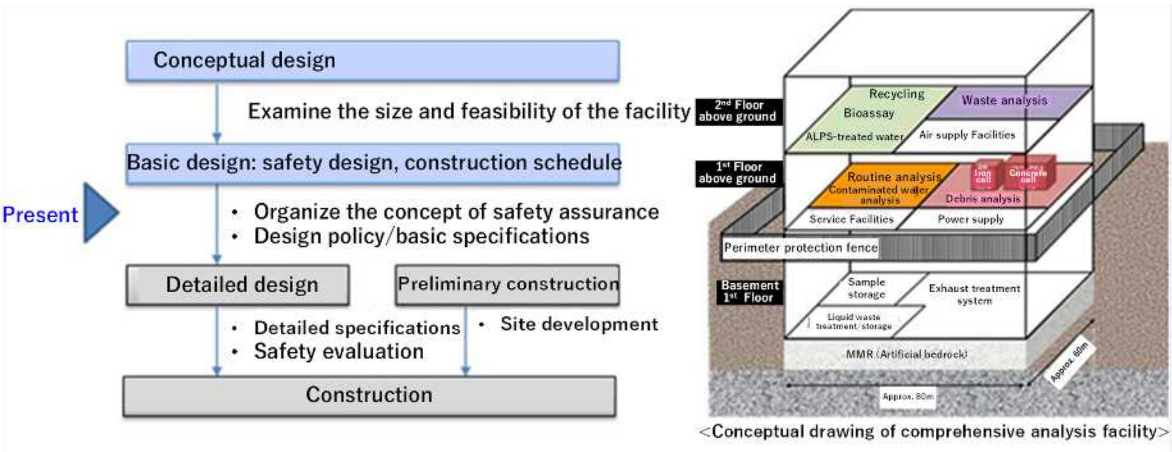
[93] IRID, 2021 Final report, "Subsidy for the Project of Decommissioning and Contaminated Water Management (Research and Development for processing/disposal of solid waste)", starting in FY2021, September 2022

[94] Material 1-3-3: "Development flow of analysis and evaluation methods", The 104th Committee on Oversight and Evaluation of Specified Nuclear Facilities, December 19, 2022

[95] Material 3-1: "Development of R&D Hub Facilities for Decommissioning", The 24th Committee on Oversight and Evaluation of Specified Nuclear Facilities, July 7, 2014

[96] Material 3-4: "Opening of the Okuma Analysis and Research Center Facility Management Building", The 52nd Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, March 29, 2018

them into safety assessment and work procedures. The objectives of Laboratory-1 are solid waste analysis and third-party analysis of ALPS-treated water,[97] and Laboratory-2 is intended to conduct fuel debris analysis. Laboratory-1 was completed in June 2022,[98,99] where the controlled area and other areas were set as a part of the specified nuclear facility, and analytical operation using radioactive materials started in October.[100] It also began third-party analyses of ALPS-treated water in March 2023.[101] Tritium analysis in Laboratory-1 has been accredited by ISO / IEC17025, an international standard that shows its ability to produce accurate measurement/calibration results, in February 2024[102]. Laboratory-2 is in the process of screening applications for approval of implementation plan changes and selecting the operator, and the construction is expected to be completed in FY2026. TEPCO is also considering the construction of facilities for analysis (comprehensive facilities for analysis) in response to the future needs of analysis, including analysis of fuel debris and solid waste, in addition to current routine analyses. The construction is expected to be completed in the second half of the 2020s. Fig. 53 shows the study progress of the comprehensive analysis facility and an image of the facility.



(Source: TEPCO)

Fig. 53 study progress of the comprehensive analysis facility and an image of the facility

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[97] Material 4: "Development Status of Radioactive Material Analysis and Research Facility Laboratory-1", The 100th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, March h31, 2022

[98] JAEA, "Completion of Laboratory-1 of the Radioactive Materials Analysis and Research Facility (Okuma Analysis and Research Center) and Future Plans", June 24, 2022

[99] Material 4-1: "Completion of Laboratory-1 of the Radioactive Materials Analysis and Research Facility (Okuma Analysis and Research Center) and Future Plans", The 103rd Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, June 30, 2022

[100] Material, Others: "Commencement of Analysis Work at Laboratory-1 of the Radioactive Materials Analysis and Research Facility", The 106th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, September 29, 2022

[101] Sector of Fukushima Research and Department, JAEA, "Start of Third-party Analysis of ALPS-treated Water in Radioactive Material Analysis and Research Facility, Laboratory 1", March 30, 2023,

[102] Fukushima Decommissioning Safety Engineering Research Institute, JAEA, "ISO/IEC 17025 accreditation ceremony held at the Analysis Section of the Analytical Control Department of the Okuma Analysis and Research Center", March 29, 2024

As shown in Fig. 54, since Laboratory-2 and the comprehensive facilities for analysis are scheduled to commence operation after the trial retrieval of fuel debris, the analysis will be conducted at the facilities for analysis in the Ibaraki area until Laboratory-2 becomes operational. Since there are more analysis items for fuel debris than for solid waste analysis, such as metallographic observation, microstructural observation, and elemental mapping, there is a possibility that the analysis capacity of Laboratory-2 will be concentrated after it commences operation. To reduce the workload in Laboratory-2, if special techniques are required for pretreating samples with a high radiation dose or if analysis and testing require an extended period, these analyses should be performed in the Ibaraki area, even after Laboratory-2 commences operation. This is 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. Currently, Laboratory-1 does not have a license for using nuclear fuel materials. However, in the long term, one of the measures to expand the analysis capacity of fuel debris is to examine the possibility of analysis using diluted solutions in Laboratory-1 after dissolving and diluting fuel debris in Laboratory-2, then to give priority to samples that can be analyzed promptly on-site and in adjacent areas of the Fukushima Daiichi NPS.

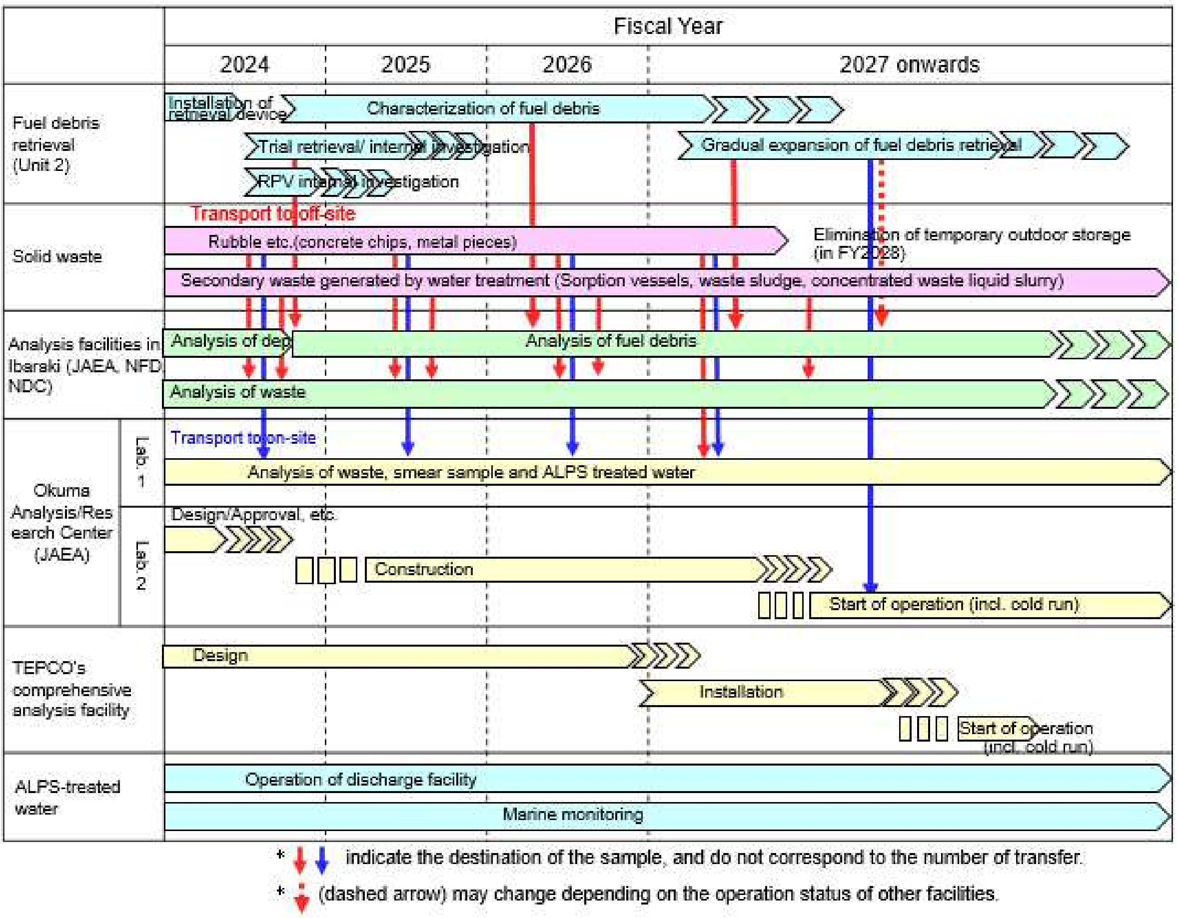

Fig. 54 Construction and operation schedule for fuel debris retrieval and new analytical laboratories

As for solid waste analysis, as the retrieval of the fuel debris progresses, it is anticipated that it will generate solid waste with which TEPCO does not have previous experience, such as fine fuel debris and filters that have captured fission products. Regarding high-radiation dose solid waste with which TEPCO has limited experience, it is desirable to analyze solid waste in the Ibaraki area for the same reasons described above, and it is necessary to continue it in the Ibaraki area for some time after Laboratory-1 is put into operation. Based on the above, since the 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 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 and the JAEA plans to consolidate and increase its focus on the facilities,[103] consideration should be given to facilities that will continue to be used going forward.

4.2.1.5 Securing human resources for analysis

Not only the facilities for analysis in the Ibaraki area but also the facilities for analysis on-site and in the area adjacent to the Fukushima Daiichi NPS are short of the human resources required to continue stable facility operation, so the securing and maintaining of analytical personnel needs to be considered. In this respect, it is important to consider in advance the qualities expected of each analytical personnel in various types of analytical work and develop analytical personnel systematically to achieve the required roles appropriately. TEPCO estimates that in addition to the current structure with 117 persons, about 30 additional persons will be required for solid waste analysis by the 2030s. In FY2023, TEPCO began training employees so that they can gain practical experience by participating in analysis projects related to the Project of Countermeasures on Decommissioning, Contaminated Water and Treated Water[104]. As the JAEA's Medium-/Long-Term Management Plan for JAEA Facilities describes the implementation of back-end measures, including decommissioning, the development of human resources necessary for decommissioning-related analysis is an important issue also for the JAEA. The JAEA is securing and training human resources by forming analysis technology network utilizing laboratories in the Ibaraki area and universities and having them verify analyses performed by the JAEA Okuma Analysis and Research Center and advance analytical technologies[105]. It is necessary for TEPCO and the JAEA to mutually identify changes in analytical needs and issues over time and cooperate in human resource development, while relevant organizations such as the Agency for Natural Resources and Energy and NDF also need to support these efforts.

[103] JAEA, "Medium-/Long-Term Management Plan for the JAEA Facilities", April 1, 2022,

[104] Material 3-4: "The analysis plan of solid waste for Decommissioning of TEPCO's Fukushima Daiichi NPS", The 112th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, March 30, 2023

[105] Material 3-3: "JAEA's Efforts to Develop Human Resources, Including Those for Analysis", The 12th Meeting of the Decommissioning R&D Partnership Council, April 4, 2024

In normal nuclear power plants, fuel is sealed in fuel cladding, and before the accident, the unsealed alpha-ray emitters were not directly handled in the Fukushima Daiichi NPS. The fuel debris generated by the accident contains unsealed fuel and fission products, and analyses entail the risk of internal/external exposure or spreading contamination. For this reason, TEPCO must develop human resources for fields with little experience in as short a time as possible. It is necessary for TEPCO to effectively work on developing analytical technicians with the cooperation of the JAEA and private-sector enterprises that have accumulated sufficient knowledge and experience in handling alpha-ray emitters and fuel analysis techniques.[106, 107] Table 7 shows the records of personnel exchange between TEPCO and the JAEA and personnel acceptance from NFD to TEPCO.

Table 7 Personnel exchange between TEPCO and JAEA and accepting personnel from NFD to TEPCO

		Fiscal Year						
		2018	2019	2020	2021	2022	2023	2024
From TEPCO to JAEA	Assigned, temporary, external researcher	1	1	3	3	4	4	3
	Transfer, reemployment	0	0	0	1	0	1	0
From JAEA to TEPCO	Assigned, temporary	0	3	11	4	1	1	1
	Transfer, reemployment	0	0	1	0	0	0	0
From NFD to TEPCO	Assigned, temporary	0	0	1	0	0	0	0
	Transfer, reemployment	1	1	0	1	0	0	0

*Data for FY2024 is as of the end of July 2024.

Analytical workers of the Fukushima Daiichi NPS on site have been mainly experienced in the analysis of liquid samples only. Therefore, in preparation for the launch of the comprehensive facility for analysis, training for analyzing samples with a high radiation dose using hot cells and glove boxes will be provided in Laboratory-1. Moreover, from FY2023, potential candidates have been sent to join R&D for development of analytical technicians[108].

As the demand for analysis is expected to increase in the future, there will be a need for highly skilled personnel capable of analysis planning in anticipation of how the analysis results will be used. Analytical evaluators in charge of this task are required to have the ability to (i) appropriately incorporate the evaluation results into the areas required for the decommissioning process (retrieval method, safeguards, storage/management, and processing/disposal), (ii) provide

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[106]TEPCO, Japan Nuclear Fuel Limited., Conclusion of “Agreement on Technical Cooperation for the decommissioning of the Fukushima Daiichi Nuclear Power Station,” January 27, 2022

[107]TEPCO, Nippon Nuclear Fuel Development, “Memorandum of Understanding for cooperation in debris analysis for the Fukushima Daiichi Nuclear Power Station,” August 1, 2022”

[108] Material 3-4: “The immediate measures to the development of analytical systems for Decommissioning of TEPCO’s Fukushima Daiichi NPS”, The 112th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, March 30, 2023

appropriate instructions for the subsequent sampling, and (iii) logically and accurately understand accident events from analytical results. However, it is difficult for individuals to have all these abilities. Therefore, the Analysis Coordination Meeting and an Analysis Support Team were organized within NDF, as shown in Fig. 55. The Analysis Coordination Meeting is responsible for confirming analysis plans and providing advice on problem-solving in response to the increased types and numbers of objects to be analyzed. The Analysis Support Team, consisting of researchers and engineers with extensive experience and knowledge in analytical practice, is to examine and discuss solutions to the issues raised, propose how to solve the issues, and report the progress. The first meeting of the Analysis Coordination Meeting and the Analysis Support Team was held in August 2023 to discuss analysis planning and problem solving[109]. For example, discussions have been held on proficiency tests for improving the credibility of analysis data, and in response to that, the NDF is considering test methods to confirm analytical techniques for solid waste.

The second meeting of the Characterization Plan Coordination Council is planned to be held in autumn 2024, and preparations are being made for establishing a fuel debris analysis evaluation and study working group (WG) in the Analysis Support Team as one of the WGs to address issues. As trial retrieval of fuel debris is to start, the fuel debris analysis evaluation and study WG will aim to discuss broadly and in depth the results of analysis of fuel debris as well as adhered materials and deposits obtained to date through PCV internal investigations, etc., and to apply the outcome of discussions in a cross-sectoral manner to all relevant fields such as accident progression analysis, storage and management, and processing and disposal. In addition, the WG will consider the data to be obtained from fuel debris samples, its importance, and how to obtain such data to contribute to future studies on the storage, management, processing and disposal. From the viewpoint of the continuity of discussions, members of the WG are to consist mainly of young or middle-ranked researchers, engineers, etc., who will be able to participate in discussions for the next 10 years at least, and TEPCO will attend the WG as an observer in a bid to develop its analysts and analysis engineers through discussions.

[109] Agenda, The 1st Characterization Plan Coordination Council, August 24, 2023

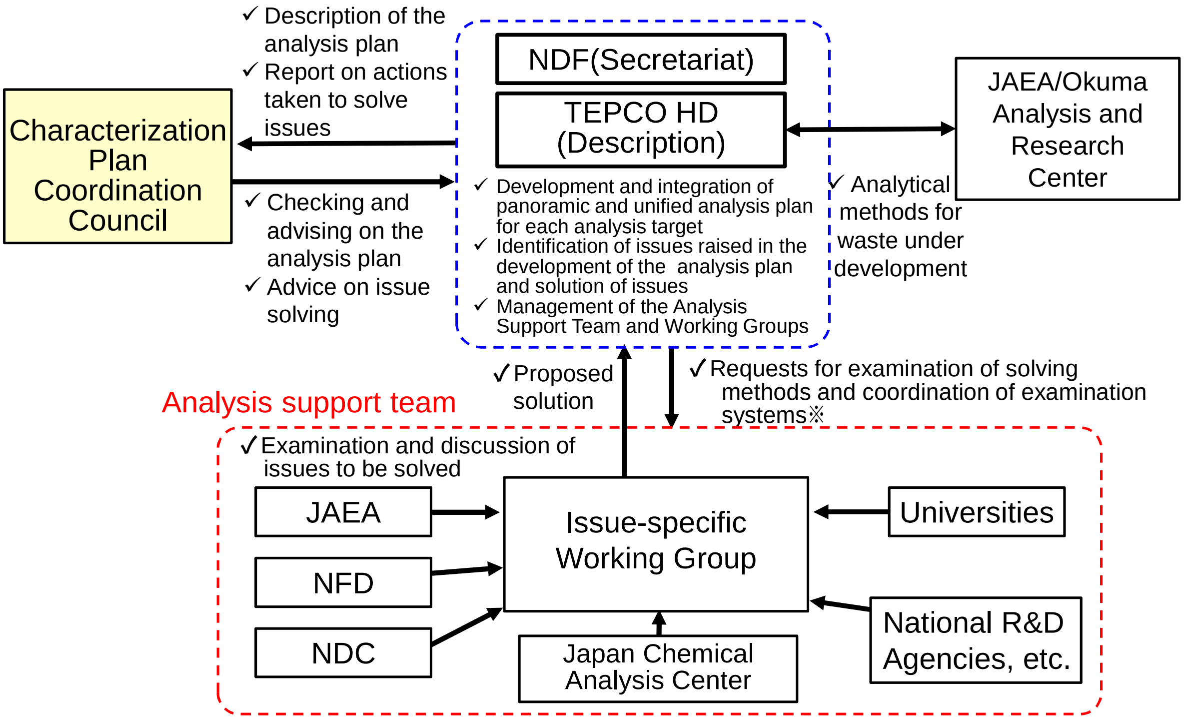

Fig. 55 Structure of the Characterization Plan Coordination Council and Analysis Support Team

4.2.2 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 difficult to identify and quantify all elements and isotopes down to trace components by analysis. As such, it is important to have a multifaceted point of view on the analytical results of samples in consideration of the impact of the error factor. As part of the verification of sample analysis results, through studies in light of existing findings, such as results of analysis, investigation, and testing, deriving consistent property evaluations will improve the reliability of analysis results, leading to higher quality in the analysis results.

To improve the quality of analysis results, the JAEA, the NFD, NDC, and Tohoku University have been cooperating to conduct chemical analysis and structural analysis using the same samples since FY 2020.[110] [111]Currently, the Ibaraki area offices are conducting to analyze the Three Mile Island Unit 2 reactor (TMI-2) debris using the latest analytical techniques to expand the fuel debris

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[110] JAEA, FY 2022 final report on the subsidy program for the Project of Decommissioning, Contaminated Water and Treated Water Management, "Development of Analysis and Estimation Technology for Characterization of Fuel Debris (Development of Technologies for Enhanced Analysis Accuracy, Thermal Behavior Estimation, and Abbreviated Analysis)" starting FY2021, October, 2023

[111] Ikeuchi, Koyama, Osaka et al., JAEA, "Development of technology for improving analytical accuracy of fuel debris, FY2020 Outcome report, (Supplementary budget for the Project of Decommissioning and Contaminated Water Management)", JAEA-Technology 2022-021, (2022)

data. TEPCO and the JAEA are cooperating in implementing activities that estimate accident behavior.[112]

Furthermore, the BSAF, BSAF-2, PreADES, and ARC-F, which have been implemented as projects of the OECD/NEA as opportunities to have international discussions and acquire accident progression and fuel debris analysis and evaluation techniques, have come to an end, and the FACE project was launched in July 2022[113]. The scope of the FACE project is (i) in-depth discussions for accident progression and associated fission product behavior and H_2 combustion; (ii) characterization of uranium-bearing particles and establishment of techniques for future fuel debris analysis for D&D; and (iii) collection and sharing of data and information. There are 24 organizations from 13 countries participating in the project, with 6 organizations from Japan: NRA, Agency for Natural Resources and Energy, the JAEA, Central Research Institute of Electric Power Industry, the Institute of Applied Energy, and NDF.

As for solid waste, to perform characterization of all solid waste which exists in large amounts using the limited analytical data, an efficient approach to ensure the required accuracy will be essential, and efficient analytical planning methods utilizing the DQO process and statistical inventory estimation methods with Bayesian statistics are being developed. Accuracy is one of the indicators for the quality of analytical data, but accuracy and measurement time are interrelated, and it is expected that increasing the measurement time can improve accuracy. However, if measurements take weeks or months, it is difficult to keep up with the increasing volume of analysis. Therefore, according to the analytical purpose, objects to be analyzed, and analytical method, it is also important to properly select the accuracy, measurement time, and measurement frequency based on the concerned analysis method.

4.2.3 Diversification of analytical techniques to increase sample size and volume

4.2.3.1 Comprehensive evaluation by diversified analysis and measurement methods

The current sample analysis for adhered material or others is mainly performed using electron microscopes after transporting smear samples to facilities for analysis in the Ibaraki area. Since density, hardness, and other items cannot be measured for micro or very small quantity of samples, it is necessary to increase the size and quantity of samples in accordance with the progress of the fuel debris retrieval process. A manipulator is used in an analysis process in a hot cell. Since it requires time for each process and the amount to be used in each hot cell is restricted for each

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[112] JAEA, FY 2022 final report on the subsidy program for the “Project of Decommissioning, Contaminated Water and Treated Water Management (Development of Analysis and Estimation Technologies for Characterization of Fuel Debris [Development of Estimation Technologies of RPV Damaged Condition, etc.])” starting FY 2022, September, 2023

[113] Organization for Economic Co-operation and Development/Nuclear Energy Agency, “Post-Fukushima Daiichi accident nuclear safety project FACE begins”, 2022

nuclide that can be handled, it is difficult to analyze many samples. Consequently, there is a large gap between the volume to be retrieved/stored and the amount of samples for analysis.

Particularly, since fuel debris is heterogeneous, 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. Given the limitations on improving the quality of analysis and sample volume, it is necessary not only to focus on increasing the number of analysis samples in conventional hot labs but also to diversify analysis and measurement methods. It is effective to assess the advantages and disadvantages of the analysis items obtained by other methods, consider complementing each other according to the use of the analysis results, and make a comprehensive evaluation. Depending on the application, it may also be worth considering methods that can only measure single items.

4.2.3.2 Use of sample analysis and non-destructive assays

Although sample analysis in a hot lab can measure many analysis items, the time required for analysis is long and the amount analyzed at one time is small. Since the samples themselves contain nuclear fuel and are likely to be adhered to with fine particles of radioactive materials, they carry the risk of exposure accidents and the spread of contamination. It is difficult to analyze large quantities of samples promptly because a certain amount of resources is to be allocated to curing equipment, decontaminating, and treating the radioactive liquid waste generated during analysis.

One of the analysis and measurement methods that complement the results of sample analysis is to evaluate the amount of nuclear fuel and radioactivity without destroying the sample using radiation, quantum, etc., emitted, scattered, or transmitted from the sample (hereinafter referred to as “non-destructive assay”). Table 8 shows the relative comparison of the items for sample analyses to be performed inside the facility for analysis and for non-destructive assays to be performed outside the facility for analysis and the sample amounts. Although sample analysis can measure many analysis items, the time required for analysis is long, and the amount analyzed at one time is small. Among the solid wastes, those with a high radiation dose generated during retrieval of fuel debris are measured with γ-rays from Cs-137, Co-60, etc., which can be measured non-destructively. With these nuclides as indicators, technology development is underway to evaluate the radioactivity of other difficult-to-measure nuclides. Although non-destructive assay can measure fewer items than that of sample analysis, the measurement time is shorter, 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, generating no radioactive waste liquid.

Table 8 Relative comparison of principal specifications between the sample analysis in the facility for analysis and the non-destructive assay outside the facility for analysis

	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.

Since fuel debris has entrained the surrounding control rods (neutron absorbers) when the nuclear fuel melted, there are concerns about the accuracy of non-destructive measurement techniques using neutrons. Moreover, if the fuel assembly was intact, a method to evaluate burnup could be used by measuring γ-rays from Cs-137, a γ-ray source with a strong penetration force. However, due to the volatilization of Cs-137 during the melting of nuclear fuel, the γ-ray doses and burnup have become incomparable. Thus, since fuel debris has impediments to non-destructive assays, it is necessary to verify the extent to which these impediments affect measurements. Therefore, the Project of Decommissioning, Contaminated Water and Treated Water Management promotes technology development aiming at on-site application through simulation analysis and actual measurement tests using existing testing devices.[114]

As an example of the application of non-destructive assay, Fig. 56 shows its use in the handling process from fuel debris retrieval to storage/management. In the figure, [the non-destructive assay ①] aims to classify the level of the solid waste, [the non-destructive assay ②] to maintain subcriticality, and [the non-destructive assay ③] to price waste for transportation and storage. Fig. 56 shows one example, and the flow may change depending on future R&D and study results. If non-destructive assay can be performed on fuel debris containers or solid waste storage containers, it will be possible to support the number of sample analyses, promptly verify the mass less than the minimum critical mass, transition to the following process in a subcritical condition, and reduce the burden during storage/management. In so doing, it is desirable to keep the range of uncertainty in

114 IRID, Final report on the subsidy program for the Project of Decommissioning, Contaminated Water and Treated Water Management "Development of Analysis and Estimation Technologies for Characterization of Fuel Debris (Development of Non-Destructive Measurement Technologies for Sorting and Segregation of Fuel Debris and Others)" starting FY 2022, October 2023, 2023

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 sample collection, to improve the reliability of the data.

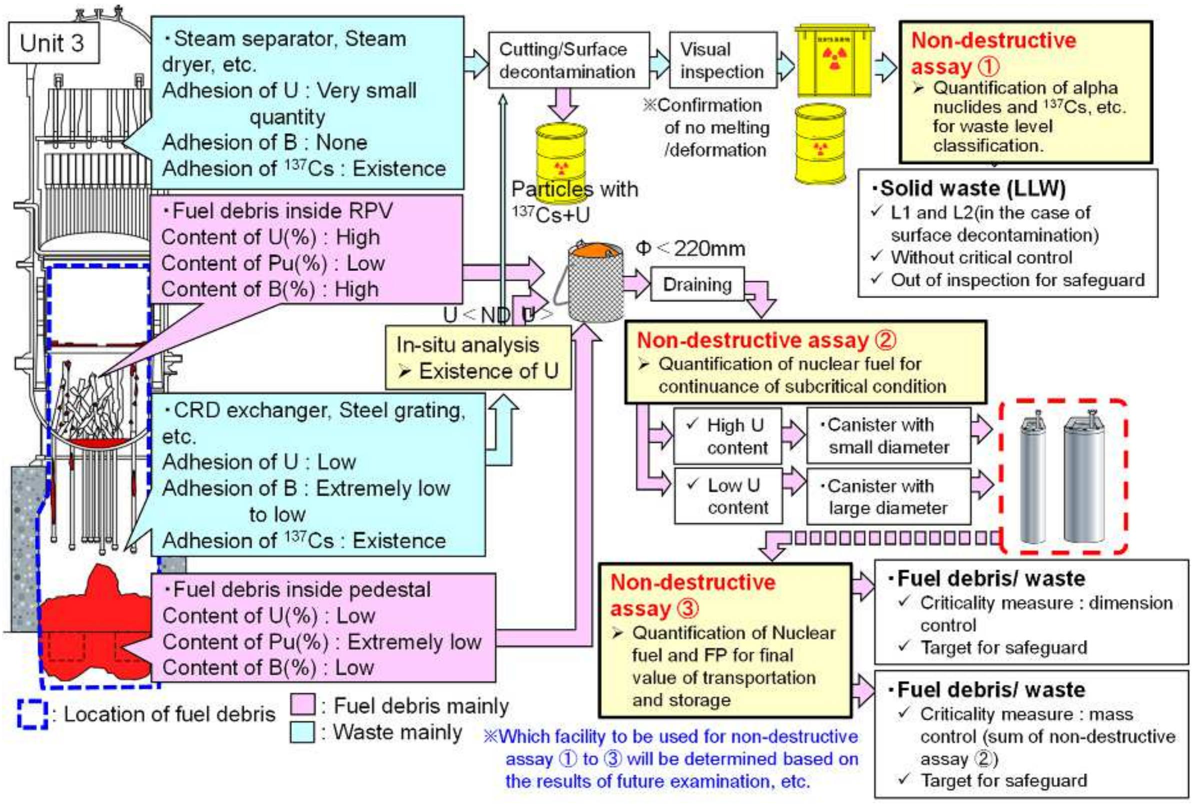


Fig. 56 An example flows of non-destructive assay in the handling process for retrieved fuel debris

Among non-destructive assay techniques, methods that detect neutrons from nuclear fission and those that use the scattering of elementary particle muons are effective for measuring fuel debris containing nuclear fuel and solid waste contaminated with α-ray emitters, but unsuitable for solid waste not containing α-ray emitters. On the other hand, methods for measuring γ-rays from fission and activation products and external measurement methods using X-ray CT can obtain information on the contents of containers even for solid waste that does not contain α-ray emitters, and are in practical use in industrial and medical applications.

4.2.3.3 Improvement in number of analyses

At the time of fuel debris retrieval, a large number of samples will have to be taken and analyzed to monitor the contamination status. A small amount of radionuclides or minimal energy discharge in these samples will undergo mass spectrometric analysis because their radiation is difficult to detect. More samples mean longer time for overall analysis, including pretreatment, thus hindering the monitoring of the contamination status. To increase the rapidness and efficiency of the analysis of nuclear fuel materials and difficult-to-measure nuclides, efforts are ongoing to develop techniques to automatically quantify these materials at the same time.

Although it is important to increase the number of analyses for each sample to obtain a complete picture, the number of analyses is insufficient for cases with a high radiation dose, such as fuel debris and cesium adsorption vessel samples, for which sampling is difficult. It is also important to improve the number of samples collected through the development of a sampling device.

4.3 Summary of analysis strategies

4.3.1 Analysis of fuel debris

Fuel debris samples taken during the trial retrieval of fuel debris will be transported to the Ibaraki area to start analysis. In preparation for that, progress has been made in the establishment of a fuel debris analysis system, improvement of the accuracy of analysis results, and domestic and international discussions. If the number of samples analyzed per year is around 6 to 12, there is expected to be enough capacity to handle them, including transport to the Ibaraki area. Therefore, it has been determined that the Ibaraki area can sufficiently handle fuel debris analysis associated with trial retrieval. However, in the subsequent gradual expansion of fuel debris retrieval, the number of samples to be analyzed will keep increasing, and therefore the establishment of the Radioactive Material Analysis and Research Facility Labotratory-2 of JAEA needs to be steadily promoted to ensure reliable analysis of samples. For further expansion of the retrieval scale that comes after that, it is important to consider establishing a comprehensive analysis facility and to collaborate with the technological development of non-destructive measurement systems and simplified analysis. As the fuel debris processing/disposal method is to be determined in Phase 3, there is a need to consider ways to obtain processing/disposal data from the retrieved fuel debris, such as measurement of thermophysical properties and the amount of hydrogen generated from water radiolysis. For this purpose, studies in these issues are accelerated with the start of trial retrieval.

4.3.2 Analysis of solid waste

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

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

5.1 Significance and the current status of research and development

There are many difficult technical issues requiring research and development in promoting the decommissioning of the Fukushima Daiichi NPS from the safety, reliability, efficiency, timeliness, and field-oriented perspectives. Based on the recommendations about the selection of retrieval method made by the Sub-Committee in March 2024, it is necessary to prioritize and accelerate research and development in consideration of the on-site application to prepare for the further expansion of the retrieval scale, which is planned for the 2030s.

To solve these technical issues, various industrial-academic-governmental entities, including overseas enterprises, are engaged in basic/fundamental research and application research by universities inside and outside Japan and by researching institutions such as the JAEA, and in applied research, practical application research and on-site demonstrations by manufacturers and TEPCO (Fig. 57).

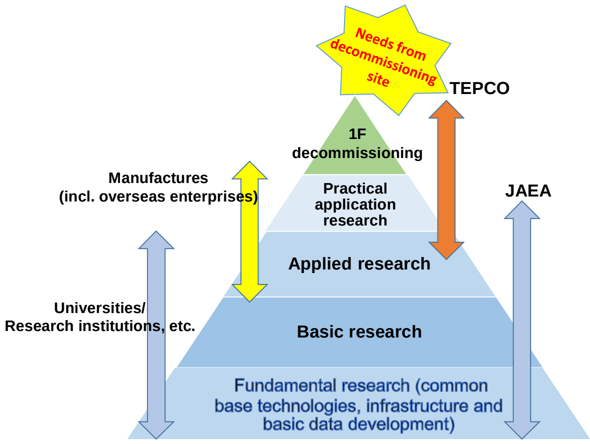


Fig. 57 Scope of studying decommissioning R&D and implementation entities

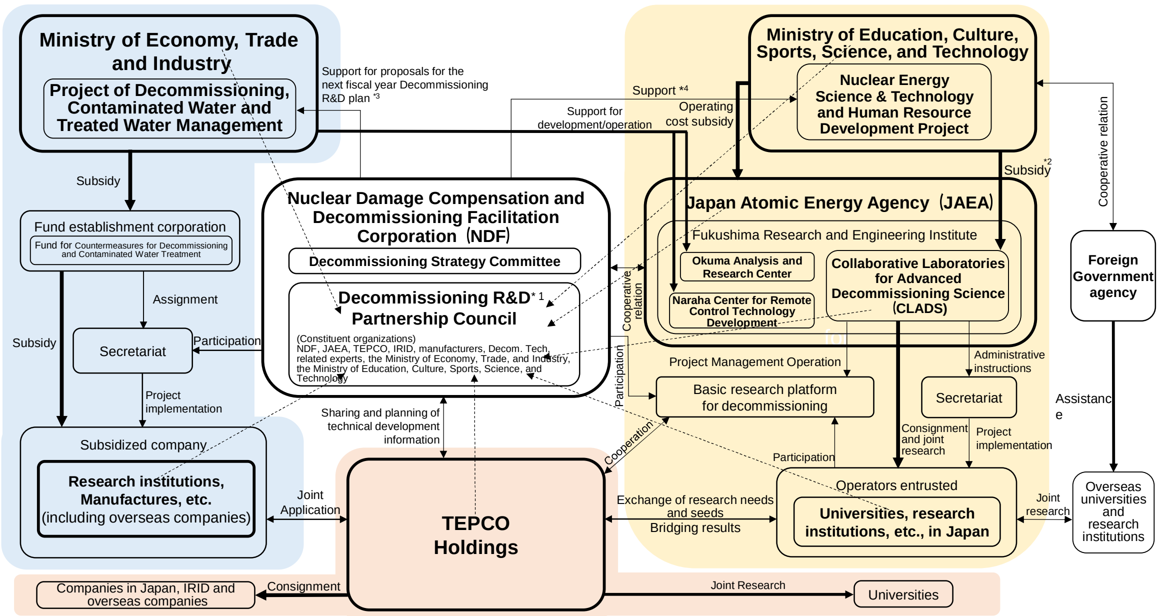
For applied research and practical application research for decommissioning, the government provides support for the R&D carried out by each organization to solve highly difficult issues through the Project of Decommissioning, Contaminated Water and Treated Water Management (hereinafter referred to as “Decommissioning Subsidized Project”) and to promote basic/fundamental research and human resource development by universities and researching institutions in Japan and overseas through the Nuclear Energy Science & Technology and Human Resource Development Project (hereinafter referred to as “the World Intelligence Project”).

TEPCO has been working on technology development that is directly linked to on-site applications. It identifies research and technology development issues and examines solutions related to the Mid-and-Long-term Decommissioning Action Plan, manages the progress of technology development, and incorporates them into the development plan.

NDF is considering the planning of the R&D medium-and-long-term plan and the next-term R&D plans for the Decommissioning Subsidized Project, while supporting the World Intelligence Project. NDF has also established the Decommissioning R&D Partnership Council with representatives of institutes involved and intellectuals from universities as its members, which discusses information sharing on needs and seeds for R&D, adjustment of R&D based on the needs of decommissioning work, and issues in promoting cooperation related to R&D and human resource development. Moreover, coordination between basic/fundamental research and applied/practical application research has been promoted mainly through the Decommissioning R&D Partnership Council.

The JAEA, as the executing entity of the World Intelligence Project, promotes basic/fundamental research and human resource development. It also plays a significant role in R&D related to analysis and estimation for the characterization of fuel debris and waste management by leveraging its knowledge and experience in the Decommissioning Subsidized Project. The JAEA restructured its organization in April 2024 and renamed its Sector of Fukushima Research and Development to Fukushima Research and Engineering Institute.

Decommissioning R&D includes three major developments, they are the Decommissioning Subsidized Project implemented by the Ministry of Economy, Trade and Industry; the World Intelligence Project implemented by the Ministry of Education, Culture, Sports, Science and Technology; and TEPCO's own technological developments. The R&D implementation structure is outlined in Fig. 58.



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

Fig. 58 Overview of the R&D structure of the decommissioning of Fukushima Daiichi NPS

Given that the progress of investigation inside the reactors has clarified on-site needs in decommissioning and that TEPCO has begun engineering work for fuel debris retrieval, since FY

2023, the leading players in the Decommissioning Subsidized Project have been shifting from the current International Research Institute for Nuclear Decommissioning (hereinafter referred to as “IRID”)-centered structure to a system where researching institutions and manufacturers are the key implementers, based on TEPCO’s needs. This calls for smooth coordination between the R&D players and TEPCO. To cope with this shift in implementing entities, NDF launched the Request for Information (hereinafter referred to as “RFI”) program in FY 2022 and reviews of subsidized projects in FY 2023, enhancing its support for the Decommissioning subsidized Project in projects proposals to address R&D details and in improvement of the actual site applicability of subsidized projects.

In March 2024, the Sub-Committee released a report, which included Recommendations for selection of method for retrieval of fuel debris. In response to this, in view of further expansion of the retrieval scale planned for the 2030s, TEPCO is proceeding with engineering, while the relevant organizations (TEPCO, JAEA, NDF, etc.) will be required to study issues including basic/fundamental research and to prioritize and accelerate R&D on fuel debris retrieval in the Decommissioning Subsidized Project, the World Intelligence Project, and TEPCO's technological developments.

Investigation inside the PCV and the trial retrieval of fuel debris are underway at the Fukushima Daiichi NPS. Used for these purposes are an ROV and other equipment designed for investigation inside the PCV, as well as robot arms, which are development results of the Decommissioning subsidized Project. In addition, small wireless drones, serpentine robots, and telescopic-type device technologically developed by TEPCO are also used, indicating that the Decommissioning subsidized Project is combined with TEPCO’s technological development in a supplementary manner. TEPCO’s technological development should continue earnestly in the future, while sharing the roles of the decommissioning subsidized project.

The results of the World Intelligence Project, including LIBS[115] for in-site analysis and geopolymers used as a candidate filler material for fuel debris retrieval, have been addressed in the R&D under the Decommissioning Subsidized Project to pursue development for on-site application. Coordination between basic/fundamental research and applied/practical application research has been enhancing and should be promoted even more.

NDF will continue opinion exchanges on the status of R&D and human resource development in the Fukushima Institute for Research, Education and Innovation (F-REI) and taking into account that research and development of robots that can be used for decommissioning is conducted in F-REI, TEPCO, F-REI, and NDF will share information.

115 Laser Breakdown Spectroscopy: A technique that can be used to quickly measure the elementary composition of the subject, such as a gas, liquid, or solid, by directly focusing a laser pulse onto the subject to generate plasma. The resulting plasma emits light, which undergoes spectral analysis for the measurement.

5.2 Key issues and strategies

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

NDF and TEPCO have been preparing and updating the R&D medium-and-long-term plan for the decommissioning of the Fukushima Daiichi NPS every fiscal year since fiscal 2020. The plan overlooks the overall research and development for about the next 10 years for decommissioning, so that R&D activities for decommissioning of Fukushima Daiichi NPS can be promoted comprehensively, systematically, and efficiently. Based on TEPCO's Mid-and-Long-term Decommissioning Action Plan, which sets forth the specific decommissioning work process toward the implementation of the government's Roadmap, the R&D medium-and-long-term plan has been developed to identify the required R&D and appropriately incorporate R&D results when needed. To make this plan a comprehensive one that covers overall decommissioning R&D, from basic/fundamental to applied/practical application research, relevant basic/fundamental research projects have been included since FY 2022. In FY 2023, TEPCO, Decom.Tech, JAEA, and NDF started activities to share issues in the R&D on the decommissioning of the Fukushima Daiichi NPS for closer cooperation (hereinafter referred to as the "Four Party Cooperative Activities"), and since have been reflecting the study results into the R&D medium-and-long-term plan. In FY 2024, in response to the recommendations on the selection of retrieval method made by the Sub-Committee, a special task force established in the Four Party Cooperative Activities will proceed with studies on issues including basic/fundamental research and on specific approach to implementation, after identifying R & D that should be prioritized and accelerated, the results is incorporated into the R&D medium-and-long-term plan. R&D medium-and-long-term plan is shown in Attachment 17.

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

(1) Overview of the Project of Decommissioning, Contaminated Water and Treated Water Management

The government has been supporting R&D to help resolve various decommissioning issues since FY 2011, immediately after the Fukushima Daiichi NPS accident. To solve technically challenging issues for decommissioning, the government launched in FY 2013 the Decommissioning Subsidized Project and has since been supporting R&D activities conducted by each institution.

a. Purpose of the project

The purpose of the Decommissioning Subsidized Project is to ensure under the state initiative that actions for decommissioning, contaminated water and treated water management are implemented safely and steadily by supporting technically challenging R&D activities in the course of decommissioning.

b. Framework of the project

R&D support is provided through the fund formulated by state subsidies.

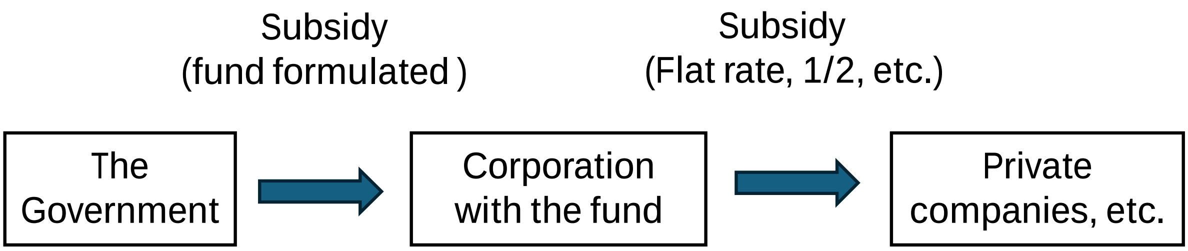


Fig. 59 Framework for Decommissioning Subsidized Project

c. Previous activities

Major issues that need to be resolved before the decommissioning of the Fukushima Daiichi NPS can be accomplished are as follows:

① Remove spent fuel assemblies from the spent fuel pools and store them safely
② Treat contaminated water and reduce its generation amount
③ Retrieve fuel debris produced by core meltdown and store it safely
④ Store, treat, and dispose of waste from the accident and future waste from fuel debris retrieval

Among the above, R&D projects to ① remove spent fuel assemblies from the spent fuel pools and store them safely and ② treat contaminated water and reduce its generation amount started in FY 2011. Once the resolution of urgent issues was in sight, these projects were finished by FY 2016 and moved to TEPCO's engineering phase. R&D projects to ③ retrieve fuel debris and ④ address waste management, which require a broad spectrum of studies and involve challenging technical issues, are still ongoing, continuing since they were launched immediately after the FY 2011 accident. Attachment 18 shows R&D activities conducted to date and their major results.

d. Ongoing R&D activities

Ongoing R&D activities and relationships among them are shown below. For each R&D theme, the reason for selection, development results, and challenges faced are described in Attachment 19.

[R&D concerning fuel debris retrieval]

- PCV internal investigation
- RPV internal investigation
- R&D on characterization of fuel debris
- R&D on environmental improvement inside reactor buildings
- R&D on the fuel debris retrieval method
- R&D on safety systems
- R&D on fuel debris containment, transportation, and storage
- Development of supporting technologies for the integrated management of the decommissioning of the Fukushima Daiichi NPS

[R&D concerning waste management]

- R&D for processing/disposal of solid waste

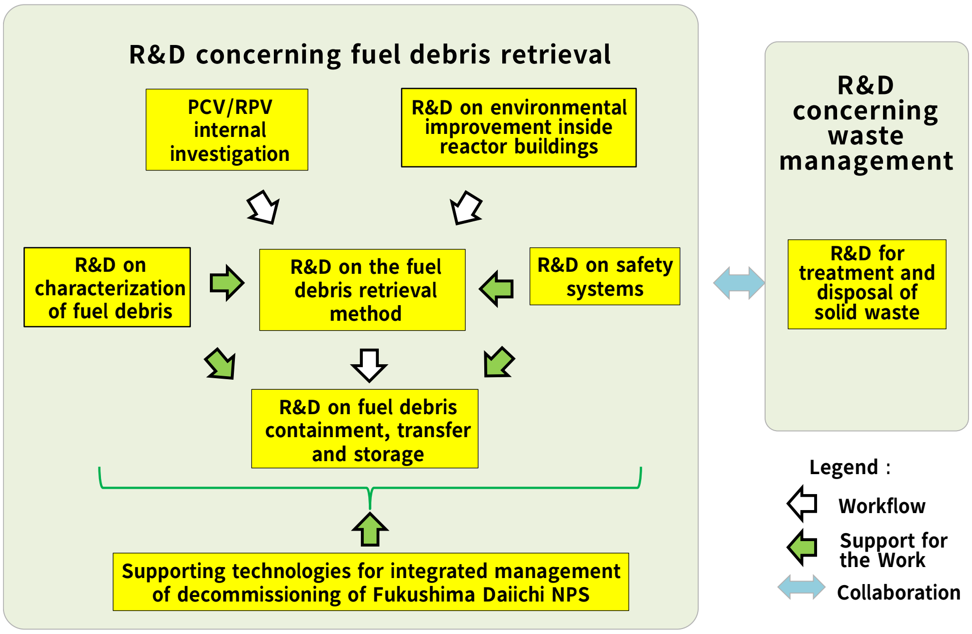


Fig. 60 Relationship between each R & D

Although the implementation of the Decommissioning subsidized Project has gradually clarified the conditions inside the reactors and facilitated discussions to resolve the issues, there should still be many R&D challenges that need to be overcome before the completion of decommissioning. Going forward, the Decommissioning subsidized Project should be continued as a key R&D project for the completion of decommissioning.

(2) The next fiscal year’s decommissioning R&D plan

In order to smoothly and steadily facilitate the Decommissioning subsidized Project, NDF is formulating the next fiscal year’s decommissioning R&D plan for the next two years. The next fiscal year's decommissioning R&D plan is coordinated and reviewed by TEPCO and the Ministry of Economy, Trade and Industry (METI), confirmed by the R&D Planning Meeting, which also includes the Ministry of Education, Sports, Culture, Science and Technology (MEXT), and then deliberated on by the NDF's committees, the Fuel Debris Retrieval Expert Committee and Waste Management Expert Committee, before being discussed by the Decommissioning Strategy Committee, etc. and summarized as an NDF proposal. This next fiscal year’s decommissioning R&D plan was reported by METI to the Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, then the Decommissioning subsidized project has been implemented accordingly. The list of FY2024 decommissioning R&D plans as the next fiscal year’s decommissioning R&D plan reported at the 123rd Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water held in February 2024[116] is shown in Fig. 61.

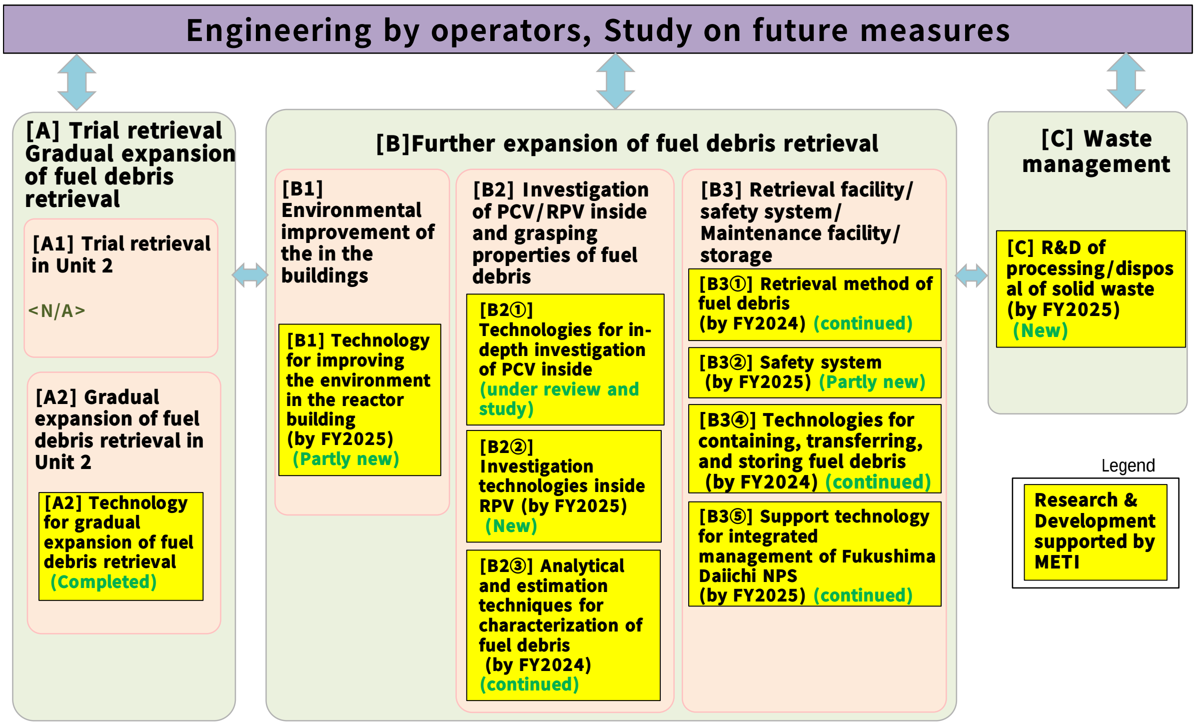


Fig. 61 List of FY 2024 decommissioning R&D plans

In developing the next fiscal year's decommissioning R&D plan, past R&D results are evaluated to identify emerging issues and issues whose level of achievement should be improved, and technical issues are being organized by selecting issues that need to be discussed from the viewpoints of necessity and priority, among issues raised by the public in response to RFI that were made to widely solicit information on the R&D details to be addressed toward the decommissioning of the Fukushima Daiichi NPS. 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.

During the current fiscal year's discussions on the next fiscal year's decommissioning R&D plan, now that the Sub-Committee has made recommendations on the selection of the fuel debris retrieval method, such selection will be made focusing on technical issue based on the recommendations.

[116] Material 4: "FY2024 decommissioning R&D plans", The 123rd Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, February 29, 2024

(3) Issues and responses concerning the Project of Decommissioning, Contaminated Water and Treated Water Management

As described in Section 5.1 Significance and the current status of research and development, decommissioning research and development are changing from an IRID-led effort to a stage where TEPCO's engineering-based development is being advanced. In light of these changes in the situation, the implementation of the Decommissioning Subsidized Project has been led by researching institutions and manufacturers since FY 2023, and TEPCO applies for subsidies jointly with subsidized operators to facilitate cooperation with them and is responsible for project management. To cope with the transition to this new implementation structure, NDF conducts RFI for ensuring its capability to propose and plan R&D, and project reviews for enhancing the function needed for securing the actual site applicability of R&D results, thus implementing the Decommissioning Subsidized Project smoothly and steadily (Fig. 62).

a. Request for Information (RFI)

As R&D planning and proposal, a request for information (RFI) is an initiative to widely solicit information on R&D details to be addressed toward decommissioning the Fukushima Daiichi NPS. Specifically, 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), the scale of R&D, potential joint R&D partners, and R&D fields. The previous IRID-led system for subsidized projects had faced challenges, such as the lack of new participation by business operators and the unearthing of development seeds for new research. Therefore, the aim is for the RFI to broaden the base of operators who join the Decommissioning Subsidized Project and to widely collect R&D seeds through public solicitation, which will lead to accelerated resolution of issues in decommissioning.

In response to the RFIs made in FYs 2022 and 2023, nearly 100 proposals were submitted during the two years, and many of them were incorporated into the next fiscal year's decommissioning R&D plan. These RFIs were also successful in terms of attracting new participants to the Decommissioning Subsidized Project, as demonstrated by the fact that multiple overseas operators and universities submitted proposals and that some universities were selected as subsidized operators in new calls for applications for Decommissioning subsidized project in the current fiscal year as a result of their proposals made in response to RFIs. A new attempt has been made in this fiscal year's RFI to discover new seeds for R&D concerning the fuel debris retrieval method by adding the Sub-Committee's report. There will be continued efforts to improve the system.

b. Project review

The project review is an initiative for Decommissioning subsidized projects in which experts and relevant organizations verify subsidized operators' activities of planning, testing, design, and production at an appropriate time from the following perspectives after setting appropriate milestones for the achievement of the objectives, and provide necessary guidance and advice.

- Determine whether a plan aligns with the set target
- Check practical engineering and applicability to actual site

In FY 2023, 10 projects that were launched during the year were reviewed, and guidance and advice (hereinafter "recommendations" collectively) were given to each project, based on the results of verification by experts and relevant organizations. These recommendations covered various aspects, such as investigation and application of similar cases, coordination with other projects, points to note in practical application, and how to summarize the results. The operators said that they would incorporate these recommendations into their projects. In this fiscal year, the target of project reviews are four subsidized projects that started during the year, in addition to the review of nine of the above ten decommissioning subsidized projects that have continued this year,

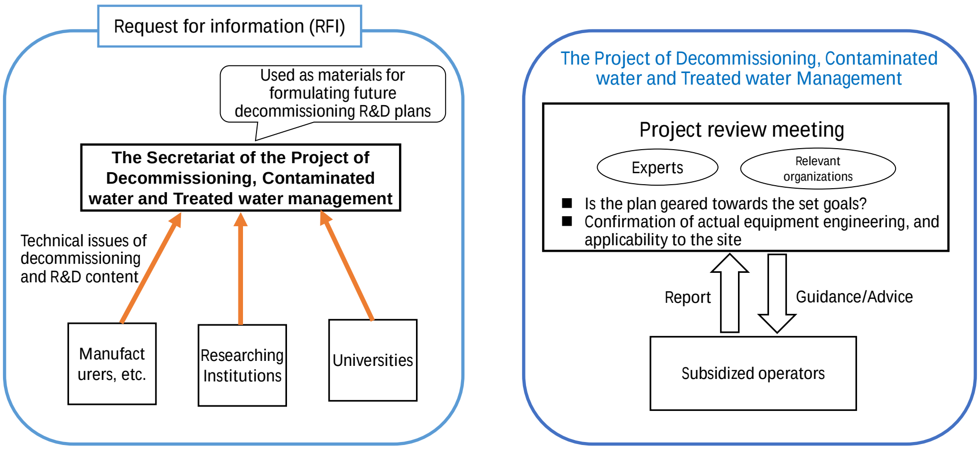


Fig. 62 RFI and project review

The Decommissioning subsidized Project should finish once the targeted results are obtained and be transferred to the next phase, which takes the form of TEPCO's engineering or TEPCO's own technological developments. In addition, regarding the outcome of the development that has been conducted through the Decommissioning Subsidized Project, since the decommissioning of the Fukushima Daiichi NPS is a national/social issue, the challenge is establishing an easily accessible structure where organizations involved in the research and development for decommissioning can make effective use of the R&D results, including the knowledge obtained. Therefore, the outcome should be archived in view of disclosing the results and sharing knowledge, and R&D results obtained under the IRID-led implementation structure are being transferred mainly to TEPCO. There is a need to build a system for archiving, and this should include aggregating and utilizing R&D results under a new implementation structure.

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

(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 faced by 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.

Against 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 over the boundaries of the nuclear field, and through close coordination and alignment including international joint research. The Collaborative Laboratories for Advanced Decommissioning Science, Fukushima Decommissioning Safety Engineering Research Institute, JAEA (hereinafter referred to as “JAEA/CLADS”) is responsible for the implementation of the World Intelligence Project, ensuring that cooperation between universities and researching institutions is strengthened, and that R&D and human resource development for decommissioning are conducted more stably and continuously over the medium to long term. In the call for proposals for the World Intelligence Project, the overall map of basic/fundamental research is used[117] 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.

In the FY 2024 World Intelligence Project, two programs, the issue-solving decommissioning research program and the decommissioning research program based on development of research human resources have adopted new issues. Attachment 20 shows the selected issues of the World Intelligence Project adopted in the past.

- Issue-solving decommissioning research program

  The program focuses on, among the issues identified in the overall map of basic/fundamental research, R&D that contributes to the resolution of issues “conducive to

[117] The overall map of basic/fundamental research compiles the necessary research elements based on the six Essential R&D Themes. The Six Essential R&D Themes were identified by a task force on research collaboration established in NDF in 2016 and summarized in an interim report of this task force (November 30, 2016).

the resolution of issues through pursuit of basic/fundamental research" and on R&D that leads to specific needs selected from among the needs at the decommissioning site.

- Decommissioning research program based on development of research human resources

  The program aims to nurture human resources capable of dealing with the issues under severe environment through decommissioning research as well as to develop international human resources for research who are needed for future decommissioning operations at the Fukushima Daiichi NPS.

In the International Collaborative Decommissioning Research Program, the continued issues are being implemented in this fiscal year, and implementation including new issues are being considered in the next fiscal year or beyond.

In the implementation of these programs, 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. In addition, external experts have been appointed as Program Officers (PO) to keep track of the progress of each R&D project, and JAEA staff members have been appointed as Research Supporters (RS) to work toward maximizing the research outcomes and their application to the decommissioning sites[118].

Going forward, it is essential to widely publish the results of the World Intelligence Project in order to convey research results to the decommissioning site. After the completion of each project, research results are compiled into a JAEA report. Videos that help visually understand the research results have also been available since FY 2022 at the website of JAEA/CLADS[119]. Easy access to the R&D results is also needed to ensure that remaining issues are deeply addressed and that the outcomes can be developed further. The JAEA has been working on the construction of databases for this purpose and offers JOPSS[120], which enables keyword-based searches through research papers not only from the World Intelligence Project but also from the JAEA.

As stated above, while proceeding with efforts to adequately apply basic/fundamental research results contributing to issue-solving to decommissioning sites. It is important to continue to promote better matching needs from decommissioning sites with seeds at universities/researching institutions by using the opportunity of Decommissioning R&D Partnership Council and serve as a bridge to share outstanding research results obtained mainly in the World Intelligence Project.

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[118] Research Supporters are JAEA personnel who support research as the JAEA individual World Intelligence Project-adopting institutions.
[119] Video introduction of research in JAEA/CLADS（https://clads.jaea.go.jp/video/）
[120] JAEA Original Paper Searching System（https://jopss.jaea.go.jp/search/servlet/interSearch）

(2) Collaboration between basic/fundamental research and applied/practical application research, and initiatives for business-academia collaboration by TEPCO

To deepen the matching between needs and seeds and to coordinate R&D for decommissioning from basic/fundamental research to applied/practical application research, there have been efforts such as workshops for the matching between needs and seeds in the World Intelligence Project, and the Four Party Cooperative Activities.

To demonstrate collaboration between the World Intelligence Project (basic/fundamental research) and the Decommissioning subsidized Project (applied/practical application research), some of the results of the World Intelligence Project have been applied to the Decommissioning subsidized Project. Going forward, the key is to enhance and foster collaboration between basic/fundamental research and applied/practical application research with a view to breaking through challenges in the decommissioning work and improving safety and efficiency of the work.

NDF will strengthen such collaboration by having the task force, under the framework of the Four Party Cooperative Activities, discuss the issues including basic/fundamental R&D in light of the recommendations by the Sub-Committee on the selection of fuel debris retrieval method, as well as specific ways of collaboration for practical application of basic/fundamental research results. It should be noted that the application on site of research results will require closer collaboration with TEPCO.

On the other hand, 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 should further strengthen their cooperation for better matching needs with seeds and serve as a bridge to share outcomes.

(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. In R&D for the decommissioning of the Fukushima Daiichi NPS, the accumulation of such activities is expected to become a source of innovation.

The building for International Research Collaboration of JAEA/CLADS, located in Tomioka-machi, Fukushima Prefecture, has been in service since 2017. The facility is shared with universities, researching institutions, and other relevant organizations to conduct R&D and develop human resources for decommissioning. The JAEA, with JAEA/CLADS as its core, is establishing a system to promote R&D and human resource development by industrial-academic-governmental institutions in an integrated manner, while forming a network in which human resources from universities, researching institutions, and industries in Japan and overseas can interact with each other.

It is also important to build research and development infrastructures as physical resources. The (testing building of) 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 remote operation training and establishment of operating procedures, etc. Performance confirmation tests of robot-arm for trial retrieval of fuel debris, as well as verification tests and training in a simulated environment of the actual machine, have been conducted there since February 2022.

In Okuma Town, Fukushima Prefecture, to conduct research and development through characterization of solid waste and fuel debris for the decommissioning of Fukushima Daiichi NPS, the JAEA Okuma Analysis and Research Center (Radioactive Material Analysis and Research Facility) is under construction. Laboratory-1, where analysis of solid waste with low to medium radiation dose and third-party analysis of ALPS-treated water are to be conducted, was completed in June 2022, and its controlled area was set in October of the same year. The third-party analysis of ALPS-treated water began in March 2023, and skills qualification and demonstration tests of analytical methods have been conducted since April 2024 to prepare for full-scale analysis of waste samples. For Laboratory-2, designed for analysis of fuel debris and other high radiation dose samples, preparations are underway to start construction by the end of this fiscal year. It is desired that these facilities for analysis will be put into service at the earliest possible date as the data from the analysis and research will be utilized to establish a technical basis for the reliable processing/disposal method of radioactive waste and its safety, as well as to characterize fuel debris, toward decommissioning the Fukushima Daiichi NPS.

In this way, research facilities related to decommissioning projects by the JAEA are located in Fukushima Prefecture, where a global R&D center for decommissioning is being formed, and R&D infrastructures for medium-and-long-term prospects are being built (Fig. 63).

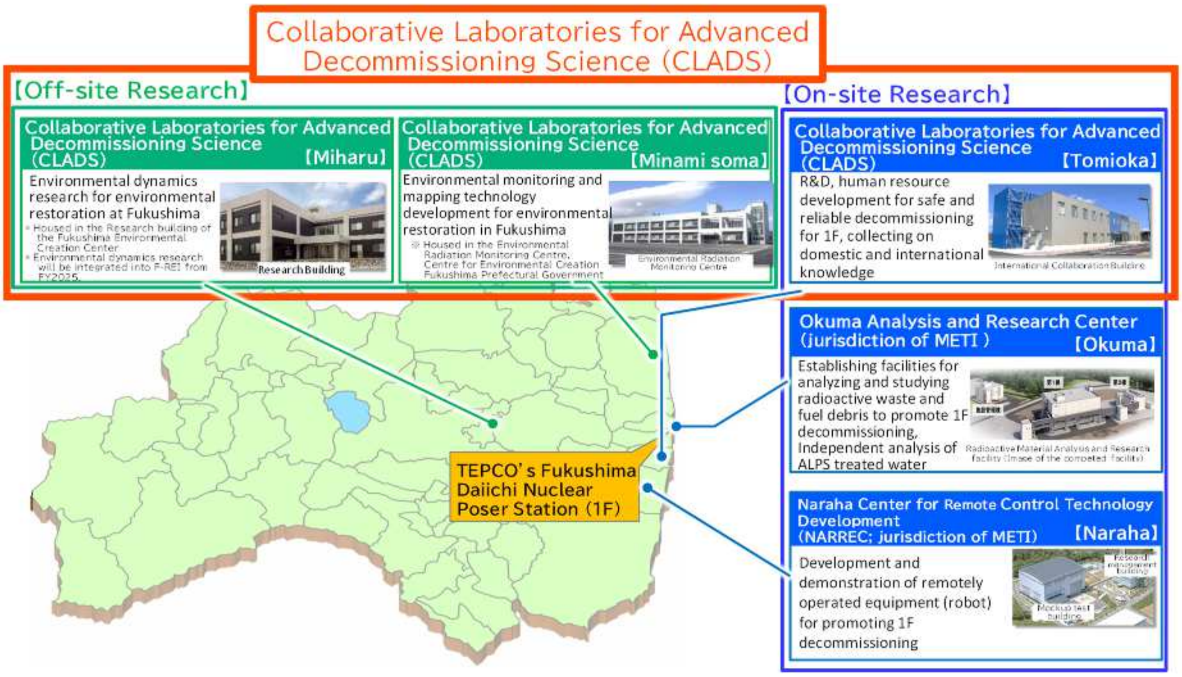

Fig. 63 Research centers for Decommissioning in Fukushima

6. Activities to support our technical strategy

6.1 Capabilities, organization, and personnel to proceed with decommissioning

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

As the site owner responsible for decommissioning the Fukushima Daiichi NPS, TEPCO manages decommissioning projects and is also responsible as a utility. While there are some roles common to both positions, how to implement the technical strategy required as a site owner of the Fukushima Daiichi NPS is extremely important for TEPCO to decommission the Fukushima Daiichi NPS. This section describes the current status of TEPCO's management of decommissioning projects, and the future efforts related to the capabilities and organization that TEPCO should have to support implementing the decommissioning technical strategy.

6.1.1.1 Significance and current status of decommissioning project management

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

TEPCO has been working to build and strengthen its project management system, which was reorganized in April 2020. Project-based organization management has been almost established through four years of operation. Now that it is in Phase 3-[1], the decommissioning work becomes more difficult and uncertain, and in order to smoothly coordinate and align the entire project with a view to the medium- to long-term, it will be more important than ever that the relevant organizations will further strengthen a management framework in cooperation with each other towards the goal to be achieved, and increase the collective strength.

Examples of main initiatives undertaken by TEPCO up to FY 2023 include reviewing the organization to appropriately meet changes in the site situation and social and local needs, enhancing risk management, and preparing a forward-looking plan (Mid-and-Long-term Decommissioning Action Plan). The major initiatives are listed below.

a. Reviewing the organization to appropriately meet changes in the site situation and social and local needs

Even after a major transformation into a project-oriented organization in April 2020, TEPCO has been flexibly and promptly reviewing its organization in accordance with changes in the site situation and social and local needs.

Table 9 shows major reorganization events that occurred between April 2020 and July 2024.

Table 9 TEPCO's reorganization events since April 2020

Date	Major changes	Purpose
April 2020	Establishment of the Project Management Office (PMO), Program Department, Decommissioning Safety and Quality Office, Design and Planning Center, Construction, Operation and Maintenance Center, and Disaster Prevention and Radiation Center	Enhance the project management function, enhance the safety and quality management function, and promote the focus on Hands-on approach and Actual spots principle (fact-finding).
October 2020	Hamadori Industry Project Office	Develop decommissioning-related industries and establish project schemes in line with the Mid-and-Long-term Action Plan for the decommissioning project.
August 2021	Establishment of the D&D Research & Development Center	Manage technology development concerning decommissioning and contaminated water management in an integrated manner to enhance engineering capacity.
August 2021	Establishment of the D&D Information & Planning Management Office	Set up the headquarters to communicate information meeting the local needs and drive equipment building.
September 2021	Establishment of the ALPS Treated Water Program Department	Mainly aimed at building relevant equipment and developing plans to ensure that organizational responsibilities are clarified and that the situation is ready for ALPS-treated water to be discharged into the sea in about two years after the adoption of the government policy.
May 2022	Establishment of the Security Management Department	Enhance physical protection and cyber security (by establishing an organization for the entire TEPCO Holdings).
July 2023	Establishment of the Office of Organizational Restructuring Preparation	Restructure the organizations relating to projects in Fukushima and foster closer cooperation among them.
July 2024	Establishment of the Water Treatment Center and abolishment of the ALPS Treated Water Program Department	Reorganize the team involved in the water treatment processes to ensure the safe and steady implementation of the series of water treatment processes, from the pumping up of stagnant water to discharge of ALPS-treated water into the sea, over the long term.
July 2024	Establishment of the Procurement Department and abolishment of the D&D Procurement Center	Manage nuclear and decommissioning procurement in an integrated manner to increase procurement capacity. Increase opportunities for participating in upstream processes, standardizing specifications, and managing suppliers in large projects, and perform contracting operating more efficiently.
August 2024	Establishment of Decommissioning Strategy Office	Further strategically promote the decommissioning toward its completion as trial retrieval of fuel debris was undertaken and the phase in the Mid-and-Long-term Roadmap shifts to Phase 3.

b. Strengthening of risk management

TEPCO has put efforts into risk management[121] associated with the operation of projects and risk management associated with the operation and maintenance of facilities to improve its risk management ability since it reformed itself into a project-based organization in April 2020. However, analysis of the four incidents[122] including body contamination during the cleansing of additionally installed ALPS pipes to find common issues discovered that risk management performed prior to starting on-site work (hereinafter referred to as “on-site risk management”) was insufficient, and TEPCO is working together with contracting companies on strengthening on-site risk management.

① Risk management associated with the operation of projects

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.

TEPCO is aware of the importance of risk management through actual decommissioning work and promoting efforts to strengthen systematic risk management in line with the workflow in Fig.64. In fact, there have been cases caused by a lack of risk awareness that should have been addressed in advance, such as delays in SGTS pipe removal operations[123]. There are a wide range of risks, such as those related to safety and project feasibility. In the future, the importance of risk management will increase to prevent or minimize the impact of such risks in the decommissioning work, which will become full-scale from Phase 3-[1].

121 Risk management refers to operation process to systematically manage risks to avoid or reduce losses, etc.

122 Total of four incidents; body contamination during the cleansing of additionally installed ALPS pipes (October 2023); leak of water containing radioactive materials from HTI (February 2024); fire alarm going off in additional solid waste incineration facility due to generation of steam in waste storage pit, etc. (February 2024); and loss of on-site electric power system A and personal injury (April 2024).

123 The pipe removal process was significantly delayed due to a lack of risk awareness, including the gap between the mock-up and actual on-site conditions, pipe-cutting equipment being stuck, oil leakage from the crane hydraulic hose, and cutting of parts where urethane was unfilled. This is considered a case where the risk became apparent due to insufficient risk management.

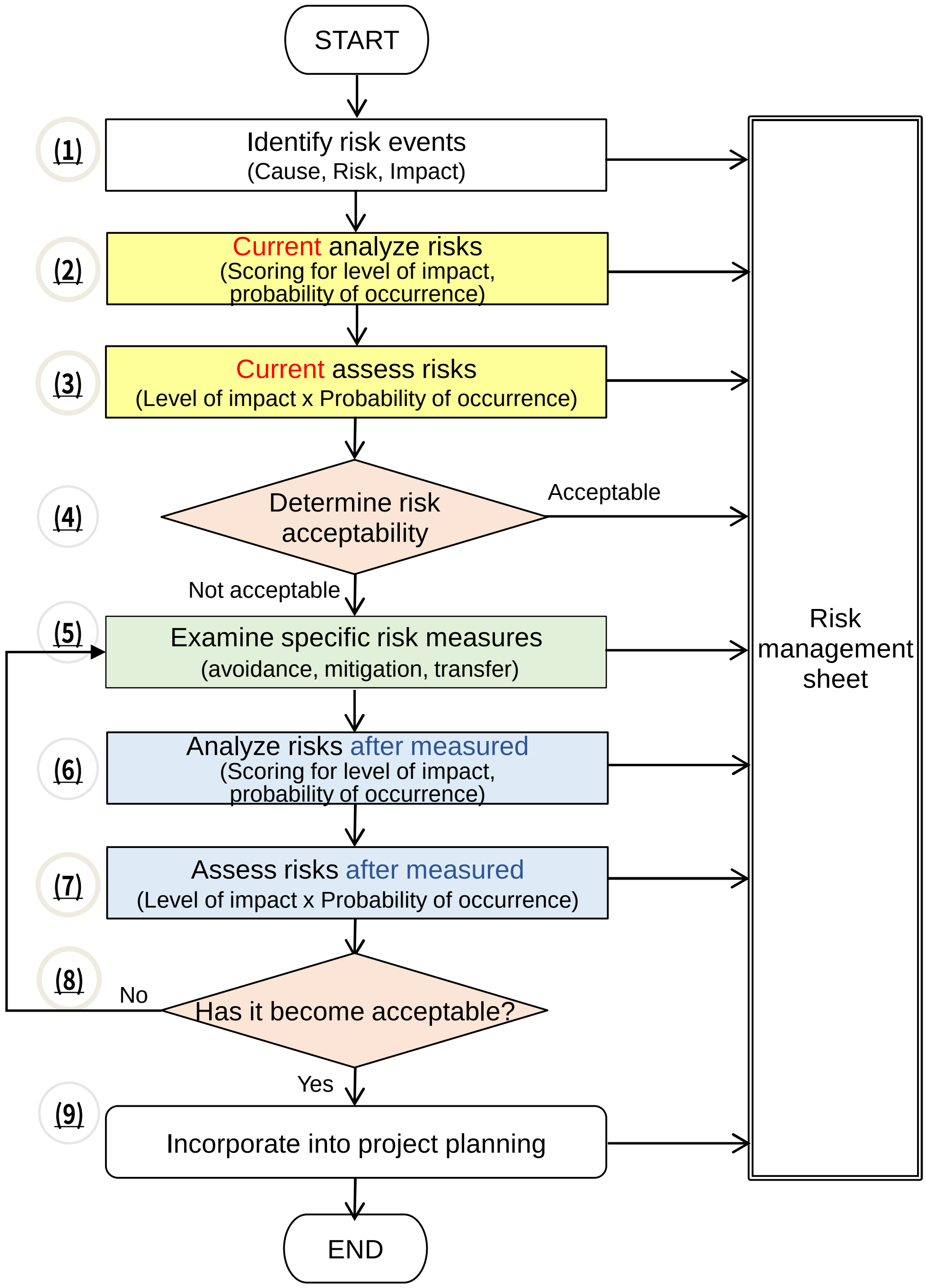

Fig. 64 Standard workflow of risk management

② Risk management associated with the operation and maintenance of facilities

Many facilities have been installed and operated at the Fukushima Daiichi NPS to proceed with decommissioning, and risk assessments need to be made for these facilities to ensure that they are properly maintained and operated. Therefore, as part of its risk management, TEPCO carries out risk assessments of facilities considered in the course of operating the facilities and evaluates the risks based on the probability of occurrence and the degree of impact. For facilities assessed as having a high risk, necessary responses are preferentially taken, and effective risk reduction measures are conducted. Furthermore, as a response to the aged deterioration risk of the above facilities, TEPCO is promoting the centralized management of facility information by incorporation of facilities subject to maintenance in a database format and is developing a system to assess aged deterioration risk based on this information and to reflect the results in long-term maintenance management plans. A challenge facing the development of this system is massive amounts of data that are aggregated for each group according to its own requirements and format, and making such data available in a unified format will require substantial time and effort. Nevertheless, a reliable database must be built to facilitate the smooth implementation of future decommissioning projects.

③ On-site risk management

Since before the four incidents occurred, TEPCO has conducted advance safety assessment for the purpose of preventing occupational accidents, consideration of ALARA for the purpose of reducing exposure of workers to radiations, design review for new equipment to be installed, etc., jointly with contracting companies as part of its on-site risk management.

However, analysis of the four cases to find common issues discovered insufficiency in the risk assessment (e.g., insufficient identification of risk factors of operations, insufficient consideration to risk manifestation scenarios for when risk becomes apparent (possible adverse effects), risk information not being shared by all relevant parties) as a common weakness. To address that, TEPCO is currently trying to find ways to improve its risk assessment to be more worksite-oriented and highly effective, by adding a new viewpoint “what happens if things go wrong” to the previously used viewpoint “what needs to be done.”

c. 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[124], the Mid-and-Long-term Roadmap decided by the Ministerial Conference on Measures for 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 2024 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. This explicitly indicated that TEPCO would develop and implement work process plans over the medium to long term under its own initiative. Since then, TEPCO has been updating the Mid-and-Long-term Decommissioning Action Plan every year to incorporate the work progress made. TEPCO also revised the target map for reducing risks, which was released in March 2024, to

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

include the policy on decommissioning from the medium- to long-term perspective. In accordance with this policy, TEPCO published the Mid-and-Long-term Decommissioning Action Plan 2024 in March 2024. The plan provides work plans for about the next ten years for each key measure, and based on the plan for the next three years, a withdrawal plan for reserve funds for decommissioning has been prepared.

Mid-and-Long-term Decommissioning Action Plan gives a certain level of transparency to the complex and long-term decommissioning project, and it can serve as effective communication tools with the local community and society.

d. Formulation of R&D medium-to-long-term plan[125]

As project difficulty and uncertainty are expected to increase in the future, coordination with R&D is becoming more important in ensuring project feasibility. TEPCO established the Decommissioning Technology Development Center in August 2021 with the aim of strengthening R&D planning and management functions to examine technical development issues and promote implementation plans. The Center identifies technology and development issues related to the Mid-and-Long-term Decommissioning Action Plan, and incorporates important issues into the R&D medium-and-long-term plan.

Such a move is necessary to facilitate the decommissioning work. Considering that the degree of difficulty and uncertainty of the project will increase in the future, it is increasingly important to strategically advance technology development, which will determine the feasibility of the project, starting from the upstream stage of the project in the medium to long term, while establishing a structure.

e. 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/analysis of monthly report budget difference reasons and strengthening management of billing timing. 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, there are still cases where the contract period of work to be carried out to advance the project is set with the fiscal year in mind, and the acceptance inspection is concentrated at the end of the fiscal year. As a result, there have been cases of recording outside

[125] For detail, refer to Chapter 5.

the period when it should have been. We believe it is important to set the contract period in a more project-oriented manner to level workloads and proceed with operations efficiently.

f. Addressing issues across projects

Addressing cross-project issues, such as preventing α-nuclide diffusion, developing a unified approach to seismic design, and eliminating work conflicts around accident reactors, becomes more important as the number of interrelated projects increases and becomes more complex. TEPCO has established a cross-divisional structure to deal with cross-sectional issues that do not fit into individual programs/projects. As such a structure is now functioning, the consciousness of these cross-sectional issues has been shared with the Chief Decommissioning Officer (hereinafter referred to as “CDO”) and other management and efforts are being made to solve such issues.

g. Nuclear security management

In September 2021, TEPCO submitted to the NRA the Improvement Action Report on the nuclear material protection incident involving unauthorized ID card use and partial loss of function of nuclear material protection equipment at the Kashiwazaki-Kariwa Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc. (hereinafter referred to as “Kashiwazaki-Kariwa”). The Improvement Action Plan for this nuclear material protection incident covers 36 items. TEPCO has moved to the implementation phase for all the items and begun effectiveness evaluations for most items. Through additional inspections, TEPCO improved measures as needed with advice from the NRA. Based on the policy for confirmation announced by the NRA in September 2022, TEPCO promoted “continuous improvement of system reliability,” “proactive involvement of the management in establishing operations for improvement,” and “establishment of a mechanism that does not make improvement actions temporary.” In addition, TEPCO does not hesitate to invest resources to strengthen on-site capabilities, particularly for nuclear security.

TEPCO summarized measures to strengthen the nuclear material physical protection function and evaluations of each measure into an Improvement Action Results Report. An additional inspection report on Kashiwazaki-Kariwa was approved at the 56th meeting of the Nuclear Regulation Authority on December 27, 2023. As a result, the handling category of the power station in the nuclear regulatory inspection was changed from Category 4 to Category 1. Changes to the FY 2023 inspection plan were also approved.

In accordance with the above policy, at the Fukushima Daiichi NPS engaged in decommissioning, the Security Management Department was established in May 2022 directly under the site superintendent to manage and operate the general nuclear security of the plant. In addition to security (monitoring and patrols), access control, and facility management related to nuclear security, the Security Management Department is also tasked with overall cybersecurity management. Since the Fukushima Daiichi NPS plans fuel removal from SFP and trial retrieval of fuel debris, it is imperative that not only TEPCO employees but also employees of contractors are more aware of the fact that there are always threats related to nuclear security in all operations, and they must exercise extreme caution. TEPCO headquarters and plants are working together to foster an organization and a corporate culture that can gain the trust of local communities and society. In addition, they are discussing the structure with the aim of the improved site-oriented project management from the perspective of ensuring nuclear security functions, work safety, and coexistence with the local community through decommissioning.

6.1.1.2 Capability an owner should possess

The importance of owner’s engineering is stated in the 4th Special Business Plan. The owner's engineering capability here refers to the capability required of TEPCO 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. These capabilities are all very important for the decommissioning project to proceed. Additionally, in view of the peculiarities of the Fukushima Daiichi NPS, the abilities for upgrading the overall decommissioning strategy to advance a coexistence of reconstruction and decommissioning are needed. In 2022, TEPCO signed a partnership agreement with Jacobs, which has extensive experience in decommissioning nuclear facilities overseas. With their support, TEPCO is working to strengthen the capabilities that an owner should have by benchmarking international good practices.

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

6.1.1.2.1 Establishment of safety first[126] and engineering based on safety and operator’s perspectives[126]

As described in the previous chapters, the on-site situation at the Fukushima Daiichi NPS has changed significantly from before the accident. A large amount of radioactive materials exists 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 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-

[126] Refer to Chapter 2 for details.

site information. Moreover, unlike other plants, it is not always clear what safety requirements should be met to achieve the objectives of individual operations.

In addition, the amount of equipment installed after the accident is increasing as the decommissioning progresses, and the conditions of the worksite have changed due to the accident and the design information prior to the accident cannot be used as is. Therefore, the framework of plant configuration managementbuilt prior to the accident needs to be revised.

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, while always keeping in mind that unpredictable situations may occur, TEPCO continuously needs to observe the site, detect changes on site as soon as possible, and look from the perspective of the site.

At this point, TEPCO should keep in mind that even if the Fukushima Daiichi NPS is in an unusual state, neglecting the safety related to decommissioning at the station is not appropriate. For example, it may be difficult to apply maintenance operation and aging management required to maintain the safety functions of conventional reactors to the Fukushima Daiichi NPS due to work safety restrictions and other reasons. However, it is not appropriate to simply relax the requirements on long-term maintenance and deterioration management due to such circumstances alone. It should also be kept in mind that the reaction of the local community will be more severe if defects resulting from deterioration occur due to such a simple management[128]. In view of the peculiarities of the Fukushima Daiichi NPS, TEPCO needs to continue instilling the safety-first approach.

To achieve this, consideration must be given not only to the on-site perspectives of those familiar with the site of the Fukushima Daiichi NPS but also to the on-site perspectives in areas where TEPCO has no experience, such as handling unsealed radioactive materials. Therefore, as such considerations need the breadth and depth of knowledge and experience beyond the scope of a single organization, TEPCO is required to establish an interdisciplinary structure.[129]

In other words, TEPCO should appropriately establish its general safety requirements at the Fukushima Daiichi NPS, which has no precedent and high uncertainties, establish agreements with

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[127] Configuration management refers to a mechanism for constantly verifying and guaranteeing that each system/equipment of a nuclear power plant is manufactured and installed, operated, and maintained as required by design.

[128] In February 2021, for example, the 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. This incident was severely criticized externally. Reflecting on this incident, TEPCO is working to improve the long-term maintenance process and other initiatives.

[129] In particular, fuel debris retrieval is extremely complicated and technically challenging. Thus, it is not easy to accomplish with only one organization's technology. Therefore, TEPCO must have engineering capabilities that enable judging the advantages and disadvantages of individual technologies and other capabilities to integrate elemental technologies to be incorporated as a system to achieve the desired performance. For this purpose, TEPCO is required to establish an interdisciplinary structure by cooperating with multiple domestic and overseas organizations with experience in technology development and application or by incorporating external personnel with extensive experience.

various stakeholders on the matters it has established, and proceed with the decommissioning work in cooperation with other parties based on the agreements.

Then, it is necessary to establish a process in which operators who are familiar with the site should be based on the actual situation of the site[130], check the safety comprehensively, determine the appropriate general safety requirements for the site, and work on it. The overall capability required for this purpose, including field capabilities[131], is engineering based on safety and operator’s perspectives, and it goes without saying that TEPCO is required to further enhance this capability. The TEPCO’s ongoing Insourcing[132] is an important measure to strengthen these capabilities and should continue to be pursued vigorously by appropriately selecting applicable projects.

6.1.1.2.2 Investigation capability at the upstream side of the project

As mentioned above, TEPCO needs to figure out for itself what to do in the face of extremely difficult and uncertain tasks without precedent, established standards, and methods to follow in decommissioning the Fukushima Daiichi NPS, which does not have the upstream design concepts and standards, unlike conventional nuclear power plants. In decommissioning work at the Fukushima Daiichi NPS, the cases [133]have been accepted, where the project is allowed to return to the process that reexamines what functions should be achieved and what general safety requirements need to be satisfied for that after the project is launched and proceeded with.

In addition, as described in Chapter 3, it is necessary to consider in advance how to deal with and manage the waste generated with the progress of the decommissioning work, including waste generated during the preparation work for fuel debris retrieval. In the future, TEPCO should clarify the significance and objectives of the project (what to do by when and for what) and general safety requirements, develop a comprehensive waste strategy covering its generation control, reuse, etc., and ensure the feasibility of the project. To this end, in the decommissioning process from its planning to implementation, enhancing the investigation capability is needed, especially at the upstream side.

However, due to the extremely high uncertainty particular to decommissioning at the Fukushima Daiichi NPS, it should also be noted that even if the investigation at the upstream side is enhanced,

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[130] When any work is to be carried out at Fukushima Daiichi NPS, in addition to the “actual situation” of the normal power plant, it is necessary to consider the feasibility and improvement of the work, including the sequential type approach, given uncertainties in on-site information peculiar to Fukushima Daiichi NPS, the lack of work experience, high radiation doses, differences in regulations, low contained energy, the lack of dynamic equipment, and the difficulty in judging the over/underestimation of the safety margin to prepare for such conditions. “Actual on-site situations” refers to such situations.

[131] On-site capability here refers to the ability to keep in mind that unpredictable situations may occur, observe on-site situations, detect changes on-site immediately, and think appropriately from the on-site perspective.

[132] Insourcing refers to improving TEPCO's own technological and management capabilities, not relying too much on partner companies, and understanding each work process and the key points in managing them.

[133] One of those cases is the delay in installing the ALPS slurry stabilization/treatment system, as described in Chapter 3. The lack of awareness of the general safety requirements for containing radioactive materials has led to rework in facility design.

it does not necessarily mean that everything will proceed according to the result of the investigation. TEPCO, based on the assumption that iteration-based engineering is inevitable to some degree in the future, should aim to optimize its research capability in the upstream of the project by adding the latest knowledge from research and development.

6.1.1.2.3 Capability to upgrade project management

In implementing larger, more complex, and highly uncertain high-difficulty projects are expected in the future, project management based on a new concept is advocated in the execution of large, highly challenging projects in both the public and private sectors in the U.S. and other Western countries, in which both the contractor and the recipient cooperate, share the contractual risks, and aim for the agreed-upon goals. Instead of one-way “Buying” from an ordering party to an order-receiving party, they work together as partners and aim “to acquire the final result (Acquisition)” by “Making”, with consideration of all steps from development, manufacturing, to even operation/maintenance (Table 10).

Table 10 Difference between “Making” and “Buying”

	Making	Buying
Objectives	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

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

Since 2022, with the assistance of Jacobs, which is well-versed in managing such projects, TEPCO has been discussing the project management required for future decommissioning work and the capabilities and mechanism required for its implementation. Jacobs has extensive decommissioning experience at Sellafield site of the UK NDA and the US DOE's nuclear sites. TEPCO is currently analyzing the gap between international good practice and TEPCO's present situation, based on a wealth of prior experience held by Jacobs. In addition, TEPCO made a cooperation agreement with Sellafield in the UK and continues to gain knowledge and develop human resources by sending employees on loan to the company. An easy path to imitating other example cases should be avoided because the best project management depends on project characteristics, the state of the country, and the situation of owners and contractors. However, TEPCO should upgrade its project management, including the relationship and contracting with contractors, to adapt to the situation where buying-oriented operation is no longer easy.

In particular, the effectiveness of collaborating with a contractor as a "partner to achieve results" should be assessed for projects where risks are high and it is difficult to have prospects, and consideration should be given to introducing such a structure.

6.1.1.2.4 Nuclear security management capability

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

As trial retrieval of fuel debris is planned to start at the Fukushima Daiichi NPS, sustained efforts to enhance nuclear security and safety awareness are needed. Through these efforts, it is necessary to communicate to local communities and society that safe conditions are maintained.

6.1.1.3 Initiatives related to organization

The Fukushima Daiichi NPS has been taking various actions, including establishing and strengthening a project management structure, from the perspective of "completing the decommissioning project". To achieve "The commitment to the people of Fukushima for achieving both reconstruction and decommissioning (hereinafter referred to as "Commitment")" announced by TEPCO in 2020, in cooperation with other offices in the Fukushima area, including the Fukushima Division and Fukushima Daini NPS, they are working to increase orders for decommissioning work at the plant to local companies, which has attained some positive results.

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

In order to achieve this, TEPCO decided to consider integrating and reorganizing the Fukushima Daini NPS and its head office, which currently belong to the Nuclear Power and Site Headquarters, into Fukushima Daiichi Decontamination and Decommissioning Engineering Company, and in July 2023, the Office of Organizational Restructuring Preparation was established as the umbrella organization for this, the examinations for integration are underway.

Until now, as an organizational structure, "Fukushima Daiichi Decontamination and Decommissioning Engineering Company is in charge of the Fukushima Daiichi NPS with accident reactors", and "the Nuclear Power and Site Headquarters is in charge of the Fukushima Daini NPS with normal reactors". However, a decision was made that Fukushima Daiichi Decontamination and Decommissioning Engineering Company should decommission both plants in an integrated manner because it is effective to share the knowhow at the Fukushima Daiichi NPS engaged in decommissioning over ten years for decommissioning the Fukushima Daini NPS, and it is desirable that both plants work together to promote coexistence with the local community by increasing order placement to local companies. Through this reorganization, TEPCO plans to accelerate further efforts for coexistence of reconstruction and decommissioning. NDF also regards these TEPCO efforts positively, and intends to support the activities so that TEPCO will step up progress to achieve coexistence of reconstruction and decommissioning as the integration and reorganization advance.

6.1.2 Building collaborative relationship with business partners

6.1.2.1 Strengthen procurement management capabilities for long-term decommissioning projects

TEPCO set up the Procurement Reform Group within the D&D Procurement Center in FY 2018 with the aim of ensuring stable procurement and increasing the participation by local companies, and since then, has been working diligently to strengthen procurement management capabilities[134]. Concretely, prime contractors who get in touch with candidate suppliers and the procurement department that conduct negotiations (Product Reform Group) were involved in projects as project members from the upstream of the projects (basic design stage) in an attempt to strengthen procurement management capabilities through collaboration between the supervisory departments and the procurement department. However, when they were first involved at the basic design stage, it turned out that a supply chain[135] was already established by the basic design contractor, leaving little chance of splitting engineering, production, and construction (EPC) contracts in view of arranging participation of local companies or promoting competition. To address this, by involving the procurement department in projects from even further upstream, i.e., the project launching stage, the supervisory department (Department of Waste Management Program) and the procurement department have been organizationally collaborating since FY 2022, from the project launching stage, with focus being put on the Waste Management Program (PG4) in which it was relatively easy to separate order placements.

Through this initiative, TEPCO successfully switched to its preferred suppliers for some procurement in specific projects of PG4, including design and manufacture. In advancing this initiative, it is essential to maintain greater transparency and fairness.

On the other hand, regarding projects of mechatronic systems for decommissioning, for which it is difficult for TEPCO to assure the performance of the plant and assume final responsibility,

[134] Procurement management capability is the ability to make things, not to buy things. Concretely, the capability to appropriately perform such duties as specifying requirements specifications, preparing RFI (request for information) and RFP (request for proposals), selecting suppliers (such as technological capability and determination of appropriate prices), selecting contract types, negotiating with suppliers, managing delivery dates, and conducting inspection and acceptance (checking qualities, delivery dates, quantities, performances, etc.). Also, the ability to place separate orders for the expansion of local procurement.

[135] A supply chain refers to a series of events (supply network) from procurement of raw materials and components for products through manufacturing, inventory control, delivery, sales and consumption of the product.

TEPCO sought to have a package deal contract for EPC. But the prime contractor in touch with candidate suppliers was highly reluctant to accept a package deal contract for EPC with the risks involved. Therefore, a progressive approach was adopted as a second-best solution in which the Engineering contract will be drawn first to see the result before entering the Production and Construction contract.

To date, the D&D Procurement Center established in the Fukushima Daiichi Decontamination and Decommissioning Engineering Company has been in charge of procurement for the decommissioning of the Fukushima Daiichi NPS. In order to address more challenging procurement issues other than the above-mentioned issue, TEPCO inaugurated a new procurement organization in July 2024, with the purpose of enhancing the procurement capacity by consolidating procurement organizations to centralize procurement, and in large-scale projects, boosting upstream participation, standardization of specifications, and strengthening of procurement management capability as well as improving the efficiency of contracting operations.

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

6.1.2.2 Consideration about site management in coordination with partner companies[136]

On April 2020, TEPCO reorganized Fukushima Daiichi Decontamination and Decommissioning Engineering Company and set up the Decommissioning Safety and Quality Office directly under CDO. This new organization entered its 5th year striving to ensure safety and maintain and improve the quality of operations. However, consecutive incidents that would lead to loss of trust from society occurred, such as bodily contamination during the cleansing of additionally installed ALPS pipes (October 2023), leakage of water containing radioactive materials from the HTI (February 2024), and the loss of the on-site electric power system A (April 2024). TEPCO addresses these incidents not only as individual cases of human error, but also regards them seriously as managerial issues, and accordingly conducts in-depth analyses in search for common factors that may cause human errors entailing high radiation risk, looking into cases in other industries as well as seeking

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

opinions from external specialists, and, on the other hand, TEPCO will not hesitate to invest in implementation of hardware or systems capable of preventing human errors. Moreover, after the loss of on-site electric power system A occurred, TEPCO carried out comprehensive inspections of all the operations in Fukushima Daiichi NPS, without any prior assumptions, in order to identify all risk factors and verify protection measures.

Taking the matter seriously and aiming to enhance efforts on education and management, TEPCO works on providing education and training about radiation protection, human performance tool (HPT)[137], as well as about the importance of basic motions, upgrading the operation risk identification level, ensuring strict compliance with predefined organization of work, and elaboration of systems to prevent human errors concerning isolation of systems. In addition, with the purpose of further improving safety and quality of the water treatment process, TEPCO embarked on organizational reinforcement including the new establishment of the Water Treatment Center[138] that centrally and continuously upgrades water treatment systems and remodels them to improve their maintainability. TEPCO is diligently devoting itself to prevention of recurrence.

For the problem with the push pipes for a telescopic device that occurred in August 2024[139], TEPCO analyzed the main causes to be its lack of checking process, lack of field workers' perspective, and insufficient training in simulated environments[140]. In this incident, while it was preparatory work, consideration was lacking toward the fact that the work was going to be conducted under a high radiation dose condition inside a reactor building, requiring heavy protective gear. From now on, TEPCO needs to enhance its capability as the owner of Fukushima

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[137]Human error prevention tool. A couple of examples are shown below.
3WAY Communication: a method to prevent communication error where a director gives instructions, a receiver repeats them back so that the director can check if the messages are correctly received.
TBM-KY: TOOLBOX MEETING in which all members involved in it will verify and check the descriptions of the operation, tools and protective gear, etc., before starting the operation, and identify dangers in the work procedure, propose measures to eliminate them, with a view to enhancing the capacity of every member to resolve problems in the face of danger. It is called TBM-KY activity together with KY activity
Activity STAR: STAR stands for Stop, Think, Action, Review; a behavior pattern that consists of "stopping", "thinking", "acting", and "reviewing."

[138] Water treatment center set up in June 2024 with following objectives:
- To improve the safety and quality of the water treatment process further and continuously in order to ensure safe operation and maintenance of equipment, by planning and implementing measures such as equipment renewal or refurbishment, in addition to improving maintainability of water treatment systems.
- A system that enables closer coordination between programs, since the water treatment process with discharge of ALPS-treated water added is composed of several programs interacting with each other, including the operation program of cesium sorption apparatus or ALPS, the discharge program of ALPS-treated water, and the tank dismantling program or secondary treatment program that depend on the progress of the future discharge of treated water.

[139] A problem occurred during the Unit 2 fuel debris trial retrieval work that started in August 2024, and the work was suspended. In this problem, while inserting a guide pipe of a telescopic device, when it was advanced to the front of the isolation valve, it was found during the final checking on site that the order of push pipes was different from the planned order.

[140] As countermeasures, TEPCO conducted re-checking and examining of the entire work schedule, further revision of procedures, and checking/examining task training and implementing additional countermeasures to address insufficiencies. TEPCO declared that in light of the lessons learned from this incident it will directly conduct checking, etc., for tasks performed in extremely harsh work environments, such as high radiation dose areas. NDF will assist TEPCO in promoting these initiatives.

Daiichi NPS so that operations can be conducted safely and steadily even in a harsh work environment.

TEPCO proceeds with these operations by concluding contracts with prime contractors. These contracts always have requirements for ensuring safety and quality of work. Meanwhile, in order to safely promote the whole decommissioning project, as the responsibility of the owner (orderer), TEPCO is tasked to supervise all operations and carefully check for any discrepancies from the contracts in terms of safety and quality. Therefore, it is important that TEPCO takes comprehensive responsibility while contracting companies fulfill their own responsibilities to thoroughly ensure safety and quality. In addition, it is equally important to provide local residents and society as a whole with attentive and detailed explanations on safety and quality assurance considering the social importance of the decommissioning of the Fukushima Daiichi NPS.

In a multilayered contracting structure, TEPCO places orders with a prime contractor (prime contract), the prime contractor places orders with a primary contractor (primary contract), the primary contractor places orders with a secondary contractor (secondary contract), and so on. The contract system is also multilayered, with orders being placed with further contractors. This creates a potential risk of a growing gray area of ambiguity in scope of responsibility. In addition, because the contract system is based on the responsibility of each layer of the contractor (individual responsibility), the contractor tends to focus only on its own scope of responsibility and not on the responsibility of other companies, even though they have a common goal to accomplish a single task safely. This makes it difficult to develop a sense of mutual solidarity to cover the gray areas. In light of the recent series of incidents, it is necessary to devise a system and contractual arrangements that will allow companies at all layers involved in a single task to function for the same purpose, while maintaining the contractual arrangements that have been in place up to now. According to the benchmark survey on the type of contract conducted by NDF to date, there are cases in which the project is progressing smoothly with the system and contractual arrangements[141] in order for the orderer and the contractor to cooperate for the same purpose in the project abroad. Referring to these good practices in Japan and abroad, TEPCO needs to establish a way of performing duties by a team suitable for the site of Fukushima Daiichi NPS, with full consideration of the safety features (peculiarities) described in “2.3.1 Basic Policy for Ensuring Safety based on

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[141] The Early Warning and Compensation Event mechanisms have been incorporated into the structure and contract provisions with the aim of having the ordering party and contractor act in a spirit of mutual trust and cooperation. This has encouraged the client and contractor to cooperate for the same purpose.

- Early Warning: A system whereby those who become aware of a "risk" that may affect safety, quality, time, cost, etc. are promptly alerted (early warning), regardless of the contractual hierarchy, to share the risk with other parties and manage the risk as a team. What is important in early warning is to form an integrated team as early as possible, share risks and gains/losses among the parties, and discuss and decide necessary measures as a team.
- Compensation event: An event subject to payment in the event of changes or additions not included in the original contract is called a compensation event. Compensation events prompt Early Warning by specifying in advance.

the Characteristics of Fukushima Daiichi NPS", while incorporating the opinions of cooperating companies.

The situation at the worksites of the Fukushima Daiichi NPS changes daily, leaving little to no room for routine work. To continuously ensure safety and quality of operations at such complicated (potentially more complicated in the future) worksites for a long period of time, in addition to exercising ingenuity in forming a contracting system and agreements for all levels of companies engaged in the project to function with the same objective, TEPCO shall consider working together with contracting companies in developing an environment necessary for attaining the objective by, for example, enhancing equipment and management to make worksites safer and introducing a sustainable and level contracting method under which contracting companies can comfortably keep working on securing and developing human resources from a long-term perspective.

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

To keep working on the decommissioning of the Fukushima Daiichi NPS that will span a long period, it is extremely important that TEPCO systematically secures and develops the human resources needed on its own initiative. In addition, it is essential to secure and develop researchers and engineers who will engage in R&D activities necessary for the decommissioning, and assuredly pass down relevant technologies and knowledge to next generations. Further, since the decommissioning of the Fukushima Daiichi NPS requires highly advanced engineering to solve extremely difficult problems, it is also important to bring human resources with diverse backgrounds and expertise in other science and technology fields into the project, not just personnel specialized in nuclear science. In order to continuously secure and develop human resources engaged in the decommissioning now and in the future and have them utilize their expertise on various occasions and opportunities, relevant organizations need to work together with the worksite to steadily promote initiatives for developing the next generation at different educational levels.

To smoothly and steadily proceed with the decommissioning that is very difficult to accomplish and runs for a long period of time, it is essential to widely and continuously gain understanding of the people. Acquiring a basic knowledge of the Fukushima Daiichi NPS is fundamental to promoting public understanding of decommissioning. Therefore, it is important to provide opportunities for many people to become interested in decommissioning and learn about related initiatives, in addition to securing opportunities for people to gain related knowledge.

6.1.3.1 Initiatives to recruit and develop personnel at TEPCO

In Fukushima Daiichi NPS, it is necessary to systematically secure and develop human resources in anticipation of the strengthening of the system to further improve work reliability, including the response to expansion of operations in line with the progress of the fuel debris retrieval plan and the prevention of human errors during system configuration. Specifically, they are to develop a staffing plan that includes the required skills and qualities and headcount, to prepare an organizational personnel development plan that outlines tactics to achieve them, and to implement measures to increase personnel motivation, while addressing short-term needs as described below.

Furthermore, to further deepen and advance the Commitment, which has been promoted since 2020, it is necessary as a stance to consider human resource allocation with a view of coexistence of reconstruction & decommissioning beyond decommissioning of the Fukushima Daiichi NPS.

6.1.3.1.1 Short-term efforts

The decommissioning work at the Fukushima Daiichi NPS is at the phase of undertaking the most critical milestone in recent years, the trial retrieval of fuel debris. To be in line with the gradual expansion of fuel debris retrieval, the entire workload of the plant is also increasing. In such a situation, the sense of busyness at the power station is also getting stronger year by year and the number of personnel required on-site is increasing.

Moreover, to prevent the recurrence of such incidents as the physical contamination incident during the piping cleaning work for the expanded ALPS (October 2023), the leakage of water containing radioactive materials from the high-temperature incinerator building (February 2024), and the shutdown of the on-site power supply system A (April 2024), it is necessary to strengthen the system to enhance on-site management by TEPCO employees. Furthermore, it is essential for TEPCO and its partner companies to work together as one to raise the level of on-site capabilities of the entire Fukushima Daiichi NPS, and it is important for TEPCO to train partner companies to achieve this.

Although TEPCO is actively recruiting to meet such strong demand for personnel on-site, it is not a one-way process and does not always ensure that the desired personnel are available.

Active recruitment should therefore continue, though, in addition to that, it is essential that its leaders[142] clarify work priorities and promote resources allocation according to the priorities, and development of human resources should be promoted to enhance versatility and productivity of existing personnel. TEPCO has been addressing kaizen activities for a long time, and it is an initiative that incorporates the methods of Toyota’s kaizen/continuous improvement method with the aim of improving quality and safety. As this is also useful for solving secondary resource issues, the activities should be continued vigorously. Other than that, it is also indispensable to provide education and training[143], conduct digital transformation (DX) [144], and obtain the necessary outputs with limited resources through efforts.

[142] A leader is a person who leads a team toward solving issues or meeting goals and is required to achieve results. In terms of TEPCO positions, this includes CDOs to team leaders.

[143] In addition to personnel development and multi-skilling through education and training, including on-the-job training (OJT) that meets direct operational needs, education and training aimed at avoiding the increase in social anxiety caused by external communication errors, preventing errors by ensuring psychological safety through internal communication, and improving management skills to facilitate projects are effective for efficient utilization of human resources.

[144] The sophistication of long-term maintenance and management of systems and equipment promoted by TEPCO is an example of saving human resources through DX promotion.

6.1.3.1.2 Medium- and long-term initiatives

Because TEPCO's goal of the coexistence of reconstruction & decommissioning cannot be achieved only through decommissioning work at the Fukushima Daiichi NPS, it is desirable to review the necessary operational management and governance of all organizations involved in the reconstruction of Fukushima and decommissioning and give shape how to secure and train required human resources in the future. The integration of the Fukushima Daiichi Decontamination and Decommissioning Engineering Company and the Fukushima Daini NPS, which TEPCO has been working on, is also crucial in the sense that it aims to optimize the use of personnel beyond the boundaries of business sites through organizational restructuring. The consolidation should be accompanied by the diversification of personnel, standardization and streamlining of business operations, and efforts to ensure the necessary personnel.

In addition, in promoting the securing of human resources over the mid-to-long term, it is necessary to pay full attention to the fact that Fukushima Daiichi Decontamination and Decommissioning Engineering Company is shifting from a routine work implementation organization as a utility to a project-based one as a decommissioning site owner. While determining the scope of the measures to secure human resources, which TEPCO has continued to apply based on the operation and maintenance of normal power stations, workloads in decommissioning work are expected to increase from now on, and it will require personnel for ever-changing project-based work as well as personnel for operation and maintenance of the new facilities that will be installed as a result of the execution of projects. To ensure such personnel, TEPCO itself should determine what type of and when personnel will be needed in the medium- to long-term, and clearly present the necessity at an early stage so that the company can carry out the activities to recruit personnel from inside and outside the company widely through various channels. This is necessary for hiring[145], reskilling employees with a view to the medium- to long-term[146], personnel management including attractive career path design for young employees, enhancing the

[145] For example, in initiatives to acquire experts, it is necessary to organize the elements that can be communicated effectively, such as the fact that this is an unprecedented project that requires many cutting-edge technologies and interaction with a wide variety of highly skilled human resources, including those overseas, can be expected.

[146] For example, it is necessary to identify and strategically acquire practical knowledge that is advanced and likely to have higher demand in the future, such as actinide chemistry, analytical assessment, and seismic and environmental impact assessment.

understanding of the community[147], and making up for personnel shortages through collaboration with external organizations[148].

In view of the fact that decommissioning is a long-term activity, TEPCO needs to work to cultivate leaders who will be responsible for decommissioning in a planned and systematic manner from a medium- to long-term standpoint. In the face of many difficult and diverse short-, medium- and long-term challenges, in order to establish a system that allows them to make choices and tackles what needs to be done according to the priorities of their work on a daily basis, it is undeniable that leaders in charge of unprecedented and difficult decommissioning projects require a higher level of courage and people skills compared to other projects, in particular. In addition, they need to possess a keen sense of perception that anticipates the changing business environment as well as the ability to adapt to change, and the ability to learn. Furthermore, if other people in the organization are influenced by the leaders who are working on decommissioning as a national challenge as well as by the leadership group following those leaders, and become aware of their own potential and motivated to grow, this will also lead to the recruitment and development of decommissioning personnel over the medium to long-term. TEPCO should systematically promote the development of leaders, as it takes a long time to develop them, and a suitable career path should be set up for their development.

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

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

In addition to securing decommissioning personnel by TEPCO, the challenge is how to open up opportunities so that excellent human resources who have graduated from universities, graduate schools, technical colleges, high schools, etc., and are specialized in science and technology are continuously sourced to various organization involved in decommissioning. In order to achieve this stably, it is necessary for higher and secondary educational institutions to create opportunities for learning and acquiring peripheral knowledge in addition to expertise, and to maintain associated systems and structures so that they can function as a whole, including teachers.

[147] For example, toward coexistence of reconstruction and decommission for a long period, the initiatives to acquire local talent by employing those from local high schools, technical colleges, and universities or employing local talents who have entered higher education in different areas are expected to deepen regional understanding as a side benefit.

[148] For example, training and securing analytical personnel is urgent, and TEPCO has started human resource development through OJT training at the JAEA and other organizations with expertise in analysis. Through such cooperation, it is necessary to promote the development of personnel engaged in analysis, including not only those performing analysis but also highly skilled analytical technicians involved in analysis planning and evaluation.

Universities/researching institutions tasked with basic/fundamental research are expected to develop human resources to make a quick response when technical issues requiring scientific knowledge occur. It is important that universities/researching institutions share awareness of issues faced by the decommissioning on-site. Relevant organizations should continue to promote and strengthen their efforts to secure and develop human resources who will lead the next generation in accordance with their respective roles and levels.

6.1.3.2.1 Initiatives at universities and researching institutions

In the World Intelligence Project, MEXT is promoting R & D and human resource development to meet the needs of the decommissioning site over the medium to long term by integrating and collaborating knowledge from diverse fields in Japan and overseas across organizational boundaries. "Decommissioning research program based on development of research human resources" in the World Intelligence Project, the third phase of the program[149] started in FY2024, aiming to develop human resources who can cope with issues in a highly uncertain and severe environment through research on the decommissioning of the Fukushima Daiichi NPS as well as to develop international research personnel required for the future decommissioning. In addition, in the Creative Robot Contest for Decommissioning organized for technical college students, as part of the World Intelligence Project, students present their research results, and on an on-going basis, they exchange views with researchers and engineers involved in the decommissioning of the Fukushima Daiichi NPS and are given awards for excellent performance.

This initiative is steadily progressing with the participation of a team from an overseas university for its 8th edition in 2023, and collaborative research between technical colleges and businesses, concerning, among others, studies on improvement of the environment in the reactor building, using remote devices.

As nine years have passed since the launch of the World Intelligence Project, these mechanisms and their implementation have produced significant results in terms of both research and human resource development in higher education institutions, and they have led to activating human resources, including graduates being actually engaged in decommissioning-related projects. The Conference for R&D Initiative on Nuclear Decommissioning Technology by the Next Generation (NDEC), a conference for students to present their research findings, which has been held nine times, in 2024, decommissioning related operators set up their booth, and active exchanges between participants took place. Under this system, projects should be implemented continuously

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

so that the perspectives of decommissioning sites in Fukushima Daiichi NPS and those of the activities in higher education institutions can be more aligned.

6.1.3.2.2 Initiatives for the students in the stage of secondary education

For junior and high school students in the earlier stage of secondary education, which is the stage before higher education, it is important to introduce the appealing points of engaging in the nuclear energy field, including decommissioning, and to make efforts to attract their technical interest with a focus on decommissioning, as well as to improve their understanding of the decommissioning and reconstruction of the Fukushima Daiichi NPS, and in a broad sense, of the career path in science and technology fields. The secondary education stage is an important preparatory stage before participating in and contributing to society while developing one's individuality and exploring one's interests. It is of great significance for students in this stage to be inspired by researchers, engineers, and science teachers who are active in society and to leverage such inspiration to make independent choices and decide their career paths. From this perspective, NDF has been organizing the International Mentoring Workshop Joshikai in Fukushima since 2019 in cooperation with the OECD/NEA. This event aims to attract female science and engineering professionals to address challenges in Fukushima, including decommissioning. It is designed for female high school students, mainly in Fukushima Prefecture, to increase their interest in science and engineering through interaction with female researchers and engineers in Japan and abroad. These opportunities have been provided to 41 high school students and others who are in the period of considering the specifics of their career options in 2024, in order to broaden their understanding of decommissioning and reconstruction and to foster interest and willingness to contribute, and there has been some level of success.

It is also necessary, through these initiatives, to expand the scope of human resource development related to the decommissioning of the Fukushima Daiichi NPS to include fundamental and related research. It is expected that initiatives to deal with the nuclear legacy and nuclear safety will take deeper root in the course of raising the level of the entire fundamental technological base in Japan.

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

If many citizens acquire basic knowledge of the accident and decommissioning, disaster response, radiation safety, and food safety related to the Fukushima Daiichi NPS, it will serve as a basis for discussions on decommissioning and related radiation safety, etc. based on accurate information and it is important to promote public understanding. In particular, from the perspective of enhancing resilience to various disasters in the future, while acquiring knowledge and experience of nuclear energy and decommissioning, opportunities to learn should be secured depending on children’s developmental stage. Since children take an interest through the knowledge and experiences of teachers, parents, and other adults around them, it is effective to further spread scientific-evidence-based knowledge of nuclear energy and decommissioning 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 in August 2024), the government is promoting the continuation and expansion of teachers and staff training and on-site classes on radiation, and the use of radiological supplementary readers. NDF also holds workshops for local students to discuss decommissioning and reconstruction, as described above.

Furthermore, from the perspective of informing the public of the current status of decommissioning, TEPCO is accepting visitors to the Fukushima Daiichi NPS and also provides virtual tours of the decommissioning site on its website. At the same time, the progress of the nuclear power plant accident and the status of the decommissioning are displayed in the TEPCO Decommissioning Archive Center displays. TEPCO should continue to actively promote efforts to arouse public interest and contribute to better understanding of the decommissioning process by accurately communicating the current status of the decommissioning of the Fukushima Daiichi NPS.

6.2 Strengthening international cooperation

6.2.1 Significance and the current status of international cooperation

6.2.1.1 Significance 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. These facilities and respective conditions of the facilities in legacy sites are diverse, but in each case, 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.

Decommissioning the Fukushima Daiichi NPS is expected to take a long time and there are challenging engineering issues regarding investigations and analyses to estimate conditions inside reactor buildings, PCVs, and RPVs, fuel debris retrieval and R&D required to execute such activities, as well as mockup tests, including training of workers. To address these issues, TEPCO has been acquiring knowledge from abroad, based on the idea that it is important to learn from lessons and experience acquired through decommissioning activities in foreign countries in order to proceed with decommissioning. Specifically, bilateral cooperation has been promoted in line with the circumstances of each partner country and useful experience of decommissioning activities around the world has been incorporated by utilizing the framework of multilateral cooperation through international organizations such as the IAEA and the OECD/NEA.

These international organizations also play a number of important and useful roles, including establishing international standards for decommissioning, consolidating and introducing technical information, collaborating and organizing researchers and engineers, peer reviews based on international standards and good practice experience, and international public relations. The involvement of engineers and researchers in formulating international standards, consolidating technical issues, and peer reviews based on Japan's experience in decommissioning is meaningful in promoting to the international community the decommissioning of the Fukushima Daiichi NPS in an open manner. It is also expected to fulfill part of Japan's responsibility to the international community by sharing its knowledge and information accumulated in Japan through many initiatives since the accident with other countries.

It is important to gain international understanding as our country moves forward with the decommissioning of Fukushima Daiichi NPS. To this end, in addition to gathering wisdom and sharing of experience, it is necessary to disseminate transparent information to the international community and to engage in continuous dialogue.

6.2.1.2 Current status of international cooperation

From this perspective of international cooperation, Japan has been holding annual dialogue and establishing a conference to share information with governmental bodies and researching institutions in other countries as an intergovernmental framework for bilateral cooperation in decommissioning. In coordination with such an intergovernmental framework, NDF and TEPCO have maintained international oollaborative relationships through cooperation agreements with professional organizations with a proven track record in decommissioning activities in the US, the UK, and France, and other countries. NDF maintains continuous communication with the countries concerned for bilateral cooperation, through regular meetings once a year (annual meetings) and irregular meetings on the occasion of visits to Japan and other countries.

With regard to multilateral cooperation, meanwhile, the government and institutions concerned in Japan have participated in various conferences and expert committees of international organizations. While TEPCO has participated in various conferences and projects organized by the IAEA and the OECD/NEA, NDF has served as a deputy chairman of the Committee on Decommissioning of Nuclear Installations and Legacy Management, a standing committee at the OECD/NEA, to contribute to maintaining the foundation for multilateral cooperation on decommissioning and disseminating information (Attachment 21).

Each of the Japanese government, TEPCO, and NDF is working with their counterparts in technical cooperation and sharing information, experience, lessons learned, etc., with the aim of building a strong cooperative relationship for long-term decommissioning in the future.

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.

Currently, decommissioning is being carried out under contracts between many companies and decommissioning executors both in Japan and abroad, and the global market for decommissioning is expanding greatly. In this context, TEPCO has been actively engaged in technological exchange with private companies overseas.

NDF, for its part, considers, when organizing a conference, holding it in-person, online, or a hybrid of in-person and online, taking into account the convenience for participants, while maintaining communication with overseas organizations (Fig. 65).

6.2.2 Key issues and strategies

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

Fig. 65 The 8th International Forum on the Decommissioning of the Fukushima Daiichi Nuclear Power Station (August 2024)

To move steadily ahead with the decommissioning of the Fukushima Daiichi NPS, which involves difficult engineering issues, it is necessary to learn lessons from achievements in overseas nuclear facilities executing difficult decommissioning work and decommissioning of legacy sites, and apply them to the decommissioning and utilize the world's highest level of technology and human resources for technologies in Japan. In other words, it is necessary to gather and utilize the world's wisdom and knowledge and, at the same time, promote research and development in Japan to solve issues while accumulating experience and achievements. Japan has received various kinds of support from foreign governmental organizations, regulatory authorities and R&D institutions staff, and independent experts by disseminating information on issues related to decommissioning to the international community and participation in international joint activities.

Decommissioning activities of legacy sites in different countries are being promoted primarily by public decommissioning implementation entities, and offer a lot of useful information as the model, and serve as references regarding technology and management. The issues they are confronting on the technology side include the necessity of expertise, approaches, and new technologies that are different from the operation and maintenance of nuclear reactors. On the management side, such issues include developing systems, policies, and strategies, project planning and management, safety assurance, and local communication. TEPCO has stationed staff at legacy sites to obtain technical knowledge of decommissioning and operational know-how through practical experience, and conducts or receives visits and regularly exchanges information with decommissioning-related organizations and companies. NDF needs to keep gathering knowledge, including lessons learned from decommissioning of overseas legacy sites and facilities engaged in extremely difficult decommissioning work around the world, through long-term partnerships with public decommissioning implementation entities that play a central role in their own country, such as NDA in the UK, CEA (French Alternative Energies and Atomic Energy Commission) in France, and the United States Department of Energy, Office of Environmental Management (DOE).

In consideration of these, decommissioning should be conducted, keeping the three strategies below in mind.

(1) Cooperation with Counterparts

It is important for TEPCO, as an entity that implements decommissioning steadily, and NDF, as an organization that provides advice and guidance to ensure proper and steady implementation of decommissioning from a mid-to-long-term perspective, to maintain and strengthen cooperation with its counterparts. To realize the decommissioning of the Fukushima Daiichi NPS, global technical and operational wisdom and knowledge should be integrated and fully incorporated them into solving the issues by maintaining a high level of cooperation with relevant organizations in Japan and existing personal contacts with overseas experts at the engineer and executive levels, and by continuing regular information exchange.

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

In order to seek possibilities to apply further technology in decommissioning, in addition to the above-mentioned in (1), collecting technical information should be continued, by staying alert on all fronts, in order to obtain cooperation from countries that do not use nuclear technology or experts in industries other than the nuclear industry. Decommissioning of the Fukushima Daiichi NPS is a process of solving unexplored engineering problems by combining knowledge from various fields, including remote technology, and is not limited to the nuclear field, and it can be expected that the decommissioning of the Fukushima Daiichi NPS could become a powerful opportunity for the creation of innovation.

(3) Continuation of mutually beneficial relationship

About thirteen years have passed since the accident, and it is important to continue these mutually beneficial relationships as a strategy while being conscious of returning the expertise and results accumulated so far to the international community. In participating in international joint activities, with the premise of the steady implementation of decommissioning, which is Japan’s top priority, securing the interests of the international community should also be taken into consideration. From the aspect of returning the results, there is a growing interest in not only the accident and decommissioning itself but also in application to issues other than nuclear field. It is also useful to respond to these changes in the international community to maintain this interest.

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.

6.2.2.2 Maintaining and developing the international community’s understanding, interest and cooperation in decommissioning

The challenge is to maintain and develop the international community’s understanding, interest and cooperation in order to bring together the world’s wisdom in the decommissioning of Fukushima Daiichi NPS and to limit the risk of confrontational structures to the implementation of decommissioning as far as possible. International opinion could considerably impact the progress and success of decommissioning. Therefore, the spread of misperceptions regarding the decommissioning of the Fukushima Daiichi NPS overseas affects the decommissioning progress. Recognizing this, it is important to strategically discuss and implement international cooperation. Efforts should be made to ensure that the view, “decommissioning of the Fukushima Daiichi NPS can be carried out safely,” is fully disseminated not only in Japan but also overseas. If such a view does not prevail, it should be kept in mind that conflicting structures may arise, and there is a risk that public opinion and understanding in Japan will be formed to affect decommissioning results.

Therefore, if there is a situation involving a lack of understanding in overseas societies at the launch of a new technological initiative or policy discussion that is considered necessary, realistic, and feasible, it could have the impact of expressing concern about such initiative, and further, calls for the suspension of the initiative for the sake of international security. This risk can be reduced by assessing these possibilities in advance by NDF and relevant organizations concerned in Japan and disseminating information proactively. On the other hand, a delayed response may risk the decommissioning project being hindered and ultimately delaying the local reconstruction. Under the circumstances, many countries have been reviewing their energy policies, in response to the change of global energy landscape, affected by recent initiatives to address climate change, changes in energy safety and security policies resulting from international conflicts, and the growing need for a more robust energy supply infrastructure. Even under such circumstances, the challenge is maintaining smooth cooperative relationships with other countries toward decommissioning of the Fukushima Daiichi NPS while gaining an accurate understanding of the updated status in the countries concerned.

The strategy for gaining international understanding needs to be divided into ① Approach to experts and ② Approach to the general public.

① Approach to experts

It is fundamental for the international community to understand that the efforts toward the decommissioning of the Fukushima Daiichi Nuclear Power Station are scientifically and technically valid and accurately understood by experts abroad. Approximately 13 years have passed since the accident, and there are signs of a decline in international interest in decommissioning technology and progress, as seen in the decreasing number of papers on decommissioning of the Fukushima Daiichi NPS presented at recent international conferences. In order to maintain interest outside Japan, dialogue and exchange should be activated outside Japan among technology implementers, technology developers, and researchers involved in the practical implementation of the technology, beyond the public and private sectors.

Until now, based on the framework for cooperation in decommissioning technology, information has been disseminated and exchanged mainly with advanced nuclear power countries that own legacy sites. For instance, NDF and TEPCO have provided technical briefing and disseminated information on the current status and challenges of decommissioning to the international community through various opportunities such as International Forums, periodic bilateral meetings, and participating in multilateral frameworks. In addition, TEPCO has actively provided opportunities for overseas experts to visit the Fukushima Daiichi NPS. These activities are significant in complementing the international publicity and are important in gaining international understanding in that they can directly communicate the latest technical information to foreign experts. Furthermore, with regard to unprecedented efforts being made in a peculiar environment of the Fukushima Daiichi NPS, such as fuel debris retrieval and waste management, it is also important to incorporate opinions from new perspectives as well as gain an accurate understanding of the efforts being made through dialogue with many experts from neighboring countries and countries that do not use nuclear technology. It is also expected that the understanding of these experts can be used as a springboard for the spread of correct understanding in their countries. Japan should also support socially influential experts to speak out based on correct knowledge in their own countries and ultimately have a positive impact on international public opinion. In the future, Japan's government agencies, TEPCO, and, in particular, the IAEA's Department of Nuclear Safety and Security, will cooperate in wide-ranging discussions to build new, strategically resilient international partnerships.

In order to contribute to the formation of international public opinion based on scientific and accurate information, efforts toward decommissioning must be correctly understood by overseas experts first. Recognizing this, Japan should work with national government agencies and international organizations to disseminate information on the achievements of its efforts towards decommissioning, as well as to engage in more careful dialogue and continue to do so.

② Approaches to the general public

The interests of the recipients of the information have changed since the time of the accident, and there are some gaps between countries in the amount of knowledge and information that are the basis of understanding. Moreover, it is necessary for Japan to actively provide information on the accident at the Fukushima Daiichi NPS, and activities and achievements toward decommissioning to countries other than advanced nuclear nations in cooperation with international organizations.

To this end, the following considerations should be made:

- Disseminating information that is easy to understand not only to experts but also to laypeople;
- Prepare well-crafted explanations by using videos and illustrations effectively while considering the interest and understanding of the recipient;
- Disseminate information in multiple languages other than Japanese and English, etc.

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. As Japan’s responsibility as the country that caused the accident, the issue for the government and other domestic organizations is to continuously and transparently disseminate accurate information on decommissioning in order to maintain and increase the understanding of the international community, and build trusting relationships. While it is difficult to obtain opinions from all members of the public, both domestic and international, it is necessary to take an attitude of disseminating information in a way that answers these concerns and questions.

Regarding the discharge of ALPS-treated water into the sea, the Ministry of Foreign Affairs of Japan (MOFA) and the Ministry of Economy, Trade and Industry (METI) are taking the lead in providing briefings at numerous ministerial meetings, international conferences, bilateral dialogues and diplomatic missions abroad, based on scientific perspectives. In addition, the Japanese government has implemented concerted measures, such as responding to IAEA reviews by the Ministry of Economy, Trade and Industry and the NRA. In this way, the Japanese government is leveraging diplomatic channels to strengthen and continue to provide explanations to international organizations, national governments, and overseas media outlets, and actively conduct public relations by disseminating information in multiple languages, and provide information to foreign media organizations via websites and media outlets. When news reports are not based on facts, they provide appropriate media responses, including briefing to media and publishing counter statements.

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

6.3 Stakeholder involvement

6.3.1 Significance and the current status of local community engagement

6.3.1.1 Basic concept

The fundamental principle for decommissioning the Fukushima Daiichi NPS is “coexistence of reconstruction and decommission.” 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 with the local people and promote coexistence with local communities to gain the trust of the community. Decommissioning should never be a hindrance to the return of residents, the settlement of people, or other aspects of reconstruction such as resettlement and relocation.

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 to eliminate them.

In addition, to accomplish the decommissioning over a 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 contribution to the reconstruction of Fukushima, as it will not only revitalize decommissioning-related industries in the region and create employment and technology but also lead to the spread of the results to other regions and industries.

Approximately 3,500 to 4,700 workers[150] are engaged in work at the Fukushima Daiichi NPS. The local employment rate[151] is about 70%. In this way, the decommissioning project is supported by the people of the region, and it is important to contribute to the steady and stable progress of the decommissioning project for a long period of time from the perspective of local employment.

In light of this, while collaborating with initiatives in the Fukushima Innovation Coast Framework Promotion Organization, the goal is to contribute to job creation, human resource development, and the creation of industrial and economic infrastructure in the region through decommissioning and to achieve coexistence of reconstruction and decommission.

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[150] The average number of employees of TEPCO and its subcontractors who are registered as radiation workers at Fukushima Daiichi NPS who actually worked on the premises of the power plant on a weekday in each month in the past two years up to June 2024, “Overview of decommissioning, contaminated water and treated water management”, The 129th Meeting of the Secretariat of the team for Decommissioning, Contaminated water and Treated water management, August 29, 2024

[151] Employment rate as of July 2024, TEPCO, “Overview of the Decommissioning, Contaminated Water and Treated Water Management”, The 129th Meeting of the Secretariat of the team for Decommissioning, Contaminated Water and Treated Water Management, August 29, 2024

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 holds International Forums to share the latest knowledge, technical achievements, and issues on decommissioning with experts in Japan and overseas, as well as a frank exchange of opinions on decommissioning with participants, including local communities and organizations concerned. In order to promote the exchange of opinions, an "interviewing activity" is held every year to hold conversations with local communities, including high school and technical college students, before the International Forum is held. Then, their real voices are collected, summarized, and edited as a booklet and distributed as the "Voice from Fukushima" at the International Forums. Through these activities, NDF is working to explain the progress of decommissioning at meetings organized by the government or local communities.

TEPCO has been working to provide briefings 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, accepting site visitors is very effective because observing the current decommissioning status and frank opinion exchanges contribute to forming a common understanding. With this in mind, TEPCO is actively accepting visitors to the Fukushima Daiichi NPS (number of visitors: 18,238 in FY 2019, 4,322 in FY 2020, 6,138 in FY 2021, 14,728 in FY 2022, and 18,516 in FY 2023). On the other hand, in the current situation where the COVID-19 pandemic necessitated or, in the future, may necessitate limiting site visits or some people are not able to visit directly, a virtual tour of the decommissioning site of the Fukushima Daiichi NPS has been available on TEPCO's website since 2018 to proactively disseminate information utilizing such simulated experience programs.

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 over 140,000 visitors as of the end of March 2024. Since FY 2020, the Center has been collaborating with 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" established at the end of March 2020, TEPCO has summarized their initiatives for the accumulation of decommissioning work into the following three 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. TEPCO reorganizes, as needed, to steadily advance these efforts for coexistence with the local community. Specifically, TEPCO established the local partnership promotion group in the Fukushima Daiichi Decontamination and Decommissioning Engineering Company in April 2020, a specialized department working to engage in promoting coexistence with the local community at the Fukushima Daiichi NPS in October 2020, and the Hamadori decommissioning industry project office that directly reports to the president. Under their assigned roles, they are engaged in internal and external coordination, on-site support in the region, and discussing medium-to-long-term direction.

With regard to initiatives (1) and (2), the following are being implemented in collaboration with the Fukushima Innovation Coast Framework Promotion Organization and the Fukushima Soso Recovery Promotion Organization.

- Establishment and operation of a joint consultation service to support matching local companies interested in participating in decommissioning projects with prime contractors considering placing orders with local companies
- Matching of decommissioning-related industries between prime contractors and local companies
- Holding decommissioning-related industrial exchange meetings to build relationships between prime contractors and local companies
- Individual visits to local companies
- Tours to the Fukushima Daiichi NPS for local companies

With orders for local companies in decommissioning operations being mainly placed in an indirect way via prime contractors, it is necessary to approach both prime contractors and local companies. Therefore, TEPCO has undertaken a survey on the needs of both prime contractors and local companies for human resource development and joint research with several universities. The contents of the “Medium-to-Long-Term Outlook for Future Orders” prepared in September 2020 are being updated as necessary to reflect the progress of decommissioning work, and briefing sessions are also being held for local commercial and industrial organizations, as well as prime contractors. Especially, since FY2022, TEPCO has shared useful information for local companies in considering participation, by refining the “Medium- to Long-Term Outlook for Future Orders” so as to clearly indicate specific operations suitable for participation of local companies. Moreover, TEPCO is making efforts to promote understanding among prime contractors and support matching with local companies by setting out in particular TEPCO’s vision about participation of local companies at briefings.

These initiatives have led to steady results, with a total of 1,183 decommissioning-related matches as of the end of August 2024 since the establishment of the Matching Support Office (organized by TEPCO, Fukushima Innovation Coast Framework Promotion Organization, and Fukushima Soso Recovery Promotion Organization) in July 2020.

With regard to initiative (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 design and technology development of relatively great difficulty, and manufacturing of high-performance products, which have been ordered outside Fukushima Prefecture, including overseas, can be completed in the Hamadori region. In particular, for “development and design” and “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 companies (announced on April 27, 2022). As specific initiatives, in October 2022, TOUSOU MIRAI MANUFACTURING was established to manufacture various core products required for decommissioning, such as spent fuel casks, and Tousou Mirai Technology Co. Ltd. (Decom.Tech) was also established to conduct basic design and research and development of systems and installations necessary for further expansion of the retrieval scale.

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 will lead to a loss of reputation and trust in the decommissioning not only in the local community but also in society as a whole, which will not only delay the decommissioning but also hinder the reconstruction of Fukushima. Therefore, TEPCO’s challenge is to accurately disseminate information on the current decommissioning status in an easy-to-understand manner by taking every possible measure. In addition to continuously providing opportunities for face-to-face initiatives, including site visits and round-table talks, TEPCO should strengthen communication that is possible even in non-face-to-face and non-contact situations by active use of tools, such as virtual tour programs and online conference systems, and further enhancing photo and video content.

Another issue for the government, NDF, and TEPCO is to make appropriate coordination and build trust with local communities by providing information more carefully. Therefore, by capturing opportunities to hold round-table talks and join local meetings/events, direct interaction with local communities and collaboration with organizations concerned will be promoted proactively. Efforts will also be made for two-way communication by conversation, including listening to concerns and questions carefully through events such as International Forums and delivering accurate information in an easy-to-understand and careful manner. The community, TEPCO, the government, NDF, and organizations concerned should take these opportunities to deepen their knowledge together in changing circumstances.

In particular, regarding the disposal of ALPS-treated water, on the basis of documents including “Progress of the Basic Policy on the Disposal of ALPS-Treated Water and Direction of Future Measures” (formulated on August 30, 2024), the government implements measures to overcome rumors, by communicating on safety backed by scientific evidence, by supporting capital investment and expansion of sales channels of fishermen, as well as by enhancing safety nets such as funds and compensation.

In addition, TEPCO has been working to suppress reputational damage through information dissemination via its “Treated-water portal site” and confirmation of the safety by relevant organizations, etc., based on the “Commencement of ocean discharge of water treated by Multi-Nuclide Removal System, etc.” (released on August 22, 2023). On August 19, 2024, “Fuel Debris Portal Site” was established to provide information on fuel debris in an easy-to-understand manner. TEPCO should continue its utmost efforts to foster the understanding of local communities and 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 shown 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. Initiative (3), “Creation of new local industries” (construction and operation of several new facilities in the 2020s and the establishment of joint ventures with partner companies), involves relatively large-scale investment and is expected to have a great economic impact on the Hamadori area. Therefore, it is necessary to steadily promote and strengthen these efforts. 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, the current activities should be continued and strengthened in a credible manner, including “(1) Increased participation of local enterprises” and “(2) Support for local enterprises to step up.” It is also necessary to carefully explain to local governments, commercial and industrial organizations, and other organizations concerned with the siting 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.

Furthermore, as mentioned above, with orders for local companies in decommissioning operations being mainly placed indirectly through prime contractors, the understanding and cooperation of each prime contractor are essential for the greater participation of local companies. Until now, prime contractors have already been committed to the participation of local companies with the objective of contributing to the reconstruction of Fukushima. Therefore, TEPCO and relevant organizations such as NDF should develop an environment in which it would be even easier in the future for prime contractors to realize the participation of local companies, by taking stock of their initiatives and of the issues raised and opinions from the viewpoint of prime contractors, sharing understanding and having discussions.

Some of the local companies do not necessarily aspire to act as the prime contractor and instead show interest in participating first as the subcontractor to acquire technical skills and experience. It is also important for TEPCO and prime contractors, working in concert, to consider, with a proper understanding of such intentions and needs of local companies, various specific initiatives including those related to the ordering and contracting process and to implement them on a trial basis. Adopting methods beneficial for both prime contractors and local companies would contribute to local companies getting more orders; examples include a scheme that grants contractual incentives such as multi-year contracts and priority order placement to a prime contractor when a certain positive outcome was achieved, regarding order placements accompanied by technical assistance or human resource development provided by the prime contractor to local companies. By continuously considering initiatives that would facilitate the participation of local companies or enable them to have order prospects on a regular and continuous basis, TEPCO should show its determination to proceed with these long-term decommissioning operations together with the local community of Fukushima.

At the same time, with regard to human resource development, the challenge is to leverage the Fukushima Decommissioning Engineer Training Center of the Fukushima Nuclear Energy Suppliers Council, which was established in 2018 and has been providing education on radiation protection and special education on specific matters such as low-voltage electricity handling, and to expand training exclusively for local companies. These various efforts should be steadily promoted while responding to changes in the situation as appropriate 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. 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. To address these issues, in addition to promoting the return of residents, Fukushima prefecture opened the "Fukushima 12-municipality Migration Support Center," which helps people move and settle in the 12 municipalities, mainly from outside the prefecture, to accelerate 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. TEPCO should consider the possibility of collaboration and cooperation with these local initiatives.

To steadily promote these efforts for coexistence with the local community, it is essential to have close cooperation between each department within TEPCO. As mentioned in 6.3.1.2 (2), TEPCO has been reorganizing itself to set up specialized departments for regional symbiosis, and initiatives 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, TEPCO should 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 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

Acronym	Official Name
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.
ALPS-treated water	Radioactive materials other than tritium have been removed from “contaminated water” to the level below regulatory standards using multinuclide removal equipment systems (ALPS：Advanced Liquid Processing System)
AWJ	Abrasive Water Jet
CRD	Control Rod Drive
DOE	United States Department of Energy
DQO process	Data Quality Objectives process: A method developed by the United States Environmental Protection Agency for planning sampling of analytical samples for decision making
FP	Fission Products
F-REI	Fukushima Institute for Research, Education and Innovation
HIC	High Integrity Container
IAEA	International Atomic Energy Agency
ILC	Interlaboratory Comparison
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
ORBS	Overarching Radiation-monitoring data Browsing System in the coastal ocean of Japan
PCV	Primary Containment Vessel
ROV	Remotely Operated Vehicle
RPV	Reactor Pressure Vessel
S/C	Suppression Chamber

Acronym	Official Name
SED	Safety and Environmental Detriment
SGTS	Standby Gas Treatment System
TMI-2	Three Mile Island Nuclear Power Plant Unit 2
Penetration X-2	PCV penetrating part X-2
Penetration X-6	PCV penetrating part X-6
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	TEPCO’s 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 submersible boat-type access investigation vehicle (ROV: 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 and radioactivity 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)
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.

Glossary	Description
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

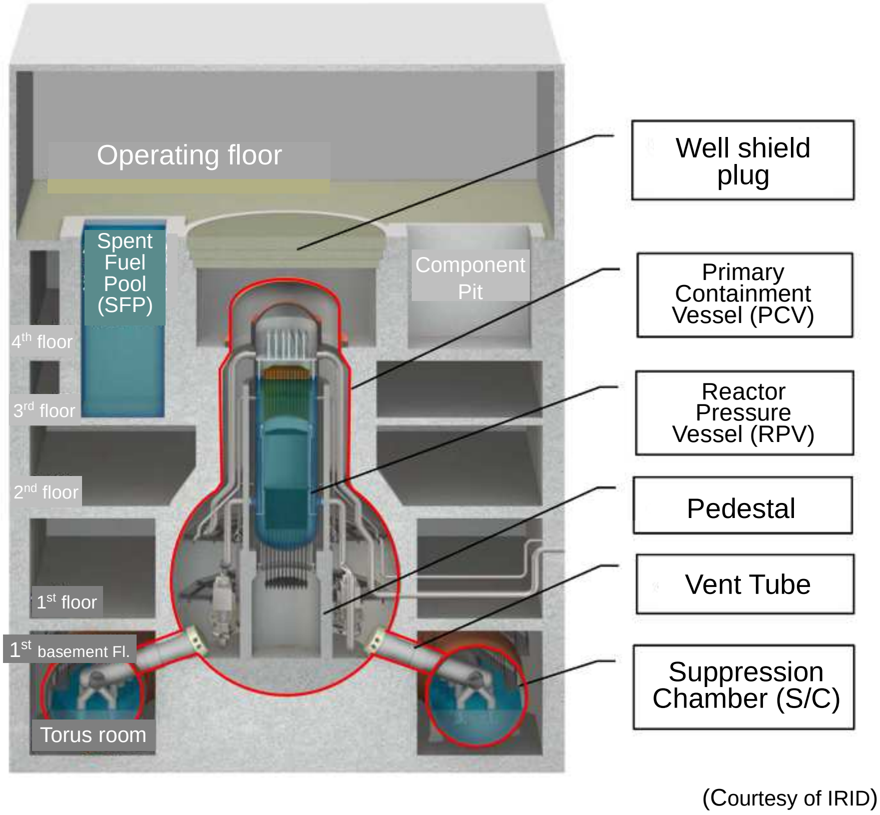

Fig. 66 Structural drawing inside Reactor building

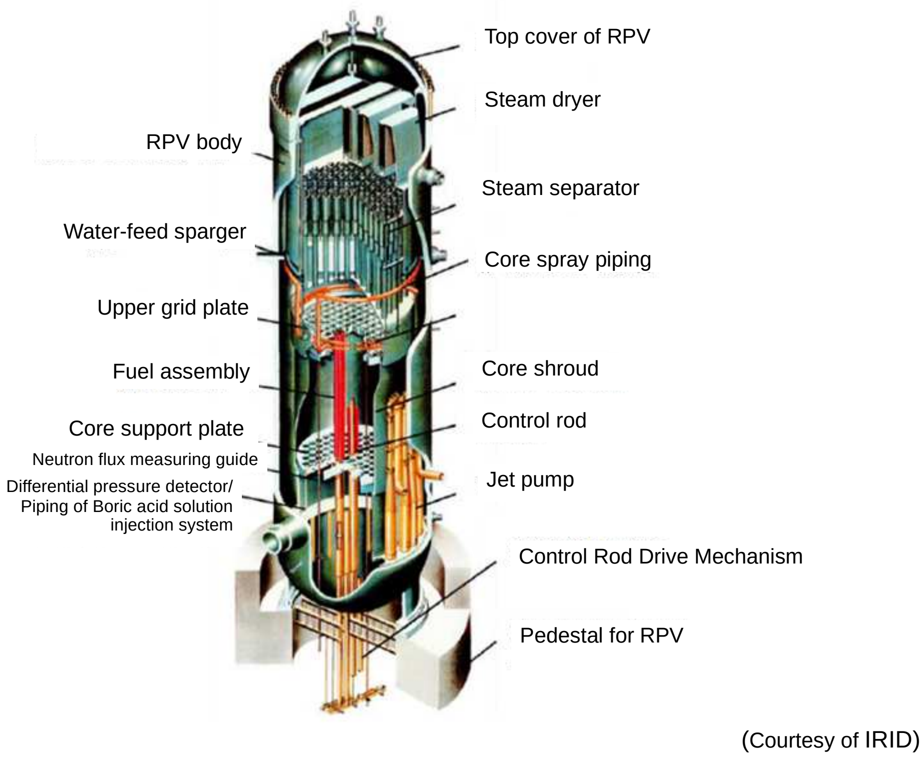

Fig. 67 Structural drawing inside Reactor Pressure Vessel (RPV)

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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 (Phase 1), the period up to fuel debris retrieval start from completion of the 1st period (Phase 2) and the period up to completion of decommissioning from completion of the 2nd period (Phase 3).

[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/management, 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 150m^3/day within 2020, in addition, set the new target to less than 100m^3/day within 2025.

[Technical Strategic Plan 2020 (October 6, 2020)]

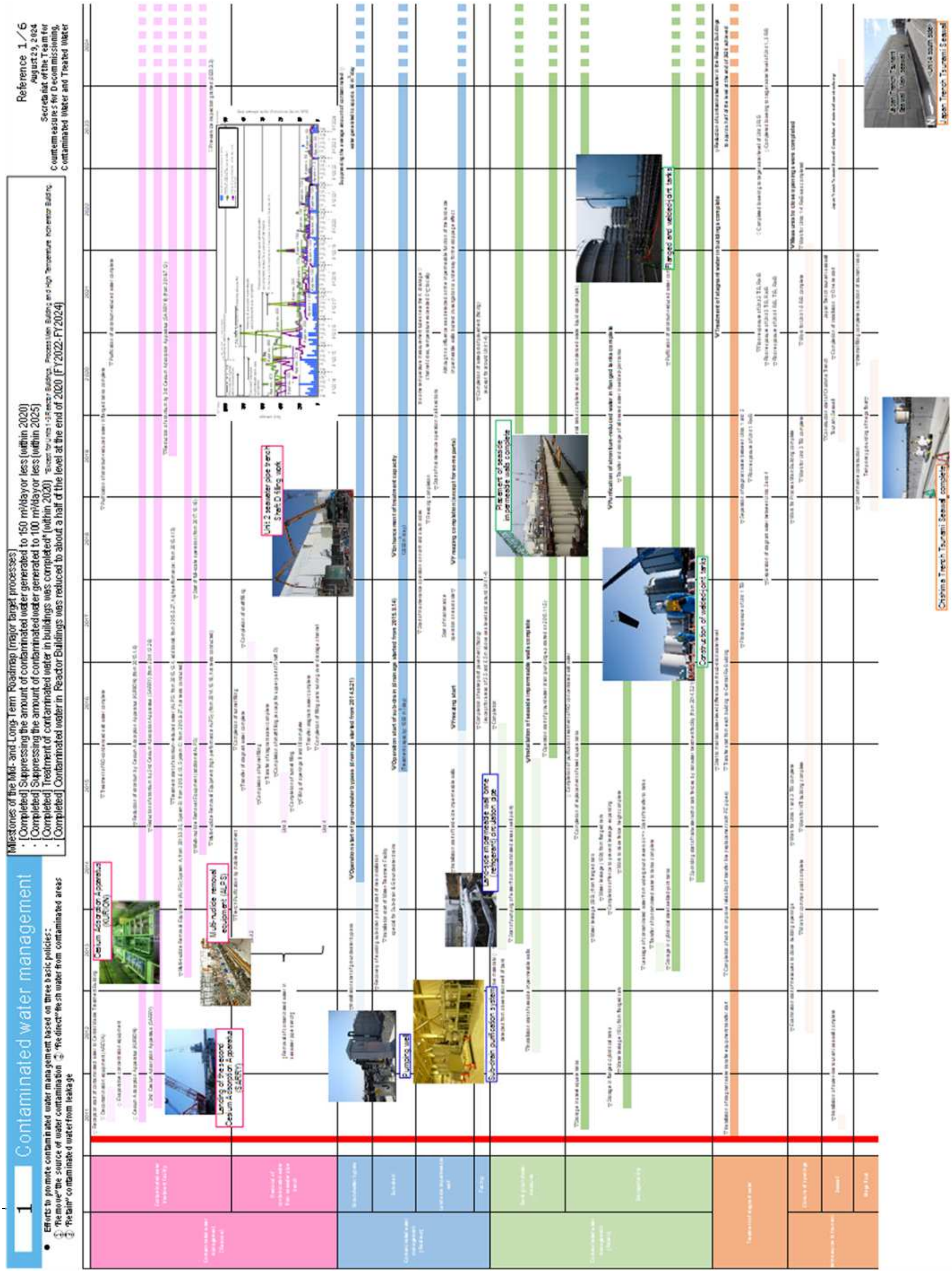
- The plan characteristically included providing of the Mid-and-Long-Term Decommissioning Action Plan, identifying of requirements for the study of fuel debris retrieval methods toward further expansion of the scale, clarifying of the concept for ensuring safety in decommissioning operations, and strengthening 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 the retrieval scale, and the efforts for the ALPS-treated water, while offering the prospects of processing/disposal method and technology related to its safety,

[Technical Strategic Plan 2022 (October 11, 2022)] • The plan presented the status of preparations for the trial retrieval in Unit 2, the overview and issues of the proposed retrieval methods that have been discussed (partial submersion method and submersion method) toward further expansion of the retrieval scale, the status of efforts to discharge ALPS-treated water into the sea and the analytical strategy for promoting decommissioning.
[Technical Strategic Plan 2023 (October 18, 2023)] • The plan presented the investigation and evaluation of the integrity of the pedestal of Unit 1, preparation for the trial retrieval in Unit 2, study for selecting methods for further expansion of the retrieval scale in Unit 3, discharge of ALPS treated water into the sea, and strengthening of the analysis system.

Attachment 2 Major accomplishments to date relating to the decommissioning of the Fukushima Daiichi NPS[152]

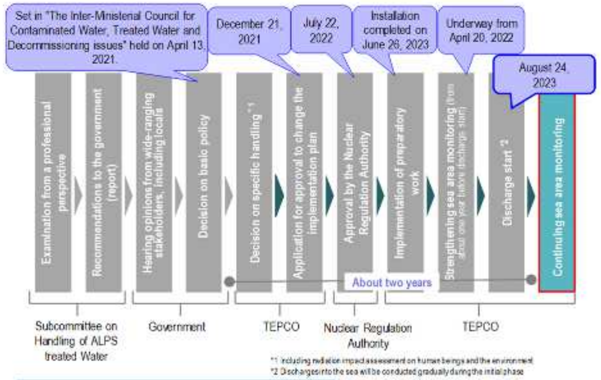


[152] "Material 2: Progress towards decommissioning, etc.", The 129th Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, August 29, 2024

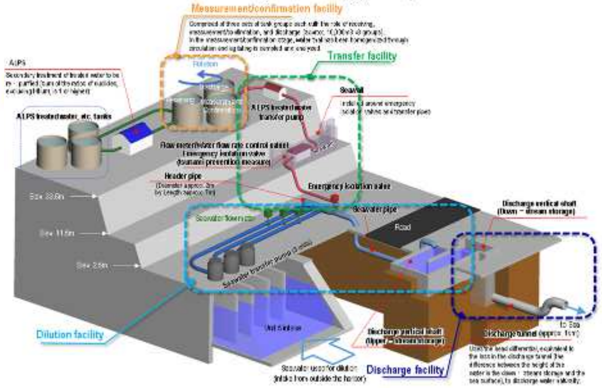
2 Handling of ALPS treated water

In "The Inter-Ministerial Council for Contaminated Water, Treated water and Decommissioning" held on April 13, the basic policy on how to handle ALPS treated water was set. Based on this, the response of TEPCO was announced on April 16.

Regarding the discharge of ALPS treated water into the sea, TEPCO must comply with regulatory and other safety-related standards to ensure the safety of the public, surrounding environment and agricultural, forestry and fishery products. To minimize adverse impacts on reputation, monitoring will be further enhanced, objectivity and transparency ensured by engaging with third-party experts and safety checked by the IAEA. Moreover, accurate information will be disseminated continuously and in a highly transparent manner.



*1 Including radiation impact assessment on human beings and the environment
*2 Discharges into the sea will be conducted gradually during the initial phase



Information provision and communication to foster understanding

■ Occasions to deepen the understanding are organized by communications related to decommission via various media and visit to the power station.

- On the dedicated website "Treated Water Portal Site" (Japanese, English, Chinese and Korean) within the TEPCO website, monitoring results of radioactive materials are published timely.

Dialogue meeting

- Visit and dialogue meeting of Fukushima Daiichi Nuclear Power Station have been held since 2019 for 13 cities, towns and villages.

- Through various opportunities such as visit and on-site explanations, communications continue where opinions of related parties are heard, their thought is taken seriously, and TEPCO conveys its efforts, thought and countermeasures for reputational damage.

● **Status of discharge of ALPS treated water into the sea**

Discharge of ALPS treated water into the sea commenced from August 24, 2023, and the 1st discharge was completed on September 11.

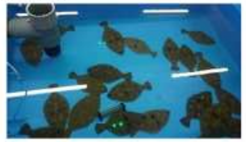
During the discharge period, no abnormality was detected by the sea area monitoring conducted by the national government, Fukushima Prefecture and TEPCO.

<Discharges in FY2023>

Tank group discharged	Tank Group C	Tank Group A	Tank Group B	Tank Group C
Tritium concentration	190,000 Bq/L	170,000 Bq/L	170,000 Bq/L	200,000 Bq/L
Discharge commencement	April 19, 2023	May 17, 2024	June 28, 2024	August 7, 2024
Discharge termination	May 7, 2023	June 4, 2024	July 16, 2024	August 25, 2024
Discharge amount	7,851 m^3	7,892 m^3	7,846 m^3	7,897 m^3
Total tritium amount	1.5 trillion Bq	1.3 trillion Bq	1.3 trillion Bq	1.6 trillion Bq

● Rearing test of marine organisms

- To alleviate concerns and lead to relief of local residents, related parties and the everyone in society, marine orgasms are being reared in tanks of seawater containing ALPS treated water and the status is compared with the original seawater controls.
- External experts also confirmed that there was no difference in rearing statuses between the tanks of the original seawater controls and those of seawater containing ALPS treated water.
- As shown in the existing research results conducted in Japan and overseas, it was confirmed that "tritium in vivo reached equilibrium in a certain time period and the concentration of tritium in vivo reaching equilibrium did not exceed the level in the growing environment."



Flounder in rearing preparation tank

Overall view of mockup tanks

- Daily rearing status is published in the TEPCO website and Twitter
  - TEPCO website: http://www.tepco.co.jp/decommission/information/newsrelease/breedingtest/index-j.html
  - TEPCO X (Old Twitter): https://twitter.com/TEPCOfishkeeper

● **Publication of the Comprehensive Report of the IAEA safety review**

The Comprehensive Report on the safety review concerning handling of ALPS-treated water was published by the IAEA on July 4, 2023.

In the Executive Summary of the IAEA Comprehensive Report, the IAEA concluded the following: (1) the activities by Japan associated with the discharge of ALPS treated water into the sea are consistent with relevant international safety standards, (2) the discharge of the ALPS treated water will have a negligible radiological impact on people and the environment.

We will continue to share necessary information with the IAEA, while striving to foster further understanding of the international community about the discharge of ALPS treated water into the sea.

https://www.iaea.org/topics/response/fukushima-daiichi-alps-treated-water-discharge-comprehensive-reports

Examination concerning handling of ALPS treated water

- Tritiated Water Taskforce (2013.12 – 2016.5, 15 meetings)
- 2016.6 Report of Tritiated Water Taskforce
- Subcommittee on Handling of ALPS treated water (2016.11 – 2020.1, 17 meetings)
- 2018.8 Explanatory and hearing meeting, receiving opinions
- 2020.2 Report of Subcommittee on Handling of ALPS treated water
- Opportunity for receiving opinions from parties concerned concerning handling of ALPS treated water (2020.4 – 2020.10, 7 meetings)
- 2021.4.13 The basic policy on the handling of ALPS treated water was set
- 2021.4.16 The response of TEPCO was announced
- 2021.12.21 The "Application Documents for Approval to Amend the Implementation Plan for Fukushima Daiichi Nuclear Power Station Specified Nuclear Facility" regarding ALPS treated water were submitted to the Nuclear Regulation Authority
- 2021.12.28 The Action Plan concerning the Continuous Implementation of the Basic Policy on Handling of ALPS Treated Water" was formulated
- Review meeting concerning the implementation plan on handling of ALPS treated water (from 2021.7 to 2022.4, 15 meetings)
- 2022.4.28, 5.13, 7.15 Application to partially revise the Application Documents for Approval to Amend the Implementation Plan was submitted
- 2022.7.22 Application for the Application Documents for Approval to Amend the Implementation Plan was approved
- 2022.8.4 Work has commenced
- 2022/8/30 The "Approach to Strengthening and Expansion of Measures in the Handling of ALPS Treated Water" was summarized
- 2022.11.14 Application for the Application Documents for Approval to Amend the Implementation Plan was submitted (amendment of organizational structure, and nuclides to be measured and assessed, and others)
- 2023.2.14, 20 Application for the Application Documents for Approval to Amend the Implementation Plan was submitted (amendment of organizational structure, and nuclides to be measured and assessed, and others)
- 2023.5.10 Approval
- 2023.6.26 Completion of installation
- 2023.7.7 Receipt of Certificate of Completion for Pre-service Inspections
- 2023.8.24 Commencement of discharge

Tank area viewed from the Large Rest House (2015.10.29)

2014 2015 2016 2017 2018 2019 2020 2021 2022 2023

Reference 3/6
August 29, 2024
Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water

3 Removal of fuel from spent pool

Milestones of the Mid- and-Long-Term Roadmap (major target processes)

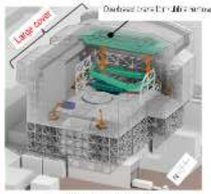
- Completion of Unit 1-6 fuel removal (within 2031)
- Completion of installation of Unit 1 large cover (around FY2023), start of Unit 1 fuel removal (FY2027-2028)
- Start of Unit 2 fuel removal (FY2024-2026)

Legend: Rubble removal, etc. → Installing a fuel removal machine → Fuel removal → Storage and handling of fuel

Unit 1

For Unit 1, a large cover will be installed over the whole building, within which rubble will be removed.

<Reference> Progress to date
Rubble removal on the north side of the operating floor started from January 2018 and has been implemented sequentially. In July and August 2019, the well plug, which was misaligned, was investigated, followed in August and September by the conditions of the overhead crane. Based on the results of these investigations, as the removal requires more careful work taking dust scattering into consideration, two methods were examined: Installing a cover after rubble removal, initially installing a large cover over the Reactor Building, then removing rubble inside the cover.

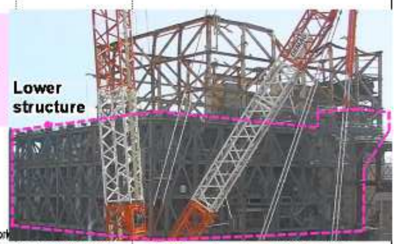


Rubble removal (image)

Fuel removal (image)

As part of efforts to remove fuel from the Unit 1 spent fuel pool, investigations are underway to ascertain the conditions of the fallen roof on the south side and the contamination of the well plug. Based on the results, "the method initially installing a large cover over the Reactor Building, then removing rubble within the cover" was selected to ensure safer and more secure removal. Work to install a large cover started from August 2021. Work to complete the installation of a large cover by around FY2023 is ongoing, with fuel removal scheduled to run from FY2027 to FY2028.

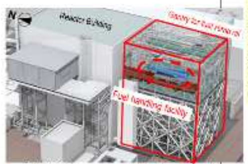
- ▼2017.12 Completion of building cover dismantling and windbreak fence installation
- ▼2018.1-2020.12 Rubble removal on the north side of Reactor Building
- ▼2018.9-12 Removal of X-braces
- ▼2020.3-6 Installation of spent fuel pool cover
- ▼2020.9-11 Measures to prevent and alleviate rubble falling
- ▼2020.11-2021.6 Dismantling of remaining cover
- ▼2021.8 Start of large cover pre-work
- ▼2022.4 Start of large cover installation work



<Unit 1 northwest side 2024.1.24>

Unit 2

For Unit 2, with the removal of spent fuel in mind, a "gantry for fuel removal" (gantry and front room) will be constructed on the south side of the building.



Unit 2 Overview of fuel removal (bird's-eye view)

<Reference> Progress to date
Previously, scope to recover the existing overhead crane and the fuel-handling machine was examined. However, the high radiation dose inside the operating floor meant the decision was taken to dismantle the upper part of the building in November 2015. Findings from internal investigations of the operating floor from November 2018 to February 2019 underlined the potential to conduct limited work there and the means of accessing from the south side was examined.

<Unit 2 Construction of gantry for fuel removal>

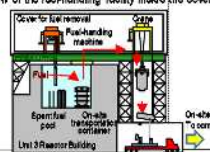
As part of efforts to remove fuel from the Unit 2 spent fuel pool and based on findings from internal operating floor investigations from November 2018 to February 2019, instead of fully dismantling the upper part of the building, the decision was made to install a small opening on the south side and use a boom crane. Examination continues to initiate fuel removal from FY2024 to FY2026.

- ▼2016.9-2017.4 West-side gantry installation work
- ▼2017.5 Opening a hole in the west-side external wall
- ▼2018.8-2020.12 Moving and containment of remaining objects
- ▼2020.6 Investigation inside the spent fuel pool
- ▼2021.6-2022.1 Decontamination of R/B operating floor (1)
- ▼2021.9-2022.5 Shielding installation in R/B operating floor (1)
- ▼2022.5-2022.6 Transfer of FHM
- ▼2022.7-2023.1 Removal and clean-up of FHM operation room
- ▼2022.12-2023.3 Removal of existing facilities in operating floor
- ▼2023.4-2023.11 Decontamination of R/B operating floor (2)
- ▼2023.11- Shielding of R/B operating floor (2)
- ▼2024.6- Completion of installation of gantry for fuel removal
- ▼2021.10-2022.4 Ground improvement work
- ▼2023.1 Start of steel erection
- ▼2023.2 Start of south-side existing facilities dismantling

Unit 3

All fuel assemblies from Unit 3 had been removed by February 2021.

Overview of the fuel-handling facility inside the cover



- ▼2013.10 Completion of removal of large rubble on the Reactor Building top floor
- ▼2015.8 Completion of removal of the fuel-handling machine B within the spent fuel pool
- ▼2016.12 Completion of shielding on the Reactor Building top floor
- ▼2017.1 Installation start of a cover for fuel removal
- ▼2019.4.15 Start of fuel removal
- ▼2021.2.28 Fuel removal completed (566 assemblies)

Before installing a cover for fuel removal, the process of removing large rubble from the spent fuel pool was completed in November 2015. To ensure safe and steady fuel removal, training via remote control was conducted at the factory using the actual fuel-handling machine to be installed on site (February – December 2015). Installation of the fuel removal cover was completed on February 23, 2018.
With fuel removal in mind, rubble retrieval training inside the pool, which was scheduled in conjunction with fuel removal training, started from March 15, 2019 and fuel removal started from April 15, 2019. Fuel removal was completed on February 28, 2021.

<Unit 3 Cover for fuel removal (dome roof) 2019.2.21>

Unit 4

All fuel assemblies from Unit 4 had been removed by December 2014.

- ▼2011.11- 2012.7 Removal of rubble on the Reactor Building top floor
- ▼2012.4-2013.3 Ground improvement and foundation work
- ▼2013.4-2013.7 Installation of external walls and roof panels
- ▼2013.6-2013.10 Installation of overhead crane and fuel-handling machine
- ▼2013.8-2013.10 Removal of rubble inside the reactor well and pool
- ▼2013.11.18 Start of fuel removal
- ▼2014.12.22 Fuel removal was completed (1533 assemblies)

<Unit 4 Cover for fuel removal>

In the Mid- and-Long-Term Roadmap, the Phase 1 target involved starting to remove fuel from inside the spent fuel pool (SFP) of the 1st Unit within two years of completing Step 2 (by December 2013).
On November 18, 2013, fuel removal from Unit 4, namely the first Unit, got underway and Phase 2 of the roadmap started.
On November 5, 2014, within a year of commencing fuel removal work, all 1,331 spent fuel assemblies in the pool had been transferred. The transfer of the remaining non-irradiated fuel assemblies to the Unit 6 SFP was completed on December 22, 2014. (two of the non-irradiated fuel assemblies were removed in advance in July 2012 for fuel checks)
This marks the completion of fuel removal from the Unit 4 Reactor Building.

Fuel removal

*Part of the photo is corrected because it includes machine information related to nuclear material protection

4 Work toward fuel debris retrieval

Milestones of the Mid- and-Long-Term Roadmap (major target processes)

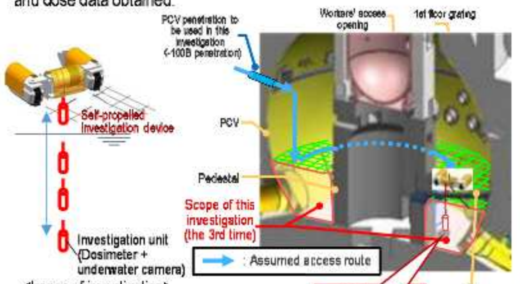
Start of fuel debris retrieval from the first unit (Unit 2). Expanding the scale in stages (within 2021 * The schedule will be extended for about 1 year due to the spread of COVID-19 infections)

Before removing fuel debris, investigations inside the Primary Containment Vessel (PCV) are conducted to inspect the conditions there, including locations of fuel debris.

Unit 1 Investigation overview

・In April 2015, a device having entered the inside of the PCV via a narrow opening (bore:φ100 mm) collected information such as images and airborne dose inside the PCV 1st floor.

・In March 2017, an investigation using a self-propelled investigation device was conducted to inspect the spreading of debris to the basement floor outside the pedestal, with images taken of the PCV bottom status for the first time. The conditions inside the PCV will continue to be examined, based on the imagery and dose data obtained.



<Image of investigation>

・In February 2022, the guide ring* was installed to facilitate the investigation. From March 28, 2023, the investigation inside the pedestal by ROV-A2 started and confirmed that a portion of the bar arrangement was exposed. Regarding the soundness of the pedestal, based on the past earthquake resistant evaluation by the International Research Institute for Nuclear Decommissioning (IRID), it was evaluated that even though a portion of the pedestal was lost, there would be no serious risk. However, as the present information is very limited, the investigation will continue to acquire as much information as possible for continued evaluation.

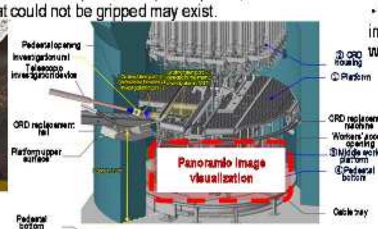
Unit 2 Investigation overview

・In January 2017, a camera was inserted from the PCV penetration to inspect the conditions of the rail on which the robot traveled. The results of a series of investigations confirmed some gratings had fallen and deformed as well as a quantity of deposit inside the pedestal.

・In January 2018, the conditions below the platform inside the pedestal were investigated. Based on the analytical results of images obtained in the investigation, deposits, probably including fuel debris, were found at the bottom of the pedestal. Moreover, multiple parts exceeding the surrounding deposits were also detected. We presumed that there were multiple instances of fuel debris falling.

・In February 2019, an investigation touching the deposits at the bottom of the pedestal and on the platform was conducted and confirmed that the pebble-shaped deposits, etc. could be moved and that hard rock-like deposits that could not be gripped may exist.

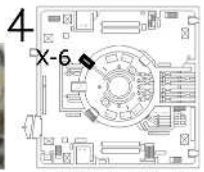
Bottom of the pedestal (after being processed in panoramic image visualization)



・In October 2020, as part of work to prepare for the PCV internal investigation and trial retrieval, a contact investigation to study deposits inside the penetration (X-6 penetration) was conducted, which involved inserting a guide pipe incorporating an investigative unit into the penetration. This confirmed that deposits inside the penetration had not deformed and come unstuck. The investigative information obtained will be utilized in the mockup test of the equipment to remove deposits inside the X-6 penetration.

<Conditions of deposits before and after contact>

<Work in front of the penetration>



<Unit 2 Reactor Building 1st floor Location of the penetration>

Unit 3 Investigation overview

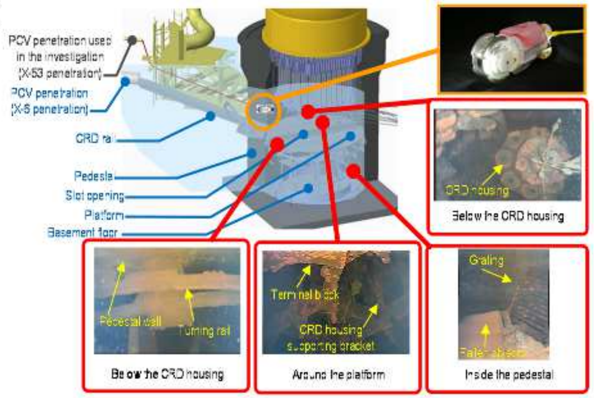
・In October 2014, the conditions of X-53 penetration, which may be under water and which is scheduled for use to investigate the inside of the PCV, was investigated via remote-controlled ultrasonic test equipment. The results showed that the penetration was not under water.

・In October 2015, to confirm the conditions inside the PCV, an investigative device was inserted into the PCV from X-53 penetration to obtain images, data on dosage and temperature and sample stagnant water. No damage to the structure and walls inside the PCV was identified and the water level was almost identical to estimated values. In addition, the dose inside the PCV was confirmed to be lower than in other Units.

・In July 2017, the inside of the PCV was investigated using the underwater ROV (remotely operated underwater vehicle) to inspect the inside of the pedestal. Analysis of the imagery obtained in the investigation identified damage to multiple structures and the supposed core internals.

・Videos obtained in the investigation were reproduced in 3D. Based on the reproduced images, the relative positions of the structures, such as the rotating platform slipping off the rail with a portion buried in deposits, were visually understood.

<Conditions inside the pedestal>



Unit 1 PCV internal investigation

Investigations inside the PCV	1st (2012.10)	- Acquiring images - Measuring the air temperature and dose rate - Measuring the water level and temperature - Sampling stagnant water - Installing permanent monitoring instrumentation
	2nd (2015.4)	Confirming the status of the PCV 1st floor - Acquiring images - Measuring the air temperature and dose rate - Replacing permanent monitoring instrumentation
	3rd (2017.3)	Confirming the status of the PCV 1st basement floor - Acquiring images - Measuring the dose rate - Sampling deposit - Replacing permanent monitoring instrumentation
	4th (From 2022.2)	Acquiring information inside PCV (inside/outside of the pedestal) - Acquiring images - Measuring deposit thickness and sampling deposit - Detecting deposit debris, 3D mapping
Leakage points from PCV	- PCV vent pipe vacuum break line bellows (identified in 2014.5) - Sand cushion drain line (identified in 2013.11)	

Evaluation of the location of fuel debris inside the reactor by measurement using muons
Confirmed that there was no large fuel in the reactor core. (2015.2-5)

Unit 2 PCV internal investigation

Investigations inside the PCV	1st (2012.1)	- Acquiring images - Measuring the air temperature
	2nd (2012.3)	- Confirming water surface - Measuring the water temperature - Measuring the dose rate
	3rd (2013.2 – 2014.6)	- Acquiring images - Sampling stagnant water - Measuring water level - Installing permanent monitoring instrumentation
	4th (2017.1-2)	- Acquiring images - Measuring the dose rate - Measuring the air temperature
	5th (2018.1)	- Acquiring images - Measuring the dose rate - Measuring the air temperature
	6th (2019.2)	- Acquiring images - Measuring the dose rate - Measuring the air temperature - Determining characteristics of a portion of deposit
Leakage points from PCV	- No leakage from the torus chamber rooftop - No leakage from any internal/external surfaces of S/C	

Evaluation of the location of fuel debris inside the reactor by measurement using muons
The existence of high-density materials, which were considered to constitute fuel debris, was confirmed at the bottom of RPV and in the lower part and outer periphery of the reactor core. It was assumed that a significant portion of fuel debris existed at the bottom of RPV. (2016.3-7)

Unit 3 PCV internal investigation

Investigations inside the PCV	1st (2015.10-12)	- Acquiring images - Measuring the air temperature and dose rate - Measuring the water level and temperature - Sampling stagnant water - Installing permanent monitoring instrumentation (2015.12)
	2nd (2017.7)	- Acquiring images - Installing permanent monitoring instrumentation (2017.8)
Leakage points from PCV	- Main steam pipe bellows (identified in 2014.5)	

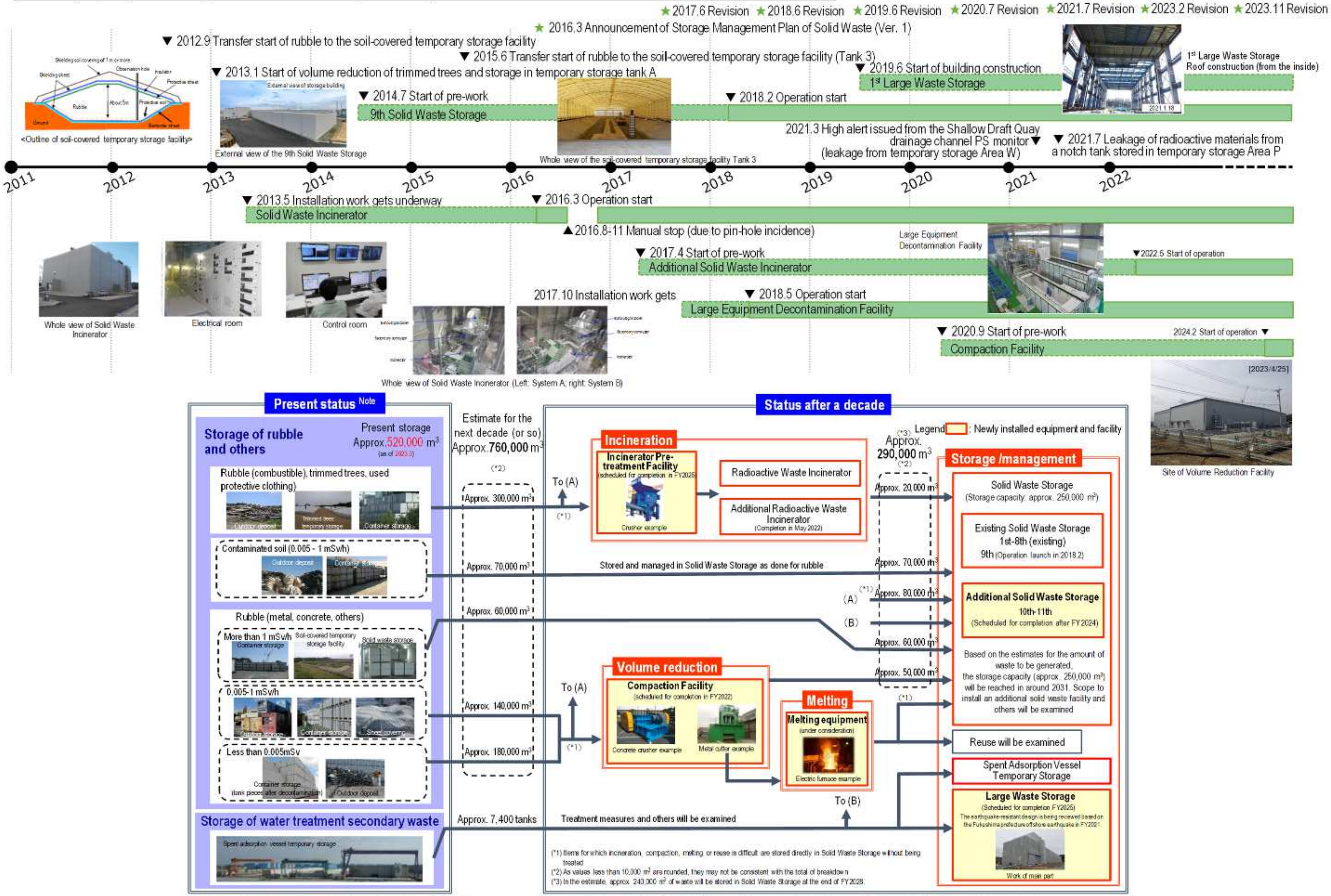
Evaluation of the location of fuel debris inside the reactor by measurement using muons
The evaluation confirmed that no large lump existed in the core area where fuel had been placed and that a portion of the fuel debris potentially existed at the bottom of the RPV. (2017.5-9)

Images are provided by the International Research Institute for Nuclear Decommissioning (IRID)

5 Management of solid radioactive waste

Reference 5／6
August 29, 2024
Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water

Milestones of the Mid- and-Long-Term Roadmap (major target processes)
Eliminating temporary outdoor storage of rubble and others * Except for secondary waste of water treatment and materials for reuse or recycling (within FY2028)



Note: Used protective clothing before incineration and BG-level concrete waste for which treatment and reuse is decided at present are not included.

- The exposure dose at the site boundaries will be reduced by aggregation to indoor storage and eliminating outdoor storage.
- The exposure dosage in exhaust gas from incinerators and at site boundaries is measured and announced on the website and others.

6 Improvement of work environment

While ensuring reliable exposure dose management for workers, sufficient personnel are secured. Moreover, while getting a handle on on-site needs, the work environment and labor conditions are continuously improved.

Regarding the site-wide reduction in the radiation dose and prevention of contamination spreading, the radiation dose on site was reduced by removal of rubble, topsoil and facing. Moreover, the operation was improved to use environmentally-improved areas as a Green Zone, within which workers are allowed to wear general work clothes and disposable dust-protective masks which are less of a physical burden.

2011 | 2012年 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023~

▼ From March 12, 2011, in response to the increased airborne concentration of radioactive materials, instructions were issued to wear full-face masks throughout the Fukushima Daichi NPS site, excluding the Main Anti-Earthquake Building and the rest house.


External view of Access Control Facility

▼ From May 2013, full-face mask unnecessary area was expanded sequentially.

▼ In June 2013, operation of the Access Control Facility started near the main gate of the Fukushima Daichi NPS, to which duties conducted at J-village were shifted, including contamination examination, decontamination, switching protective equipment on and off and distribution/collection of dosimeters.


Large rest house under construction
(2014.9.30)


Access Control Facility
(2014.11.7)

▼ To help workers in the Fukushima Daichi NPS precisely understand the conditions of their workplaces, a total of 86 dose-rate monitors were installed by January 2015. These monitors allow workers to confirm on-site dose rates at their workplaces in real time.

▼ In March 2015, the Fukushima revitalization meal service center opened.

▼ A large rest house for workers was established and its operation commenced in May 2015.
Spaces in the large rest house are also installed for office work and collective worker safety checks as well as taking rest. In March 2016, a convenience store opened in the large rest house. In April, the shower room went into operation.

▼ In February 2017, operation started at the Partner Companies Building next to the New Administration Office Building.

▼ In May 2017, a heliport for emergency transport was installed inside the Fukushima Daichi NPS and went into operation. Compared to the previous operation (at Koriyama Coast, Futaba Town or Fukushima Daini NPS, relaying to a doctor helicopter), a faster response is available for seriously ill patients requiring treatment at external medical institutions.

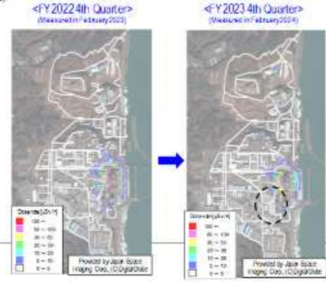
▼ From November 2018, from the west-side high-ground area, where Unit 1-4 can be viewed, visitors can see the site in their normal clothes without having to change.


Visit by Governor of Fukushima Prefecture to the Fukushima Daichi NPS (2018.11.1)


Visit by Prime Minister Kishida to the Fukushima Daichi NPS (2021.10.17)


Visit by Prime Minister Kishida to the Fukushima Daichi NPS (2023.8.21)
Observation of ALPS Treated Water Dilution/Discharge Facilities from high ground on Units 5 and 6 side

<Travel survey results of major roads within the site>
It was confirmed that compared with the last fiscal year, the dose rate has been declining on roads on the west and south sides of the High Temperature Incinerator Building (area circled by black dot line).



▼ In May 2013, areas excluding those around Unit 1-4, tank areas and rubble storage areas were set to full-face mask unnecessary areas.

▼ In May 2015, full-face mask unnecessary area was expanded to cover about 90% of the site.

▼ In March 2016, based on the progress of measures to reduce the environmental dosage on site, the site was categorized into two zones: Highly contaminated area around Unit 1-4 buildings, etc. and other areas where limited operation started to optimize protective equipment according to each category.

▼ In March 2017, the G-zone area was expanded (to cover 95% of the whole site).

▼ In May 2018, within about 96% of the site, workers are allowed to wear light equipment such as general workwear and disposable dust-protective masks.

▼ In August 2021, operation started while eliminating the need for the DS2 mask during light work in G-zone outside the protection area around Unit 1-4 (except for inside Units 5 and 6).


Move in general working clothes
(2018.1.7)

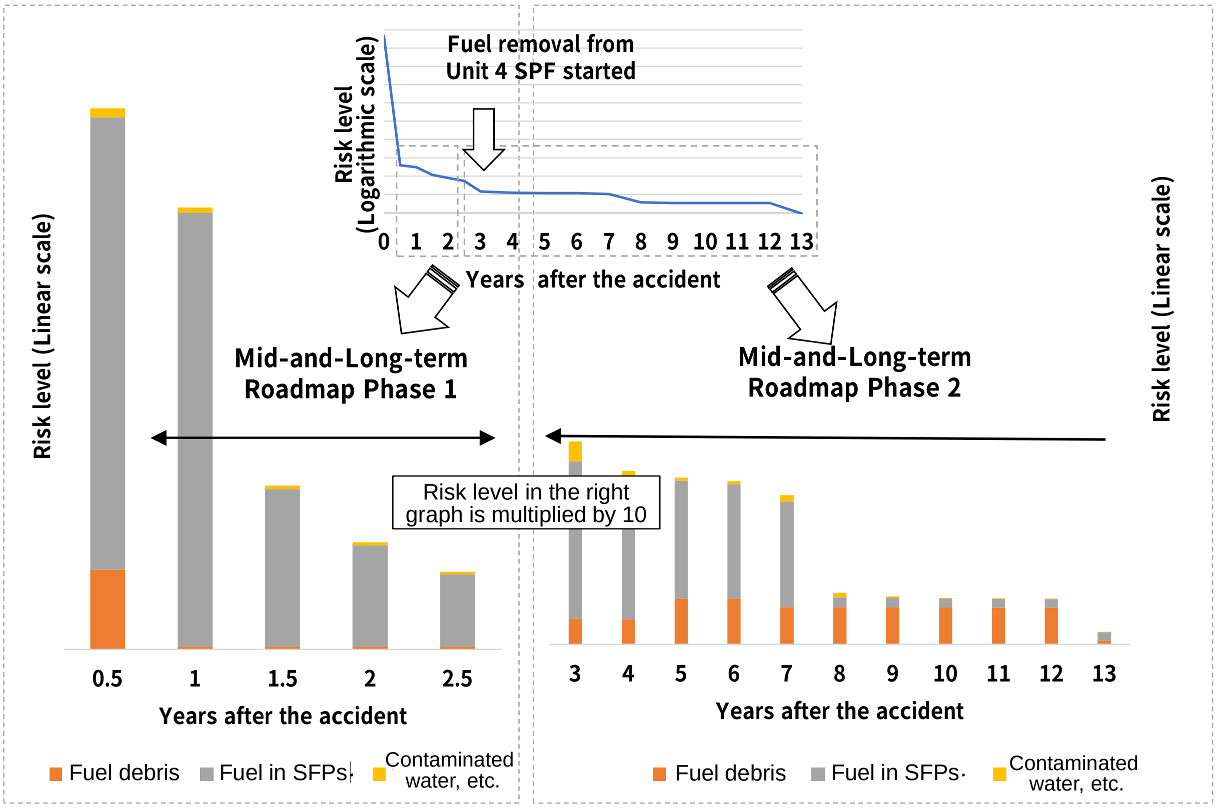

Facing
(2017.4.13)

Attachment 3 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. A3-1. 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 Requiring Level for 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. 4 in Chapter 2 of main part.)

Fig. A3-1 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. A3-1. With a logarithmic scale, risk sources can be indicated that are too small to be displayed in the linear scale of Fig. A3-1. 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. A3- 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 became higher 11 years after the accident, because some ALPS slurry stored in HICs affected by beta irradiation need to be transferred. However, it has been decreasing since 12 years after the accident as a result of the transfer operations that have been carried out. In addition, the risk level of the water stored in tanks (flanged tank and welded tank) is decreasing as the treatment of stored water in flanged tanks progresses, and is expected to decrease further once the treatment of the remaining concentrated saltwater is completed. The risk level of contaminated structures in the building has increased in the 12-year post-accident assessment based on the accumulated hydrogen that flowed into the system connected to the PCV during the accident and the results of the integrity assessment that assumed hydrogen explosions in the relevant piping in case.

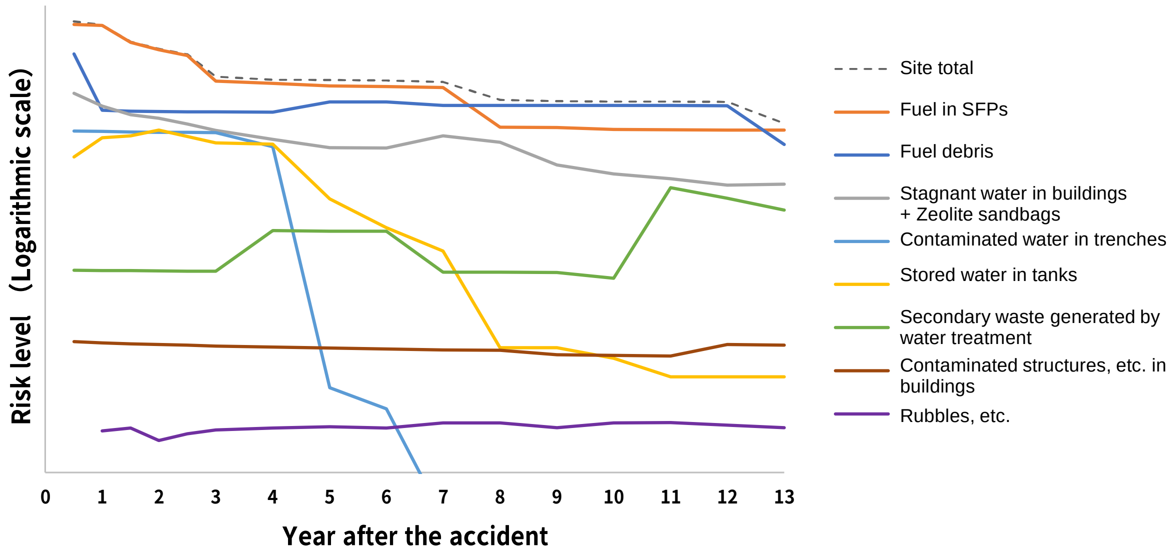


Fig. A3-2 Change in the risk level for each major risk source

(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 Requiring Level for Safety Management, and the risk level was lowered (completed in 2014)[153].

Although the effect of risk level reduction was observed due to the decrease in Requiring Level for 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[154]. In order to prevent dust scattering during rubble removal, a large cover will be installed, and fuel removal from SFP is planned to start in FY2027 to FY2028[155].

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 FY2026120[155].

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[156].

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 eighth 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 Requiring Level for 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 Requiring Level for Safety Management; however, this effect is currently lost. In addition, based

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

[154] TEPCO, The 57th Committee on Oversight and Evaluation 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", December 26, 2017

[155] TEPCO, Mid-and-Long-term Decommissioning Action Plan, March 28, 2024

[156] TEPCO, Decommissioning project, Status of the decommissioning work, Fuel removal from spent fuel pool in Unit 3, (Website)

on the finding that, 13 years after the accident, the time for the hydrogen concentration to reach the flammable limit (4%) when nitrogen injection to and exhaust from PCV are stopped has greatly increased compared to shortly after the accident[157], the change in the hydrogen concentration after stopping nitrogen injection that affects the time allowable (Control Factor, see Attachment 5) was reviewed taking into account decay of radioactivity and distribution of fuel debris. As a result, the time margin for the risk to become apparent increases, and therefore the risk level of fuel debris has become lower than that in previous evaluations.

(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. As for the stagnant water in the process main building and high-temperature incinerator building that are to receive stagnant water transferred from the reactor building, in order to lower the water level to expose the floor surface, recovery of zeolite sandbags placed on the basement floors (to be started in FY 2025), establishment of facilities to receive stagnant water from the reactor building, and installation of an α-nuclide removal system are planned[158].

(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)[159]. 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 [160].

(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-

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[157] Material 1-3: Status of studies on enhancement of containment function of PCV (Hydrogen explosion in PCV), the Technical Meeting on the Examination of the Implementation Plan of the Measures for the Specified Reactor Facilities, June 5, 2023

[158] TEPCO, Material 4-2-3: Progress in the treatment of stagnant water in the buildings, the 111th Committee on Oversight and Evaluation of Specified Nuclear Facilities, February 19, 2024

[159] TEPCO, Decommissioning project, Status of the decommissioning work, Removal of contaminated water in seawater pipe trenches, (Website)

[160] TEPCO, Inspection of stagnant water contains radioactive materials observed in trenches of Fukushima Daiichi NPS (FY2023)”

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)[161].

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).

As for the concentrated saltwater remaining at the bottom of the flanged tanks, the residual water was being collected by filtering for dismantling the tanks. However, as of the end of April 2024, highly viscous sludge was found to have accumulated, and the efficiency of recovery by filtering was poor. For that reason, the recovery method was reviewed, and the plan is to temporarily transfer to temporary tanks using suction pumps, etc.[162]

(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 the dominant factor among the secondary waste generated by water treatment due to the ALPS slurry stored in the HIC to be transferred since 2011, after the accident. HICs that are evaluated to have exceeded or are close to exceeding the standard value for cumulative absorbed dose are planned to be transferred, the risk level is on a downward trend based on the progress of the transfer work by the end of FY2023. The numbers of HICs with the integrated absorbed dose exceeding 5000 kGy by the end of FY 2024, FY 2025, and FY 2026 are estimated to be 23, 26, and 48, respectively[163]. Although the number of HICs

[161] TEPCO, Decommissioning project, Status of the decommissioning work, Purification of contaminated water, (Website)

[162] TEPCO, Material 3-1: “Progress of flanged tank dismantling in Area E”, the 125th The Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, April 25, 2024

[163] TEPCO, Material 4-4: “Progress of HIC slurry transfer work”, the 112th Committee on oversight and evaluation of specified nuclear facilities, April 26, 2024

whose integrated absorbed dose approached the standard value will gradually increase over time, ensuring that the integrated 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 sludge from decontamination equipment stored in the main process building (T.P. 8.5m) will be extracted (planned for FY2027), placed in a storage container, and transferred to the elevated area (T.P. 33.5m) [164].

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

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, has been increased from that indicated in the Technical Strategic Plan 2022, based on the accumulated hydrogen that flowed into the system connected to the PCV during the accident and the results of the integrity assessment that assumed hydrogen explosions in the relevant piping in case. For the Unit 3 S/C that exceeded the elastic deformation range as a result of the integrity assessment assuming hydrogen explosions, purging operations started. However, purging of the stagnant hydrogen is a time-consuming process conducted gradually, and therefore the risk level is still the same 13 years after the accident[165,166].

(8) Rubble, etc.

Rubble, 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 Requiring Level for Safety Management, and the rubble stored in outdoor sheet covered storage and outdoor accumulation are of the highest risk level. In the past, the facilities with better-controlled condition have been enhanced by soil covered temporary storage facilities (in 2012), fallen tree temporary storage pool (in 2013), expansion of solid waste storage facilities (in 2018), etc. In

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[164] TEPCO, Reference 4-2-4: "Progress of recovery unit for sludge in decontamination equipment", The 111th Committee on Oversight and Evaluation of Specified Nuclear Facilities, February 19, 2024

[165] TEPCO, Material 3-3: "Start of purging operations of the stagnant gas in the S/C of Unit 3", the 121st The Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, December 21, 2023

[166] TEPCO, Material 3-1: "Status of purging operations of stagnant gas in the S/C in Unit 3", the 18th Technical Meeting on the Examination of the Implementation Plan of the Measures for the Specified Reactor Facilities, April 5, 2024

addition, the rubble from temporary storage facilities was transferred to the better-controlled solid waste storage facility (in 2020). As for rubble, etc., temporarily stored outdoors, the plan is to eliminate them by FY 2028 by incinerating and reducing their volume and storing them in the solid waste storage facility. Among these activities, incineration and volume reduction process have become available for both combustibles and incombustibles as the additional solid waste incinerator and volume reduction facility started operation in May 2022 and February 2024, respectively. Regarding the solid waste storage facility to store the rubble, the plan is to secure a site on the premise and build additional storage facilities if the predicted amount of solid waste generation changes and if the storage facility does not provide enough space[155].

Attachment 4 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, Contaminated Water and Treated Water Management. As a result, it has been confirmed that the main equipment and reactor buildings have a certain level of seismic margin.

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

- Existing equipment/systems and buildings (including modified areas; the impact of aging is also considered necessary)
  - Control the deterioration of containment functions of PCV, RPV, and reactor buildings, etc., and control/prevent large releases 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 releases 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 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 the 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, the lowering of the water level in the PCVs of Units 1 and 3 was confirmed in the earthquakes that occurred on February 13, 2021, and March 16, 2022 with epicenters off the coast of Fukushima Prefecture.[167, 168] Although cooling functions were maintained in both cases, in light of both earthquakes, in order to maintain and manage the equipment/systems and buildings with the above functions over the medium-and-long term, it is necessary to conduct impact assessments on the accident impact, aging degradation, and external events (earthquakes and tsunamis, etc.) anticipated during the decommissioning period. As the information on facilities and equipment was limited in the past impact assessment, it is necessary to make maximum use of existing techniques and investigation results as well as to develop new techniques in the investigation plan for further understanding the situation in the future. 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 appropriately understand the actual situation of the impact of the accident and thinning caused by aging degradation. However, because of the high-radiation dose environment, the information available is limited, and establishing conservative conditions for examination may increase the difficulty of implementing measures. Therefore, 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, a method should be devised to reduce uncertainties in the scope and method of feedback, etc., such as utilizing the

[167] An earthquake with its epicenter off the coast of Fukushima Prefecture. A maximum intensity of upper 6 was observed in Miyagi and Fukushima Prefectures. In the Fukushima Daiichi NPS, the second basement floor of the Unit 6 reactor building (on the foundation plate) recorded the quake with a 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 application of the new seismic design policy determined by the NRA.

[168] An earthquake with its epicenter off the coast of Fukushima Prefecture. A maximum intensity of upper 6 was observed in Miyagi and Fukushima Prefectures. In the Fukushima Daiichi NPS, the second basement floor of the Unit 6 reactor building (on the foundation plate) recorded the quake with a maximum acceleration of 221 gal.

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, the water level lowering plan was developed for the S/Cs in Units 1 and 3 with water levels higher than during normal operation caused by the accident, and the PCV water level of Unit 1 is gradually lowered.

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, the verification of 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, the deterioration, and the condition of 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.
- Investigation of concrete in 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 measures can be for the structures themselves and the environment in which they are installed. Generally, measures for the former include coatings, but this is extremely difficult considering that 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 through 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 perform seismic evaluation based on seismic ground motion shown in the new seismic design policy and seismic classes determined by the NRA[169, 170]. 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 this, they should be defined appropriately while considering the perspective of risk assessments. In doing so, although ensuring safety is without 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 application while ensuring the independence of the review.

In addition, in the evaluation of existing systems, even for components that do not directly affect seismic resistance or that are ignored in the seismic assessment, if parts or other components are 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.

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[169] NRA, Material 3: "The concept of seismic 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", the 19th Nuclear Regulation Authority meeting, July 7, 2021

[170] NRA, Material 2: "The concept of seismic 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)", the 30th Nuclear Regulation Authority meeting, September 8, 2021

Attachment 5 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[171] 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 "Requiring Level for Safety Management" of risk sources.

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

or

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

Hazard Potential is an indicator that shows the impact on the public based on the radioactivity and other material of the risk source, while the Requiring Level for Safety Management in the first formula is an indicator of the long-term stability and handleability of the risk source due to the sufficiency of the containment function of the facility containing the risk source and the characteristics (degradation, activity level), etc. of the risk source. The Requiring Level for Safety Management in the second formula is an indicator that shows the time delay until the risk of contaminated soil becomes apparent to the public due to the distance to the site boundary, groundwater flow conditions, etc., the benefits of early implementation of risk reduction measures, and the current assessment and the uncertainty of future predictions. The SED indicators for the major risk sources at the Fukushima Daiichi NPS are assessed according to the first formula. Both Hazard Potential and Requiring Level for Safety Management are factors to be considered in determining the priority of risk reduction measures, and the SED indicator developed by the NDA is expressed in the form of a multiplication so that the contribution of both Hazard Potential and Requiring Level for Safety Management to the priority can be roughly expressed. Risk sources with weak containment and large amounts of radioactivity have a high priority for action, whereas risk sources with adequate containment and small amounts of radioactivity have a low priority for action.

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[171] NDA Prioritization – Calculation of Safety and Environmental Detriment score, EPGR02 Rev.6, April 2011.

When comparing the intermediate state of these risk sources, i.e. risk sources with sufficient containment function and large amounts of radioactivity with those with weak containment function and small amounts of radioactivity, the latter have a higher priority for action, and therefore, as a contribution to priority, Requiring Level for Safety Management should be set to dominate over Hazard Potential. However, as discussed below, while the Hazard Potential is directly influenced by numerical values such as radioactivity, the FD and WUD, which constitute Requiring Level for Safety Management in the first formula, are each assigned a score in the range of 2 to 100, if the Requiring Level for Safety Management is defined only by the product of FD and WUD and multiplied by the Hazard Potential, the Hazard Potential can be more dominant as a contribution to the priority of measures. Taking these considerations into account, to increase the contribution of Requiring Level for Safety Management to the priority of countermeasures, the SED indicator is set to multiply the Hazard Potential by the Requiring Level for Safety Management, defined as the product of FD and WUD to the fourth power[172].

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[173]. 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.

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

Form Factor (FF), as shown in Table A5-1, 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

[172] The NDA Prioritization Process - Development Process Route Map Report, EGR014 Rev.0, July 2006.
[173] Instruction for the calculation of the Radiological Hazard Potential, EGPR02-WI01 Rev.3, March 2010.

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 the case of solid is set to a sufficiently small value assuming that the solid materials are less easily released.

In Table A5-1, 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 A5-2, 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) Requiring Level for 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 apply to the Fukushima Daiichi NPS if they are used as defined by the NDA, they are re-defined as shown in Table A5-3 and Table A5-4 respectively.

(3) Requiring Level for Safety Management - SSR, BER and CU

The definition of SSR, BER and CU used for Requiring Level for Safety Management assessment for contaminated soil is the same as the one defined by the NDA and each score is shown in Table A5-5.

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 A5-1 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 A5-2 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 A5-3 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 potential 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 potential 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 A5-4 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 A5-5 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 6 Risk sources that are not explicitly addressed in the major risk sources

Major risk sources are listed in 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 A6-1 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[174].

Table A6- 1 Risk sources that are not explicitly addressed in the major risk sources[175] (1/3)

Issue	Risk source	Descriptions
Contaminated water management	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[176]. For reactor buildings of Units 1 to 3, process main building and high temperature incinerator building, stagnant water processing is underway.
	Rainwater leaking 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 drainpipes. The roof drain was repaired and closed[177]. Facing of T.P. 2 m and T.P. 6.5 m and T.P. 8.5 m outside the land-side impermeable wall has been completed[178]. Of the total area of approximately 60,000 m^2 near Units 1 to 4 inside the land-side impermeable wall, facing has been completed for approximately 50%[179].
	Underground water tank	The residual water in all the underground water tanks were completely recovered [180]. Dismantling and removal policies are under consideration.
	Accumulated water on site	Extracted by the comprehensive risk inspection performed in 2015[181]. Since then, the concentration of radioactive materials and volume of water are being checked accordingly [182].

[174] NRA, "Measures for Mid-term Risk Reduction at TEPCO's Fukushima Daiichi NPS (Risk Map)", (March 2024 Edition)

[175] The megafloat was included in this table up to the Technical Strategic Plan 2023, but it was removed in this version as the risk of it going adrift due to tsunamis has become sufficiently low. The megafloat is grounded in the harbor with its interior filled with mortar and is currently used as a revetment and cargo unloading facility.

[176] Reference 3-5: "Progress of the treatment of stagnant water in buildings, etc.", The 87th Committee on Oversight and Evaluation of Specified Nuclear Facilities, January 25, 2021

[177] Material 3-1: "Progress of rainwater control for roofs", The 78th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, May 28, 2020

[178] "Progress and review of measures to control generation of contaminated water, Groundwater and rainwater inflow for each building", the 84th Committee on Oversight and Evaluation of Specified Nuclear Facilities, October 19, 2020

[179] Material 3-1: "Status of groundwater level and contaminated water generation around the buildings", the 123rd Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, February 29, 2024

[180] Material 3-6: "On-site Monitoring Status (Conditions of Water Discharge Channels in Units 1 to 3 and Underground Water Storage Tanks)", The 44th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, July 28, 2017

[181] TEPCO, Comprehensive Risk Inspection of Fukushima Daiichi NPS that impacts outside the Site Boundary - Review Results, April 28, 2015

[182] Material 1: "Status of contaminated water and other accumulated water on the premises", The 124th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water (as of March 21, 2024)", March 28, 2024

Table A6- 1 Risk sources that are not explicitly addressed in the major risk sources (2/3)

Issue	Risk source	Descriptions
Risk reduction in reactor building	Fuel in Units 5/6 SFP	Unit 5 : 1,374, Unit 6 : 1,412[183]
	Spent control rods, etc.	Spent control rods, etc.: 22,305. Shroud fragments, etc.: 193 m^3 [184]. The major nuclide is Co-60.
	In-pool water	Salt removal in Units 2 to 4 was completed in 2013.
Solid radioactive materials	Rubbles around buildings	Dismantling of rubble 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[185]. The major nuclide is Co-60.
Important issues to progress decommissioning	Dust in operating floor	Below the target value of release control (1×10^7 Bq/h). Gradually declining[186].
	Radiation source of reactor buildings	Unit 1: On the 3rd floor, a maximum of approximately 48 mSv/h was measured near the isolation condenser (IC) connecting pipe. On the 4th floor, a maximum of approximately 34 mSv/h was measured near the IC[187]. Unit 3: On the 1st floor, radiation doses are high on the floor surface of the south passageway. A maximum of 39 mSv/h was measured. On the 2nd floor, a maximum of 90 mSv was measured[187]. 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[188].
	Drainage	In drainage A, Cs-137: lowered to ND ~ 23 Bq/L [189]. 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[190], and measures such as operation of discriminating-type PSF monitors were taken[191]. Operation of drainage channel D was started in FY 2022 as measures against heavy rains[192].

[183] Material 3-2: “Storage status of spent fuel, etc.”, The 124th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, March 28, 2024

[184] TEPCO, "Solid waste in Fukushima Daiichi Nuclear Power Station", Regular meeting on circulating injection cooling and stagnant water at Fukushima Daiichi NPS, April 5, 2024.

[185] TEPCO, 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

[186] TEPCO, Daily Analysis Results of Radioactive Materials at Fukushima Daiichi NPS, (Website).

[187] Material 3-1: “Interim report on investigation and analysis of the accident of TEPCO’s Fukushima Daiichi NPS (2023 edition) (Proposal), the 36th The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station”, March 7, 2023

[188] Material 3: “Progress of On-site investigation”, the 14 The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, October 16, 2020

[189] Material 2: “Status of measures for reducing the concentration of wastewater in drainage channel K”, The 32nd Committee on Oversight and Evaluation of Specified Nuclear Facilities, March 4, 2015

[190] “Reference 2: Measures for rainwater inleak control (Progress of installing purification materials for rainwater drainage in turbine buildings)”, The 63rd Committee on Oversight and Evaluation of Specified Nuclear Facilities, October 15, 2018

[191] Material 3-6: “Starting of operation of PSF monitor in the Drainage channel K”, The 74th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, January 30, 2020

[192] TEPCO, News release "Starting of operation of Drainage channel D at Fukushima Daiichi Nuclear Power Station (for reducing the risk of flooding at heavy rain)", July 19, 2022

Table A6- 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[193]. Exhaust stack of Units 3/4 : Measured 3mSv/h at the base[194]. Stagnant water (depth of approximately 1 m) due to rain was observed in June 2023, and approximately 0.165 to 0.352 mSv/h was measured then[195].
	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[196]

193 TEPCO, "Completion of Dismantling of Exhaust Stack of Units 1/2 at Fukushima Daiichi NPS", May 1, 2020

194 Material: "Interim report on the investigation and analysis of the accident at TEPCO's Fukushima Daiichi NPS (proposal)", The 19th The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station", March 5, 2021

195 Material 2-4: "Progress of on-site research for dismantling exhaust stack of Units 3/4", the 40th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, October 30, 2023

196 TEPCO, Results of daily analysis of Radioactive substances at Fukushima Daiichi Nuclear Power Station (Website)

Attachment 7 Change in risk over time

Overview of the concept of risk management in the UK is shown in Fig. A7-1. 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.

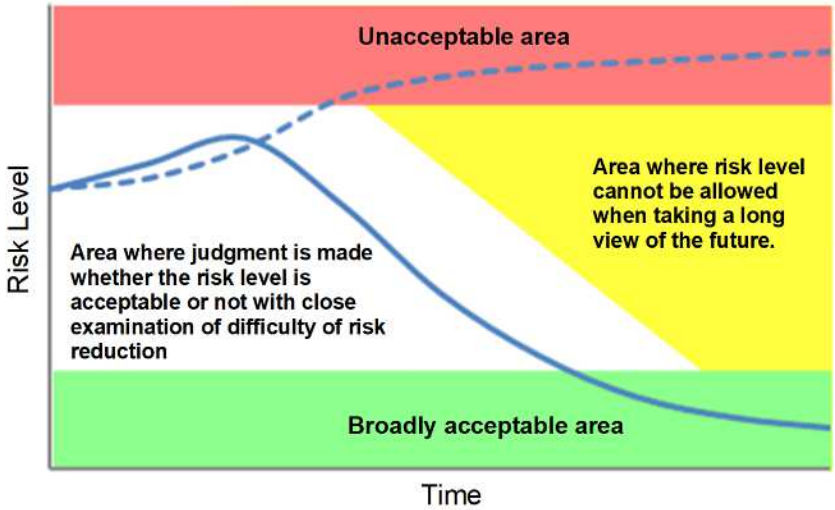


Fig. A7-1 Change in risk over time [197]

[197] 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 8 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[198],[199].

The condition inside PCV is as shown in Fig. A8-1, 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 specific unit. For more detail, as shown in Fig A8-1, fuel debris can be classified by form such as damaged pellets, debris, crust, etc.

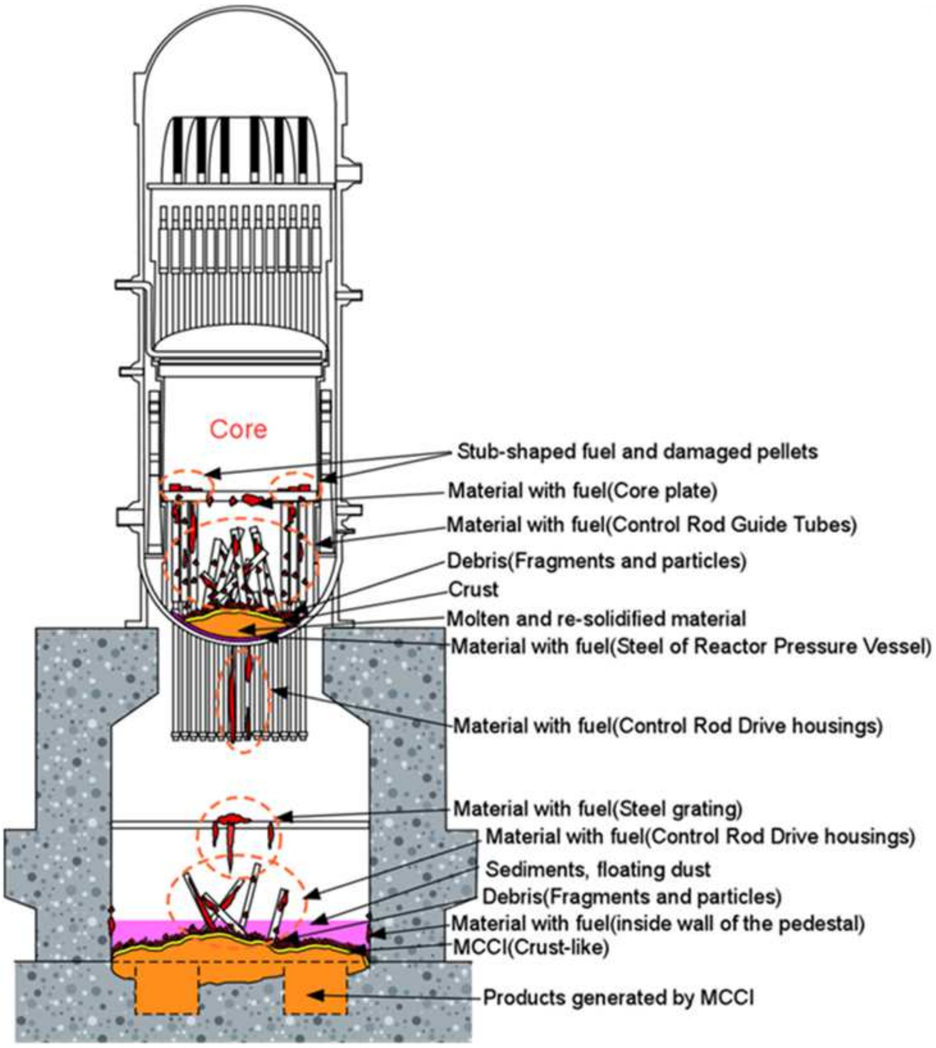


Fig. A8-1 Estimated inside of the PCV of the Fukushima Daiichi NPS

198 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)

199 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 to.

Based on this, an example of fuel debris concept as a retrieval target of fuel debris is as shown in Fig. A8-2. 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.

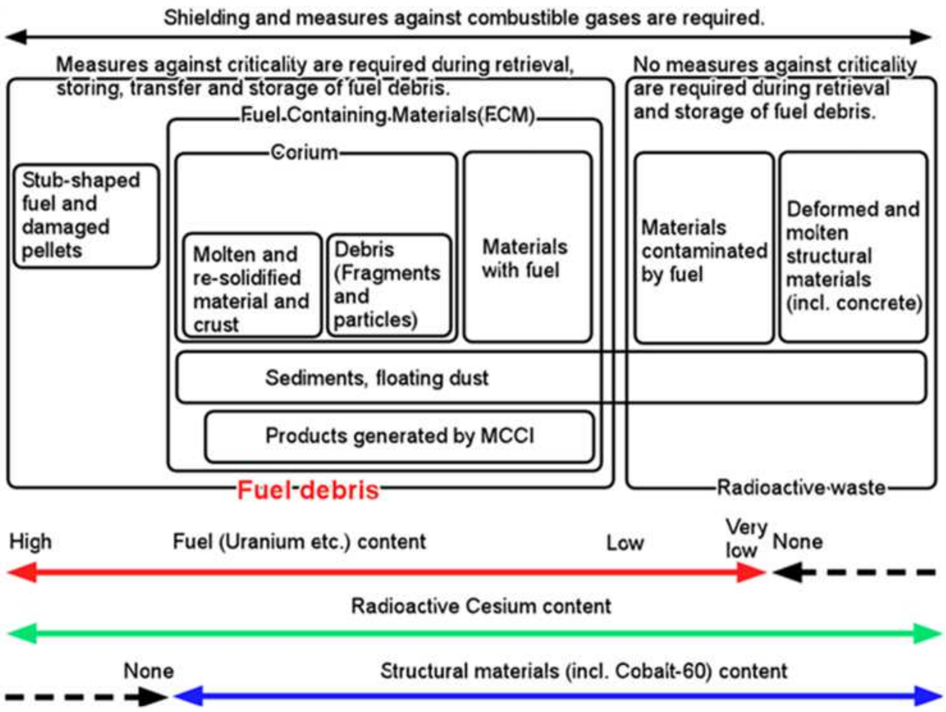


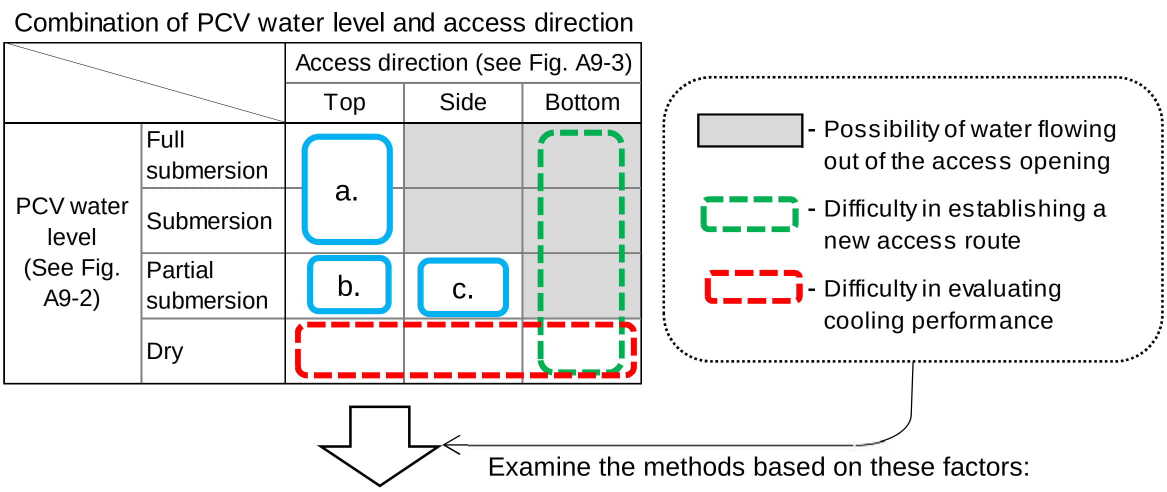
Fig. A8-2 An example of organized concept of fuel debris as fuel debris retrieval target at the Fukushima Daiichi NPS

【Glossaries and Terms】

FCM	: Fuel Containing Materials. It refers broadly that molten fuel components 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, which includes calcium, silicone, etc. which are concrete components.
Fuel deposits	: Molten fuel that has adhered to and solidified on components that do not originally contain fuel components, like CRD housing and grating, where fuel adhesions can be observed by sight.
Fuel contaminant	: A substance that adheres to 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 9 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 Fig.s A9-1 to A9-3)



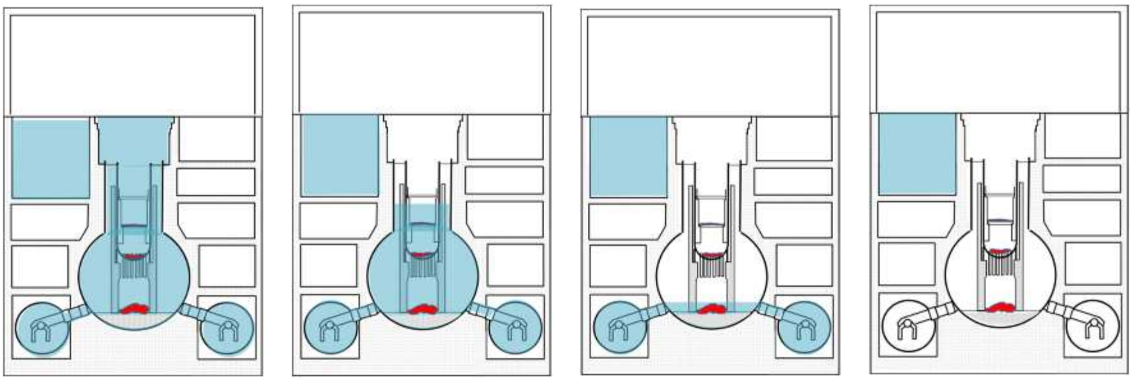
Method of focus and its name

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. A9-1 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. A9-2 Classification of methods according to the PCV water level

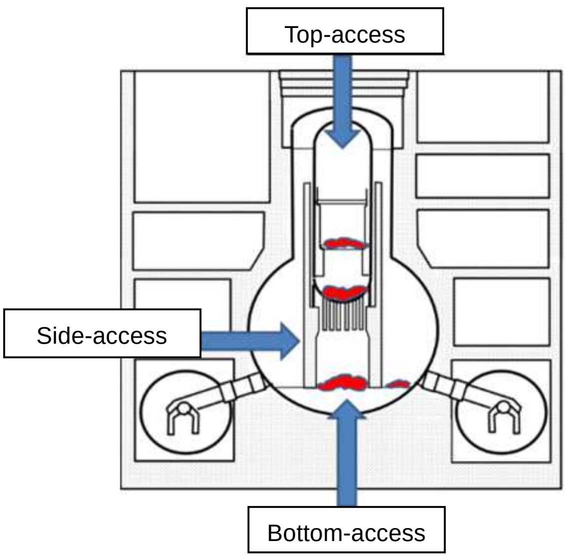


Fig. A9-3 Access direction to fuel debris

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 gradually expanded, 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. A9-4.

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 to 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.

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-tight 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 high.
- Reliable: Some deposits potential of fuel debris is movable, and access route to reach them has been identified.
- Prompt: The risk of the entire fuel debris of Units 1 to 3 can be reduced promptly, and information and experience of the fuel debris retrieval work can be obtained promptly.
- Fuel removal from SFP and fuel debris retrieval can be performed simultaneously by considering the vertical work.

The risk of the entire fuel debris of Units 1 to 3 can be reduced "promptly" by using the arm-type access device, etc. at Unit 2 to safely and reliably retrieve fuel debris, start and continue the series of operations from retrieval to containing, transfer and storage at an early stage, and promptly obtain information and experience necessary for the subsequent procedures.

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

① Fuel debris retrieval work is to start from small-scale operation such as gripping and sucking by using the arm-type access equipment that actual site applicability is getting in sight and the air-tight enclosure that contains the arm-type access equipment under basic condition with the existing safety system and without significant modification of the state of the site.

② Based on information and experiences accumulated through fuel debris retrieval operations, works for processing fuel debris retrieval and for removing obstacles are to be studied. Fuel debris retrieval by crushing or cutting during the small-scale retrieval work phase is to be performed without significant modification of existing safety system.

③ Retrieved fuel debris firstly contained in a small container is transferred to the storage facility located within Fukushima Daiichi NPS site and further contained in the canister for temporarily storing in a dry condition.

④ Unit 2 is appropriate as the "first implementing unit" from a viewpoint of optimization of the overall decommissioning work of Fukushima Daiichi NPS. Thus, a series of operation from fuel debris retrieval to containing, transfer and storage will be continued at unit 2, and essential information and experience will be accumulated for the subsequent procedures. However, the procedure should be performed while setting certain hold points as appropriate before the start of retrieval and confirming the validity.

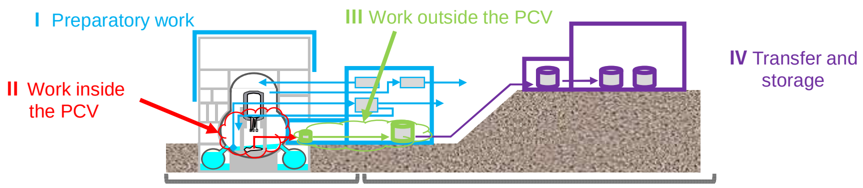
⑤ While proceeding with engineering studies on new safety systems and retrieval/storage facilities, as well as evaluation of safety and actual site applicability, by continuously conducting improvement of working environment, PCV internal investigation and necessary R&D, such as radiation dose reduction, PCV water level lowering and securing working space, the retrieval methods for the expansion of retrieval scale and for fuel debris retrieval from other than the first implementation unit need to be established, including methods of containment, transfer, and storage, based on the accumulated information and experience through fuel debris retrieval work of the first implementing unit.

Fig. A9-4 Flow of examinations for determining the fuel debris retrieval method for the first implementing unit"

TEPCO is currently conducting a conceptual study on the further expansion of fuel debris retrieval in scale, starting with Unit 3, and examining scenarios and methods for fuel debris retrieval.

The following are the works implemented in FY 2021. In examining methods, the work process was roughly divided into two processes: retrieval and transfer/storage. 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 that there were four major work phases, from Phase 1 to Phase 4 (see Fig. A9-5). To examine methods by work phase, the potential methods for each work phase were identified exhaustively, not ruling out any possibilities (setting a longlist), and then methods with low rationality were screened out (organizing a shortlist). Next, each of the shortlisted methods was scored by multi-attribute decision analysis (MADA) evaluation.[200] The basic specifications and conditions of these methods proposed as candidates 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. A9-6).

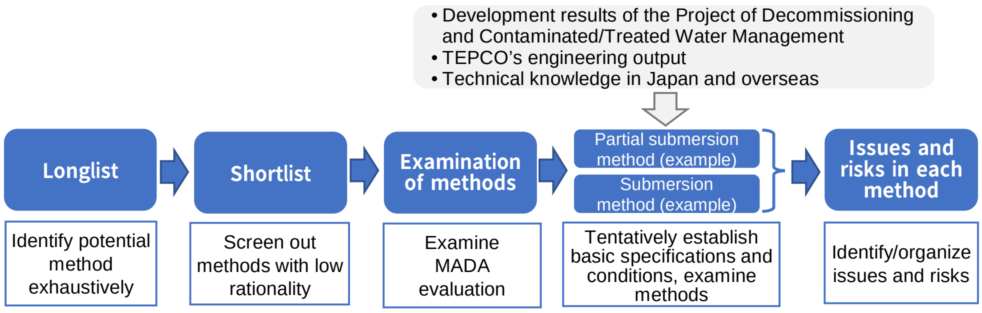
【Retrieval process】		【Transfer and storage process】	
Phase Ⅰ Preparatory work	Phase Ⅱ Work inside the PCV	Phase Ⅲ Work outside the PCV	Phase Ⅳ Transfer and storage
• Reuse, decontamination and dismantling of existing facilities • Establish PCV access route • Introduce safety system and facility • Install 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. A9-5 Conceptual diagram of each work phase (a division of process)

[200] A 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)) × (Weight of each attribute (evaluation item) = Importance)” will remain. As this was used to examine retrieval methods, it is thought that evaluation by this methodology will be effective in narrowing down multiple method options (e.g., access devices) hereafter.



(TEPCO material edited by NDF)

Fig. A9-6 Examination flow for retrieval methods in FY 2021 (outline)

As a result of the above examination, the partial submersion methods and submersion methods are in discussion. This partial submersion method does not use the top or side access method alone, which has been examined previously, but combines them (see Fig.A9-7) 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 (filling the PCV with water: the 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. A9-8) 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 as containment barriers (see Fig. A9-9) for a conceptual drawing of the current submersion method [shell method])

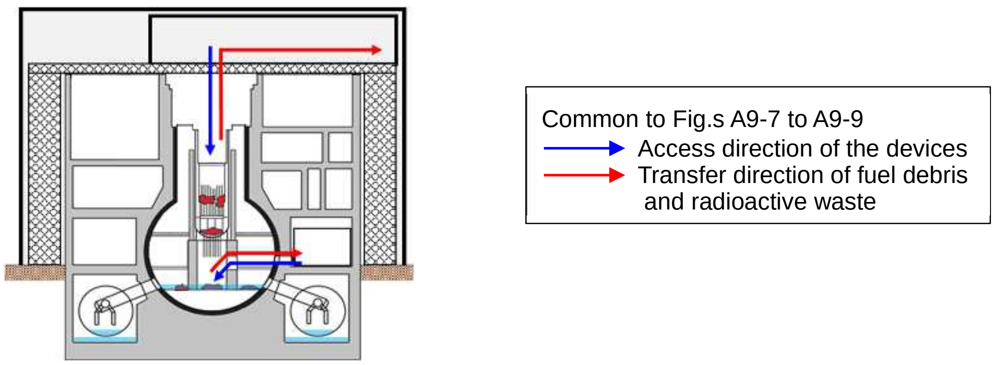


Fig. A9-7 An example of partial submersion method
(Conceptual drawing of combination of top and side access)

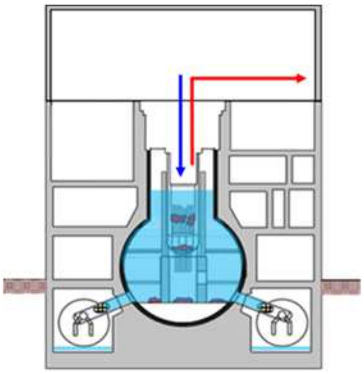


Fig. A9-8 Reference:
Conventional submersion method
(Conceptual drawing of the PCV
submersion method))

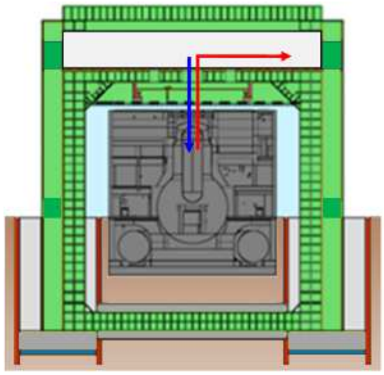


Fig. A9-9 An example of submersion methods
(Conceptual drawing of shell method)

In the Technical Strategic Plan 2023, six factors that make it difficult to retrieve fuel debris are identified first of all, and the points to be noted when examining and evaluating retrieval methods are summarized based on these factors. Next, the issues extracted from the construction sequences are classified into the above six factors for each method of partial submersion method, partial submersion with solidification/fill method (partial submersion option), and submersion method (shell method), and the issues and the policy of the measures are summarized and examined. The partial submersion method option (RPV solidification/fill) was devised as a possible measure to reduce the difficulty of the issues of partial submersion method. It is a method to excavate and retrieve fuel debris together with the filler material after solidifying the pedestal bottom, RPV, reactor well, etc. with the filler material to physically stabilize them (Fig. A9-10).

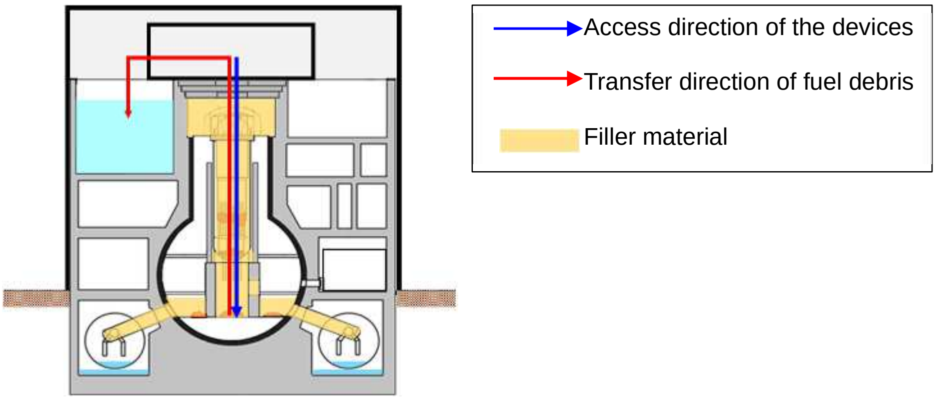


Fig. A9-10 An example of partial submersion method option (Solidification/fill)

Attachment 10 Continuation of accident analysis activities (clarification of events that occurred at the time of the accident) (progress of recent activities)

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

As part of accident analysis activities by TEPCO itself, to clarify the events that occurred at the time of the accident, TEPCO identified 52 issues as "unconfirmed and unresolved issues on the Fukushima Daiichi nuclear accident," and has made reports on the progress of investigations and examinations based on the outcome of internal investigations and other findings (Table A10-1). At the 1st progress report in December 2013, TEPCO reported its conclusions on 10 issues including the possibility of loss of cooling water at Unit 1 affected by the earthquake (Unit-1/Issue-4)[201]. In addition, among the 10 issues reported, studies were continued for two issues: the amount of water injected into the reactor using fire engines (Common/Issue-2) and the behavior of reactor water levels after stopping Unit 3 HPCI (Unit-3/Issue-5). The remaining 44 issues including these two were divided into 10 high priority issues and the other 34 issues. Study results were reported for the 10 high priority issues by the 4th progress report in December 2015, and for 20 issues including "Core damage and the location of core debris" among the 34 low priority issues by the 6th progress report in November 2022[202]. In total, in the past six progress reports, study results have been reported on 10 issues that are important for understanding the accident progression mechanism, one issue on the estimated fuel debris distribution based on site information, and 27 issues that help to understand the accident progression mechanism. Of which, studies are continued for some issues including core damage and debris location (Common/Issue-10) and hydrogen explosion in reactor buildings (Common/Issue-11). Meanwhile, studies are not progressing well on 14 issues, including reaction between molten core substances and concrete and release of radioactive materials from containment vessels during venting. Going forward, internal investigations to be carried out in the course of the trial retrieval in Unit 2 and analysis of retrieved fuel debris are expected to provide information useful for such accident analysis activities.

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[201] "First Progress Report", Report on the results of investigation and examination of unconfirmed and unresolved issues on the development mechanism of the Fukushima Daiichi Nuclear accident, December 13, 2015

[202] The 6th Progress Report on the Investigation and examination of unconfirmed and unsolved Issues on the development mechanism of the Fukushima Daiichi nuclear accident, Attachment 2 [List of issues to be investigated], November 10, 2022

Table A 10-1 Report status of unconfirmed and unresolved issues on the Fukushima Daiichi nuclear accident[203]

(Reported, Yet to be reported)

Issue No.	Issue name	Progress report status
Common/Issue-1 (High priority issue)	SRV operations after core damage	4th 6th (additional report)
Common/Issue-2 (High priority issue)	Amounts of water injected into the reactor by fire engines	1st to 3rd* 5th (additional report)
Common/Issue-3	Water evaporation in the reference leg of water level indicators	3rd, 5th
Common/Issue-4	Water leaks from PLR pump mechanical seals	Yet to be reported
Common/Issue-5	Core-concrete reactions	Yet to be reported
Common/Issue-6 (High priority issue)	Molten core behavior on falling to the lower plenum	4th
Common/Issue-7	Correlation between the timing of a large amount of radioactive materials released into the air and the monitoring data	5th
Common/Issue-8	Radioactive materials release behavior at the time of PCV venting	Yet to be reported
Common/Issue-9 (High priority issue)	Air dose increases around March 20th	3rd
Common/Issue-10	Core damage and the location of core debris	6th
Common/Issue-11	Reactor building hydrogen explosions	5th
Common/Issue-12	Knowledge about massive, synchronized earthquakes with accompanying tsunami	Yet to be reported
Common/Issue-13	Intensified seismic activities in the southern area of Hama-dori in Fukushima Prefecture	Yet to be reported
Common/Issue-14	Exact timing of the tsunami wave arrivals at major buildings of the Fukushima Daiichi NPS and their inundation routes	1st*, 2nd 5th (additional report)
Common/Issue-15	Impacts of tsunami wave forces	Yet to be reported
Common/Issue-16	Investigation from the viewpoint of human factors	Yet to be reported
Unit-1/Issue-1	Deterioration of IC heat removal performance due to hydrogen gas in Unit-1	3rd
Unit-1/Issue-2	Plant behavior if the Unit-1 ICs had functioned	3rd
Unit-1/Issue-3	RPV water level indicator readings at Unit-1 after loss of true value indications	3rd
Unit-1/Issue-4	LOCA possibility at Unit-1 due to the earthquake	1st*
Unit-1/Issue-5	Leaks in gaseous phase from Unit-1 RPV	Yet to be reported
Unit-1/Issue-6	Leaks in gaseous phase from Unit-1 PCV	Yet to be reported
Unit-1/Issue-7	Dose rate increase in Unit-1 reactor building on March 11th	Yet to be reported
Unit-1/Issue-8	Causes of high contamination in the southeast area of the 1st floor in the Unit-1 reactor building	6th

[203] The 6th Progress Report on the Investigation and examination of unconfirmed and unsolved issues on the development mechanism of the Fukushima Daiichi nuclear accident, Attachment 2 [List of issues to be investigated], November 10, 2022
(https://www.tepco.co.jp/decommission/information/accident_unconfirmed/pdf/221110j0106.pdf)

Issue No.	Issue name	Progress report status
Unit-1/Issue-9 (High priority issue)	Causes of high dose contamination around the Unit-1 RCW piping	4th 6th (additional report)
Unit-1/Issue-10	High dose rates contamination near the Unit-1 SGTS piping	Yet to be reported
Unit-1/Issue-11	Impacts of water injection interruptions on the accident progression	4th
Unit-2/Issue-1	RCIC flow rates after loss of DC power supply at Unit-2	1st
Unit-2/Issue-2	Cause of RCIC shutdown at Unit-2	Yet to be reported
Unit-2/Issue-3	Behavior of S/C pressure indicator of Unit-2 after 21:00 on March 14th	6th
Unit-2/Issue-4	Unit-2 RHR system operating conditions after tsunami arrival	1st
Unit-2/Issue-5	PCV pressure behavior at Unit-2 after about 13:00 on March 14th	1st
Unit-2/Issue-6	PCV pressure behavior upon forced SRV opening at Unit-2	4th
Unit-2/Issue-7 (High priority issue)	RPV pressure increase after forced depressurization at Unit-2	2nd, 3rd
Unit-2/Issue-8	Leaks in gaseous phase from Unit-2 RPV	4th
Unit-2/Issue-9 (High priority issue)	Consideration of possible rupture disc actuation at Unit-2	3rd
Unit-2/Issue-10	Condensation behavior upon hydrogen-rich steam release at Unit-2	3rd, 4th
Unit-2/Issue-11	Leaks in gaseous phase from Unit-2 PCV	6th
Unit-2/Issue-12	Sharp increase of CAMS readings on March 15th at Unit-2	2nd, 4th, 6th
Unit-2/Issue-13	Grounds for no hydrogen explosion at Unit-2	Yet to be reported
Unit-3/Issue-1 (High priority issue)	Causes of repeated shutdown of RCIC at Unit-3	2nd
Unit-3/Issue-2	RPV water level indicator readings at Unit-3 after loss of true value indications	5th
Unit-3/Issue-3 (High priority issue)	Thermal stratification in the S/C of Unit-3	4th
Unit-3/Issue-4	Reactor water level behavior during HPCI in operation at Unit-3	1st, 2nd 6th (additional report)
Unit-3/Issue-5 (High priority issue)	Reactor water level behavior after the loss of function of HPCI at Unit-3	1st*, 2nd 5th (additional report)
Unit-3/Issue-6	Rapid depressurization at about 09:00 on March 13th at Unit-3	1st*
Unit-3/Issue-7	RPV pressure behavior after rapid depressurization at Unit-3 on March 13th	1st, 4th
Unit-3/Issue-8	PCV pressure behavior upon venting operations at Unit-3	4th, 6th
Unit-3/Issue-9	Leaks in gaseous phase from Unit-3 RPV	6th
Unit-3/Issue-10	Leaks in gaseous phase from Unit-3 PCV	4th, 6th
Unit-3/Issue-11	Large amount of steam discharge from the top of Unit-3 R/B	4th, 6th
Unit-3/Issue-12	Impacts of water injection interruptions on the accident progression	Yet to be reported

* For these 5 issues, the examination results that were available at the time were reported in the 1st progress report as key issues for understanding the accident. Among them, Common/Issue－2 and Unit-3/Issue-5 were regrouped into 10 high priority issues.

Note: Dates of reports on the "Investigation and Examination of Unconfirmed and Unsolved Issues on the Development Mechanism of the Fukushima Daiichi Nuclear Accident"

1st Progress Report, December 13, 2013

2nd Progress Report, August 6, 2014

3rd Progress Report, May 20, 2015

4th Progress Report, December 17, 2015

5th Progress Report, December 25, 2017

6th Progress Report, November 10, 2022

In addition, TEPCO has been reflecting knowledge obtained by internal investigations of reactor buildings and PCV of Fukushima Daiichi NPS Units 1-3 and collected deposit sample analysis data on the studies of fuel debris retrieval methods and storage/management, examination of unconfirmed and unresolved issues on the Fukushima Daiichi NPS accident, and estimating the core damage status and distribution of fuel debris.

For Unit 1, in FY 2022, PCV internal investigations in Unit 1 were conducted jointly with IRID/Hitachi-GE Nuclear Energy, Ltd. using a submersible ROV, and they succeeded in observing the conditions inside the pedestal for the first time since the accident[204,205,206,207,208,209]. Analysis of the obtained samples found that their main component was iron rust, and particulates containing uranium, zirconium, silicon, and aluminum were detected in trace amounts[210]. In FY 2023, internal investigation of PCV gas phase was carried out using a drone, successfully obtaining observation data for inside the pedestal and the upper part of the PCV, such as damaging of CRD housing under RPV and adhesion of materials that are possibly fuel

[204] Material 3-3: "Unit 1 PCV internal investigation (latter half)", The 110th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, January 26, 2023

[205] Material 3-3: "Unit 1 PCV internal investigation (latter half)", The 111th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, February 22, 2023

[206] Material 3-3: "Unit 1 PCV internal investigation (latter half)", The 112th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, March 30, 2023

[207] Material 3-3: "Unit 1 PCV internal investigation (latter half)", The 113th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, April 27, 2023

[208] Material 3-3: "Unit 1 PCV internal investigation (latter half)", The 114th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, May 25, 2023

[209] Material 3-3: "Unit 1 PCV internal investigation (Analysis of deposits acquired in the investigation by ROV-E)", The 115th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, June 29, 2023

[210] Material 3-3: "Analysis of deposits at the bottom of the Unit 1 containment vessel", The 121st Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, December 21, 2023

debris[211,212,213,214]. Currently, creation of 3D models is in progress[215]. Further, TEPCO proceeded with collection and analysis of samples including RCW heat exchanger residual water and stagnant gas from which high radiation doses were observed[216,217,218,219], water contained in S/C to reduce PCV water level[220,221,222,223], and substances adhered inside the door of X-2 penetration [224].

For Unit 2, TEPCO propelled internal investigation and deposit removal work for the X-6 penetration that is to be used for trial debris retrieval, and conducted sampling of

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[211] Material 3-3: "Unit 1 PCV internal investigation (dry part survey)", The 121st Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, December 21, 2023

[212] Material 3-3: "Unit 1 PCV internal investigation (dry part survey)", The 122nd Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, January 26, 2024

[213] Material 3-3: "Unit 1 PCV internal investigation (dry part survey)", The 123rd Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, February 29, 2024

[214] Material 3-3: "Unit 1 PCV internal investigation (dry part survey)", The 124th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, March 28, 2024

[215] Material 3-3: "Unit 1 PCV internal investigation (dry part survey)", The 127th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, June 27, 2024

[216] Material 3-3: "Response to the stagnant gas detected in the header piping at the inlet of the RCW heat exchanger in Unit 1", The 111th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, February 22, 2023

[217] Material 3-3: "Sampling of the Unit 1 RCW heat exchanger and response to the accumulated hydrogen event", The 112th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, March 30, 2023

[218] Material 3-3: "Sampling results of the RCW heat exchanger (C) in Unit 1", The 116th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, July 27, 2023

[219] Material 3-3: "Analysis results of deposits observed at the Unit 1 RCW system", The 123rd Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, February 29, 2024

[220] Material 3-3: "Implementation of SC water sampling for lowering the water level in Unit 1 PCV", The 115th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, June 29, 2023

[221] Material 3-3: "Progress of work for lowering the water level in Unit 1 PCV", The 117th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, August 31, 2023

[222] Material 3-3: "Implementation system of SC water sampling for lowering the water level in Unit 1 PCV", The 120th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, November 30, 2023

[223] Material 3-3: "Progress of work for lowering the water level in Unit 1 PCV (Follow-Up of the sampling results)", The 120th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, December 21, 2023

[224] Material 3-3: "Sampling inside Unit 1 PCV (Inner door of penetration X-2)", The 126th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, May 30, 2024

deposits[225,226,227,228,229,230,231,232,233,234,235,236,237,238,239,240,241]. In addition, TEPCO conducted investigation on the accessibility to the underground floors of reactor buildings to identify the cause of shutdown of RCIC which was operational for about three days after the accident[242] and

[225] Material 3-3: "Preparations for the PCV internal investigation and trial retrieval work at Unit 2", The 111th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, February 22, 2023

[226] Material 3-3: "Preparations for the PCV internal investigation and trial retrieval work at Unit 2", The 112th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, March 30, 2023

[227] Material 3-3: "Preparations for the PCV internal investigation and trial retrieval work at Unit 2", The 113th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, April 27, 2023

[228] Material 3-3: "Preparations for the PCV internal investigation and trial retrieval work at Unit 2", The 114th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, May 25, 2023

[229] Material 3-3: "Preparations for the PCV internal investigation and trial retrieval work at Unit 2", The 115th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, June 29, 2023

[230] Material 3-3: "Preparations for the PCV internal investigation and trial retrieval work at Unit 2", The 116th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, July 27, 2023

[231] Material 3-3: "Preparations for the PCV internal investigation and trial retrieval work at Unit 2", The 117th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, August 31, 2023

[232] Material 3-3: "Preparations for the PCV internal investigation and trial retrieval work at Unit 2", The 118th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, September 28, 2023

[233] Material 3-3: "Preparations for the PCV internal investigation and trial retrieval work at Unit 2", The 119th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, October 26, 2023

[234] Material 3-3: "Preparations for the PCV internal investigation and trial retrieval work at Unit 2", The 120th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, November 30, 2023

[235] Material 3-3: "Preparations for the PCV internal investigation and trial retrieval work at Unit 2", The 121st Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, December 21, 2023

[236] Material 3-3: "Preparations for the PCV internal investigation and trial retrieval work at Unit 2", The 122nd Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, January 25, 2024

[237] Material 3-3: "Preparations for the PCV internal investigation and trial retrieval work at Unit 2", The 123rd Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, February 29, 20244

[238] Material 3-3: "Preparations for the PCV internal investigation and trial retrieval work at Unit 2", The 124th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, March 28, 2024

[239] Material 3-3: "Preparations for the PCV internal investigation and trial retrieval work at Unit 2", The 125th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, April 25, 2024

[240] Material 3-3: "Preparations for the PCV internal investigation and trial retrieval work at Unit 2", The 126th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, May 30, 2024

[241] Material 3-3: "Preparations for the PCV internal investigation and trial retrieval work at Unit 2", The 127th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, June 27, 2024

[242] Material 3-3: "Internal investigation of Unit 2 reactor building (Confirmation of the situation for the accessibility of the first basement)", The 110th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, January 26, 2023

radiation dose reduction, cleaning, and sampling work for reactor system instrumentation piping in preparation for RPV internal investigation[243,244,245].

For Unit 3, TEPCO conducted investigation of water contained in S/C and stagnant gas to reduce PCV water level[246,247,248] and sampling of water contained in HCU into which FP was assumed to have flowed when the CRD at the bottom of the reactor was damaged at the time of the accident[249].

Further, for sections that still show the traces of the accident inside reactor buildings, TEPCO plans to prioritize its investigation into them before the information on the accident is lost to utilize collected data in examinations, as stated in the "Mid-to-Long-term Examination Plan for 1F." In FY 2024, TEPCO is working on understanding the current situation inside the Unit 3 buildings in terms of spatial information and radiation dose rate information, to be used for deciding the need for detailed investigation in the future[250,251,252].

The findings obtained from these investigations and analyses are incorporated into diagrams that estimate the condition inside the reactor vessel, which are used to determine the cause of the accident. The examination results and the related diagrams are available to the public on debrisWiki[253].

TEPCO identified 52 unconfirmed and unresolved issues regarding the Fukushima Daiichi nuclear accident, categorized them by priority level, and has been studying them. In the past six progress reports, TEPCO reported study results on 10 issues that are important for understanding the accident progression mechanism, one issue on the estimated fuel debris distribution based

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243 Material 3-3: "Work to reduce the dose of the reactor system instrumentation piping for the internal investigation of the Unit 2 RPV", The 116th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, July 27, 2023

244 Material 3-3: "Work to reduce the dose of the reactor system instrumentation piping for the internal investigation of the Unit 2 RPV", The 118th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, September 28, 2023

245 Material 3-3: "Work to reduce the dose of the reactor system instrumentation piping for the internal investigation of the Unit 2 RPV", The 119th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, October 26, 2023

246 Material 3-3: "Purging of stagnant gas in the SC of Unit 3", The 118th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, September 28, 2023

247 Material 3-3: "Measurement and analysis results of stagnant gas in the SC of Unit 3", The 120th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, November 30, 2023

248 Material 3-3: "Start of purging of stagnant gas in the SC of Unit 3", The 121st Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, December 21, 2023

249 Material 3-3: "Sampling of HCU water of the Unit 3", The 127th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, June 27, 2024

250 Material 3-3: "Investigation plan inside the Unit 3 reactor building", The 124th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, March 28, 2024

251 Material 3-3: "Investigation plan inside the Unit 3 reactor building", The 126th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, May 30, 2024

252 Material 3-3: "Investigation plan inside the Unit 3 reactor building", The 127th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Water, June 27, 2024

253 debrisWiki: https://fdada-plus.info/wiki

on site information, and 27 issues that help to understand the accident progression mechanism[254]. Among them, studies are continuing for 12 issues including the distribution of fuel debris. Meanwhile, studies are not progressing well on 14 issues.

The NRA, which is in charge of the ongoing accident investigation and analysis, has established The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station in cooperation with TEPCO and has been engaged in studies on accident analysis[255]. The FY2022 interim report summarized the results of an investigation on matters concerning radioactive material release pathways (vent pipes and shield plugs contamination mechanisms, degree of contamination, and nuclide release timing) and matters concerning hydrogen explosion (physical and chemical mechanisms of hydrogen combustion)[256,257,258,259].

In FY 2023, the results of Unit 1 containment vessel internal investigation using ROV were summarized[260,261,262] and opinions regarding the loss of concrete observed in the investigation were exchanged[263,264,265,266,267], but the damage mechanism is yet to be identified. The results of gas phase investigation using a drone[268] were also shared. In addition, for Unit 1, information was shared and opinions were exchanged regarding the cause of high radiation doses at

254 "Sixth Progress Report": Results of investigation and examination of unconfirmed and unsolved issues on the development mechanism of the Fukushima Daiichi Nuclear Accident, November 10, 2022 (https://www.tepco.co.jp/decommission/information/accident_unconfirmed/pdf/221110j0101.pdf)

255 Article 4, Paragraph 1, Item 11 of the Act for Establishment of the Nuclear Regulation Authority" 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”

256 Interim Report on investigation and analysis of the accident at TEPCO's Fukushima Daiichi Nuclear Power Station - Review from September 2019 to March 2021 -, March 5, 2021

257 NRA, About "Interim Report on investigation and analysis of the accident at TEPCO's Fukushima Daiichi Nuclear Power Station, Tokyo Electric Power Company", June 19, 2021

258 Interim Report on investigation and analysis of the accident at TEPCO's Fukushima Daiichi Nuclear Power Station (2023 edition)

259 Material 4: “Status of investigation and analysis of the accident of TEPCO’s Fukushima Daiichi Nuclear Power Station (NRA)”, The 38th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, June 22, 2023

260 Material 1: “Status of Unit1 PCV internal investigation [IRID/TEPCO]”, The 37th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, April 24, 2023

261 Material 1-1: “Status of Unit1 PCV internal investigation [IRID/TEPCO]”, The 38th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, June 22, 2023

262 Material 1: “Status of Unit1 PCV internal investigation [TEPCO]”, The 39th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, September 12, 2023

263 Material 1-2: “Examination of events related to concrete confirmed by the internal investigation of the Unit 1 PCV of TEPCO's Fukushima Daiichi NPS”, The 38th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, June 22, 2023

264 Material 1-3: “Experiments on loss of concrete, etc. [NRA]”, The 38th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, June 22, 2023

265 Material 4-5: “Experiments on loss of concrete, etc. [NRA]”, The 38th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, September 12, 2023

266 Material 1-2: “Concrete damage event observed in the lower pedestal of Unit 1 [NRA]”, The 44th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, March 29, 2024

267 Material 1-3: “Progress of experiments on concrete damage events in the Unit 1 pedestal [Osaka University/ Fukushima National College of Technology/ NRA]”, The 44th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, March 29, 2024

268 Material 1-1: “Implementation of the Unit 1 PCV internal investigation (dry part investigation) [TEPCO]”, The 44th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, March 29, 2024

RCW[269,270,271,272,273,274,275,276,277,278,279,280,281], confirmation of stagnant gas in CUW piping[282], and sampling of water contained in S/C[283]. For Unit 2, information was shared regarding preparatory work for trial debris retrieval[284,285] and preparatory work for RPV internal investigation[286]. In addition, consideration was given to the formation mechanism of deposits found in the penetration

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269 Material 4: "On-site investigation of the auxiliary cooling system of the Unit 1 reactor [NRA]", The 37th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, April 24, 2023

270 Material 3-1: "Contamination route in the Unit 1 RCW system and sampling of the RCW heat exchanger (c) [TEPCO]", The 38th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, June 22, 2023

271 Material 3-2: "Containment isolation valves of RCW system at Fukushima Daiichi NPS [TEPCO]", The 38th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, June 22, 2023

272 Material 3-3: "Contamination of the auxiliary cooling system of Unit 1 [NRA]", The 38th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, June 22, 2023

273 Material 4-1: "Examination of the estimation of the contamination route in the Unit 1 RCW system and sampling results of the RCW heat exchanger (C) [TEPCO]", The 39th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, September 12, 2023

274 Material 2-5: "Reasons for the application of motor-operated valves to containment isolation valves in RCW systems [TEPCO]", The 40th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, October 30, 2023

275 Material 2-1: "Examination of the estimation of the contamination route in the Unit 1 RCW system [TEPCO]", The 42nd Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, February 16, 2024

276 Material 2-2: "Analysis results of the deposits in the Unit 1 RCW system [TEPCO]", The 42nd Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, February 16, 2024

277 Material 2-3: "Analysis results of sampling water in the Unit 1 RCW system [TEPCO]", The 42nd Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, February 16, 2024

278 Material 2-4: "Examination of the estimation of the contamination route of the Unit 1 RCW system [NRA]", The 42nd Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, February 16, 2024

279 Material 2-2: "Results of provisional examination of the estimation of contamination route in the Unit 1 RCW system and items requiring further examinations [NRA]", The 43rd Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, March 12, 2024

280 Material 2-1: "Examination of the estimation of contamination route in the Unit 1 RCW system [TEPCO/ Hitachi-GE Nuclear Energy, Inc.]," The 44th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, March 29, 2024

281 Material 2-2: "Flow of discussion on estimation of contamination route in the Unit 1 RCW system (proposal) [NRA]", The 44th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, March 29, 2024

282 Material 4-3: "Progress of work for lowering the Unit 1 PCV water level (Confirmation of stagnant gas in CUW Piping of Unit 1) [TEPCO]", The 39th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear power station, September 12, 2023

283 Material 5-3: "Sampling of water content in the S/C to lower the water level in the Unit 1 PCV (including checking the bottom of the S/C) [TEPCO]", The 41st Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, December 25, 2023

284 Material 2-2: "Preparations for the Unit 2 PCV internal investigation and trial retrieval [TEPCO]", The 40th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, October 30, 2023

285 Material 3-2: "On-site information on the Unit 2 penetration X-6 [TEPCO]", The 41st Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, December 25, 2023

286 Material 2-3: "Results of dose reduction for reactor system instrumentation piping for Unit 2 RPV internal investigation [TEPCO]", The 40th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, December 30, 2023

X-6 based on the analysis results of the samples[287,288,289,290,291]. Also, understanding was shared on the reason contamination is relatively low in the differential pressure regulation line[292,293]. For Unit 3, toward the examination of the impact of combustible gases on hydrogen explosion, combustion tests and analysis using materials equivalent to actual equipment, investigation on the generation conditions of combustible gases and their compositions, and estimation of the leak

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[287] Material 2-3: “Examination of the formation process of deposits in the Unit 2 penetration X-6 [NRA]”, The 43rd Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, March 12, 2024

[288] Material 3-1: “Analysis results of sample attached to penetration X-6 probe (FY 2021) [JAEA]”, The 41st Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, December 25, 2023

[289] Material 2-4: “Analysis of smear samples at JAEA [JAEA]”, The 43rd Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, March 12, 2024

[290] Material 3-1: “Organize the results of smear sample analysis [JAEA]”, The 44th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, March 29, 2024

[291] Material 3-2: “Views on the results of smear sample analyses and future efforts [NRA]”, The 44th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, March 29, 2024

[292] Material 2-1: “Results of on-site investigation of checklist for the Unit 2 reactor cavity differential pressure adjustment line valve [TEPCO]”, The 40th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, October 30, 2023

[293] Material 5-1: “Interpretation of the relatively small contamination of the differential pressure adjustment line at Unit 2 [TEPCO]”, The 41st Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, December 25, 2023

pathways and explosion mechanism are continued[294,295,296,297,298,299,300,301,302,303,304,305,306]. In addition, information was shared on purging of stagnant gas in S/C[307], and consideration was given to the cause of high radiation doses observed immediately after the accident[308,309] as an issue that applies to Unit 1 as well. The investigation results on the Unit 1/2 SGTS piping[310,311,312]

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[294] Material 2-1: “Analysis results of pyrolysis product gases of organic materials in BWR Containment Vessel [JAEA]”, The 37th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, April 24, 2023

[295] Material 2-2: “Progress of evaluation of the amount of flammable gas generated from cables, etc. and combustible organic gas combustion test [TEPCO]”, The 37th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, April 24, 2023

[296] Material 3: “Examination of the effect of flammable organic gas in hydrogen explosion at the Fukushima Daiichi nuclear accident [Nagaoka University of Technology]”, The 37th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station”, April 24, 2023

[297] Material 5-1: “CFD analysis of hydrogen localization by condensation in CIGMA system [JAEA]”, The 37th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, April 24, 2023

[298] Material 2-1: “Fiscal 2023 Expenses for Commission of disaster prevention measures, etc. for nuclear facilities, Project of (Examination of the effect of flammable organic gas in hydrogen explosion at the Fukushima Daiichi nuclear accident [Nagaoka University of Technology]”, The 38th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station [Nagaoka University of Technology, June 22, 2023”

[299] Material 2-2: “Supplementary material on "Estimation of leakage routes and explosion mechanisms that contributed to the hydrogen explosion at Unit 3 of Fukushima Daiichi NPS" [TEPCO]”, The 37th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, June 22, 2023

[300] Material 2-3: “Findings and future developments concerning hydrogen behavior in buildings obtained from analysis by TEPCO Systems Corporation [NRA]," The 38th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, June 22, 2023

[301] Material 4-4: “Experimental program for hydrogen accumulation by condensation in CIGMA system [JAEA],", The 37th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, September 12, 2023

[302] Material1-1: “Examination of the hydrogen explosion at Unit 3 (overall summary) [NRA], The 43rd Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, March 12, 2024

[303] Material1-2: “Experiments on hydrogen localization by condensation in CIGMA system [JAEA], The 43rd Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, March 12, 2024

[304] Material1-3: “Fiscal 2023 Expenses for Commission of disaster prevention measures, etc. for nuclear facilities, (Investigation of the effects of Flammable organic gases on hydrogen explosions at the TEPCO's Fukushima Daiichi nuclear accident) [Nagaoka University of Technology], The 43rd Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, March 12, 2024

[305] Material1-4: “Summary of damages to the reactor building caused by the Unit 3 hydrogen explosion [NRA], The 43rd Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, March 12, 2024

[306] Material1-5: “Materials that may have supplied flammable organic material at the Unit 3 hydrogen explosion [NRA], The 43rd Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, March 12, 2024

[307] Material 5-2: “Purging operations of the stagnant gas in the S/C of Unit 3 [TEPCO]”, The 41st Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, December 25, 2023

[308] Material 3: “Toward the cause estimation of the high dose rate in the early phase of the accident at Units 1 and 3 of the Fukushima Daiichi NPS (Raising of issues) [NRA],", The 39th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, September 12, 2023

[309] Material 1-4: “Additional information on ‘Toward the cause estimation of the high dose rate in the early phase of the accident at Units 1 and 3 of Fukushima Daiichi NPS (Raising of issues) [NRA],", The 40th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, October 30, 2023

[310] Material 2-6: “Measurement of SGTS piping at Units 1 and 2 [TEPCO]”, The 40th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, October 30, 2023

[311] Material 4-1: “Results of smear filter paper analysis of Standby Gas Treatment System (SGTS) piping at Fukushima Daiichi Nuclear Power Station Units 1 and 2 [TEPCO]”, The 41st Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, December 25, 2023

[312] Material 4-2: “Measurement for SGTS piping at Unit 1 [NRA]”, The 41st Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, December 25, 2023

and on the exhaust stacks and SGTS piping toward dismantling of Unit 3/4 exhaust stacks[313,314,] were also shared. Studies on the utilization of monitoring post data were continued[315,316,317,318,319,320,321,322].

In FY 2024, NRA Secretariat's recommendation on the 2024 version interim report on the investigation and analysis of the accident at TEPCO's Fukushima Daiichi Nuclear Power Station[323,324] was presented. Opinions are being actively exchanged on modifications suggested by TEPCO, Hitachi-GE Nuclear Energy, Ltd., and other parties and on public comments[325,326,327,328]. In addition, matters to be investigated in FY 2024[329] were announced, and opinions are being exchanged on the state of operation of the Unit 1 isolation condenser (IC) at

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313 Material 4-2: "Status of Site Investigation for Dismantling of Units 3/4 exhaust stacks [TEPCO]", The 39th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, September 2, 2023

314 Material 2-4: "Status of Site Investigation for Dismantling of Units 3/4 exhaust stacks [TEPCO]", The 40th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, October 30, 2023

315 Material 2: "Examination of the use of monitoring post data [NRA]", The 39th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, September 12, 2023

316 Material 1-1: "Estimation of accident progression at Unit 1 based on air dose rate monitoring data [TEPCO]", The 40th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, October 30, 2023

317 Material 1-2: "Examination of the dose to the surrounding area from radioisotopes filled on the Unit 1 operating floor [NRA]", The 40th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, October 30, 2023

318 Material 1-3: "Examination of ambient dose rates near the main gate and MP-8 on March 12, 2011 [NRA]", The 40th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, October 30, 2023

319 Material 2: "Dose rates at monitoring posts, etc. due to plume [NRA]", The 41st Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, December 25, 2023

320 Material 1-1: "Relationship between dose rates at monitoring posts, etc. and events at the reactor [NRA]", The 42nd Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, February 16, 2024

321 Material 1-2: "Major issues of Relationship between dose rates at monitoring posts, etc. and events at the reactor (March 12, 2011) [NRA]", The 42nd Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, February 16, 2024

322 Material 2-1: "Organize the status of the study based on monitoring post data [NRA]", The 43rd Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, March 12, 2024

323 Material 1-1: "Interim report on Investigation and analysis of the accident at TEPCO's Fukushima Daiichi NPS (Draft Version 2024) (Main body) [NRA]", The 45th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, April 19, 2024

324 Material 1-2: "Interim report on Investigation and analysis of the accident at TEPCO's Fukushima Daiichi NPS (Draft Version 2024) (Reference and Attachment) [NRA]", The 45th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, April 19, 2024

325 Material 1-1: "Our approach to the comments on the (Draft) Interim report on Investigation and analysis of the accident at TEPCO's Fukushima Daiichi NPS (Version 2024) (Draft) [NRA]", The 45th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, June 11, 2024

326 Material 1-2: "Proposed amendments to the draft of Interim Report (2024 version) [Tokyo Electric Power Company Holdings, Inc./Hitachi GE Nuclear Energy, Inc.]", The 46th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, June 11, 2024

327 Material 1-3: "Proposed Amendments to the draft of Interim Report (2024 version) based on the results of the Call for comments [NRA]", The 46th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, June 11, 2024

328 Material 1-4: "Interim Report on Investigation and analysis of the accident at TEPCO's Fukushima Daiichi Nuclear Power Station (2024 version) (draft) [NRA]", The 46th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, June 11, 2024

329 Material 1: "Investigation Items for FY2024 [NRA]", The 47th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, July 22, 2024

the time of the accident[330,331] and on the cause of the deformation of the Unit 1 shield plug[332]. TEPCO reported the results of Unit 3 reactor building internal investigation[333] and the schedule of analysis and evaluation of samples related to the Primary Containment Vessel internal investigation[334].

The Atomic Energy Society of Japan (AESJ) established the “Investigation Committee on the Nuclear Accident at the Fukushima Daiichi Nuclear Power Station” (AESJ Investigation Committee) to investigate the accident for clarifying the underlying and fundamental causes, and to make recommendations across various fields. The results of the investigation were summarized in the Final Report released in March 2014. AESJ also inaugurated the “AESJ Review Committee on Decommissioning of the Fukushima Daiichi NPS” and continues activities concerning the decommissioning utilizing its special knowledge and expertise in the field, including identification of issues and consideration to countermeasures[335]. In FY 2023, AESJ hosted the 7th symposium on the decommissioning of the TEPCO’s Fukushima Daiichi NPS under the theme “handling of radioactive waste generated through decommissioning of Fukushima Daiichi NPS.” AESJ organized featured sessions on the technical development of robots that contribute to the decommissioning of the Fukushima Daiichi NPS in the 2023 Fall Meeting and on addressing risks in view of the completion of the decommissioning in the 2023 Spring Meeting (Annual Meeting).

With regard to accident analysis activities, some areas including the inside of the reactor buildings have become more accessible now more than 10 years after the accident through the improvement in the on-site environment and advancement in the decommissioning techniques and it has become possible to collect samples necessary for accident analysis and checking the state of facilities, although many areas such as inside the Primary Containment Vessel still remain unsuited for humans to approach due to high radiation doses or other reasons. As the decommissioning project progresses, more field findings and information are published by TEPCO. Meanwhile, for sections that still show the traces of the accident, it is becoming more important to conduct investigation before the information on the accident is lost and contemplate the need for detailed investigation in the future.

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330 Material 2-1: “Study on Isolation condenser (IC) (1st) [NRA]”, The 47th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, July 22, 2024

331 Material 2-2: “Questions about Unit 1 IC [TEPCO]”, The 47th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, July 22, 2024

332 Material 1: “Examination of the cause of the deformation of the shield plug at Unit 1, etc. [NRA]”, The 47th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, July 22, 2024

333 Material 4-1: “Results of the Unit 3 reactor building internal investigation [TEPCO]”, The 47th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, July 22, 2024

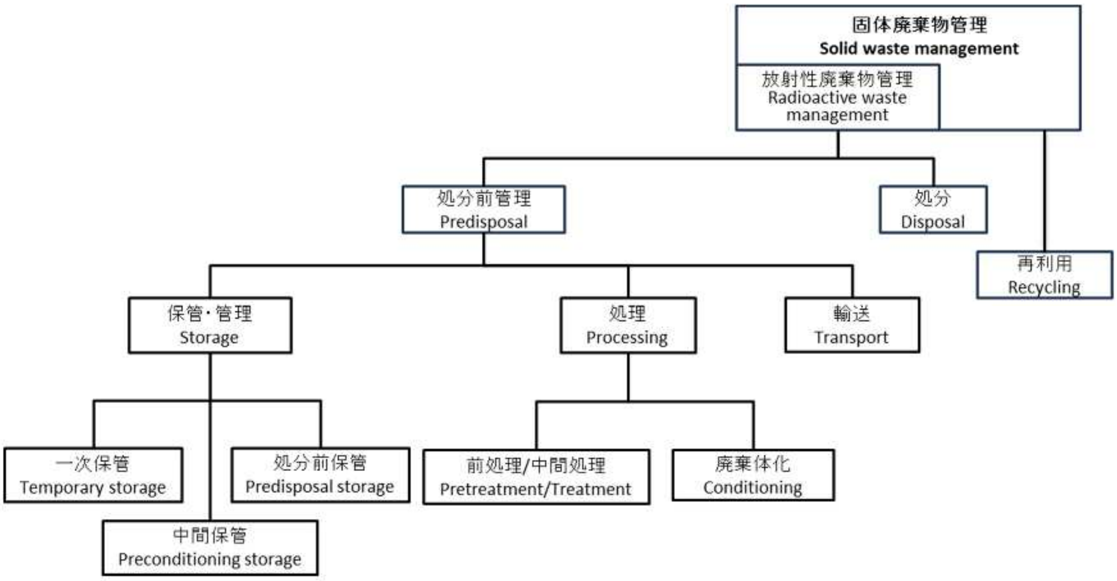
334 Material 4-2: “Schedule for analysis and evaluation of samples related to the investigation inside the PCV at Fukushima Daiichi Nuclear Power Station [TEPCO]”, The 47th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, July 22, 2024

335 AESJ, https://www.aesj.net/aesj_fukushima/fukushima-decommissioning

Attachment 11 Terms related to solid waste management

IAEA Safety Requirements GSR-Part 5[336] explains that predisposal of radioactive waste encompass all stages of radioactive waste management from generation to disposal, including storage/management, processing, and transportation. Terms related to the management of solid waste, developed based on the IAEA's glossary of terms for radioactive waste management[337], is shown in Fig. A 11-1. Within the predisposal 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., and it is thought to be necessary that the form is suitable for storage/management and transportation.

As for recycling, those that have not come into contact with radioactive materials and those that were managed as radioactive waste first and then satisfied the criteria for clearance and regulatory exclusion from regulatory control for radiation protection purposes were both made subject to solid waste management.



- **Storage:** General term for the following processes to maintain and manage solid wastes in a safe and stable condition
  - **Temporary storage**: Immediate storage of solid waste after generated until Pretreatment/Treatment is performed
  - **Treatment**: Storage of solid wastes after Pretreatment/Treatment until Conditioning is performed
  - **Predisposal Storage**: Storage of solid wastes after Conditioning in a safe and stable condition until placed in a disposal site

- **Processing**: General term for treatment processes performed on solid waste.
  - **Pretreatment/Treatment**: After solid waste is generated, operations such as collection, sorting, chemical control, and decontamination are called Pretreatment. The treatment processes that follow, as necessary, considering the safety of storage/management and the rationality of entire processing/disposal, are called Treatment.
  - **Conditioning**: Processes to produce waste packages suitable for handling, transportation, storage/management and/or disposal
- **Disposal**: Final placement of radioactive waste in a disposal site

Fig. A 11-1 Terms related to solid waste management

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

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

Attachment 12 Disposal of radioactive waste[338,339,340]

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)[341] 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”[342] 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. A 12-1. Each classification is also shown in Table A12-1.

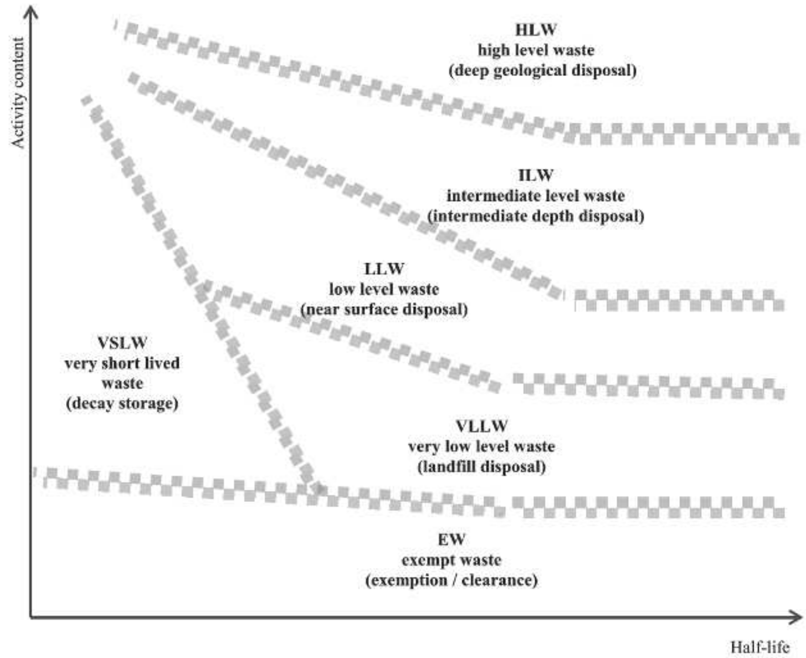


Fig. A 12-1 Conceptual diagram of waste classification

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

Table A 12-1 Classification of radioactive waste in GSG-1

Classification	Description of Classification
Exempted waste (EW)	Waste satisfying the criteria for clearance, 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 a 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 A12-2.

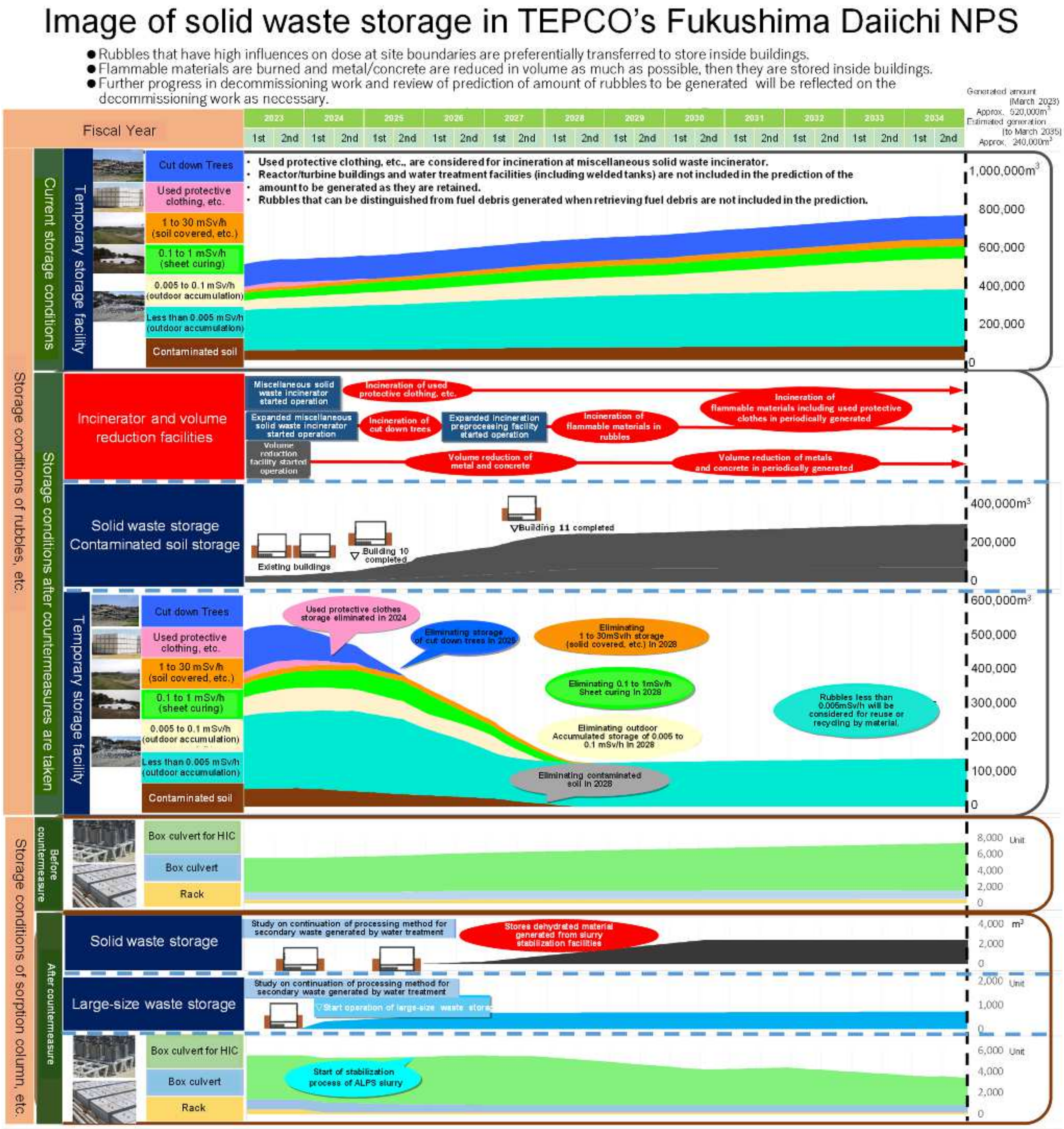
Of these, only waste with relatively low-level radioactivity generated through the operation of nuclear power plants has been subject to disposal in pits since 1992 at the Rokkasho Low-level Radioactive Waste Disposal Center of Japan Nuclear Fuel Limited in Rokkasho Village, Aomori Prefecture. Including 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 A 12-2 Types of Radioactive Waste Generated by the Operation of Nuclear Power Plants

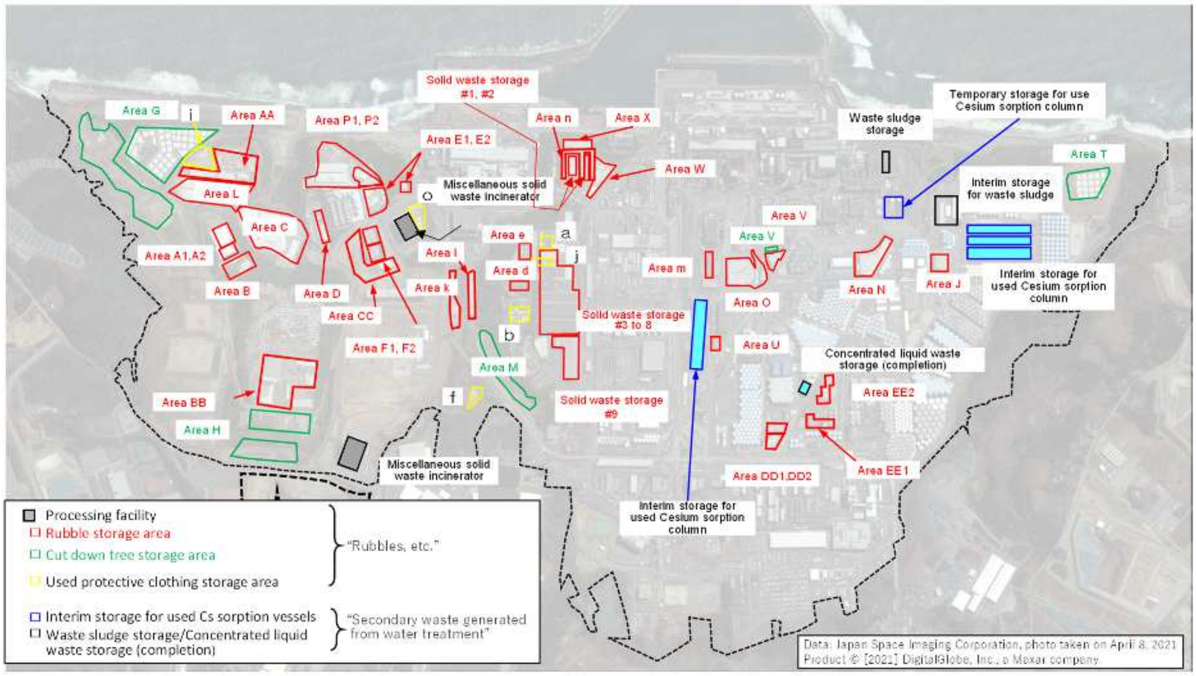
<table>
<tr><th colspan="3">Types of Radioactive Waste</th><th>Examples of Waste</th><th>Site generated</th><th>Disposal Method (example)</th></tr>
<tr><td rowspan="5">Low-level Radioactive Waste</td><td rowspan="3">Waste from Nuclear Power Plants</td><td>Waste with extremely low radiation level</td><td>Concrete, metal, etc.</td><td rowspan="3">Nuclear Power Plant</td><td>Trench disposal (Near surface disposal (L3))</td></tr>
<tr><td>Waste with relatively low radiation level</td><td>Effluent, filter, waste equipment, solidification of consumables</td><td>Pit disposal (Near surface disposal (L2))</td></tr>
<tr><td>Waste with relatively high radiation level</td><td>Control rod, structures inside reactor</td><td>Intermediate depth disposal (L1)</td></tr>
<tr><td colspan="2">Uranium Waste</td><td>Consumables, sludge, waste equipment</td><td>Uranium enrichment and fuel processing facility</td><td>Intermediate depth disposal, Pit disposal or Trench disposal, geological disposal in some cases</td></tr>
<tr><td colspan="2">Radioactive Waste includes Transuranic Nuclide (TRU Waste)</td><td>Parts of control rod, effluent, filter</td><td>Spent fuel reprocessing facility, MOX fuel fabrication facility</td><td>Geological disposal, Intermediate depth disposal or Pit disposal</td></tr>
<tr><td colspan="3">High-level Radioactive Waste</td><td>Vitrified waste</td><td>Spent fuel reprocessing facility</td><td>Geological disposal</td></tr>
<tr><td colspan="3">Waste below the clearance level</td><td>Most of demolition waste of nuclear power plants</td><td>All the above sites</td><td>Reuse / Disposal as general goods</td></tr>
</table>

Fig. A 12-2 Japan Nuclear Fuel Ltd. Low-level Radioactive Waste Disposal Center

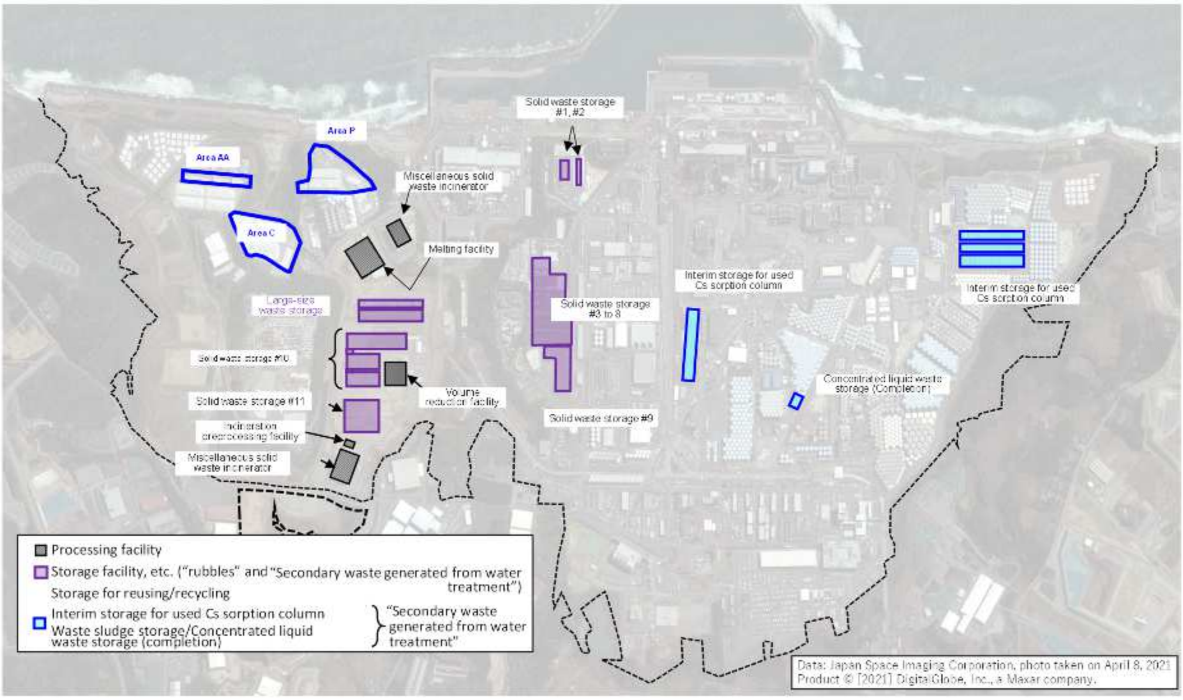
Attachment 13 Overall image of storage management plan for the Fukushima Daiichi NPS [343]



[343] TEPCO, Solid Waste Storage Management Plan for Fukushima Daichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc., February 2023 edition (issued on February 20, 2023)



(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 treatment"

Fig. A 13-1 Present and future storage conditions of "rubble, etc." and "secondary waste generated by water treatment" on site of the Fukushima Daiichi NPS

Attachment 14 Status of development and examination of technologies in various fields for each solid waste

The key to examining individual waste streams lies in summarizing the status of previous R&D outcomes and examinations in each field, ranging from characterization to disposal. Initiatives were thus undertaken to summarize, as Table A 14-1 shows, the status of technology development and examination in each solid waste field. Table A 14-1 will be reviewed every fiscal year, based on the progress made in the status of technology development and examinations.

Table A 14-1 List of the status of development and examination of technologies in various fields for each solid waste

Solid waste (Individual waste stream)	Stream number	Solid waste management							
		Radioactive waste management							
		Characterization	Temporary storage	Pretreatment /Treatment	Preconditioning storage	Conditioning	Predisposal storage	Disposal	Recycling
Waste from demolition									
Reactor pressure vessel	S1	Yellow	Grey	Grey	Grey	Blue	Grey	Yellow	Grey
Primary containment vessel metal	S2	Yellow	Grey	Grey	Grey	Blue	Grey	Yellow	Grey
Primary containment vessel concrete	S3	Yellow	Grey	Grey	Grey	Blue	Grey	Red	Grey
In-building metal	S4	Yellow	Blue	Grey	Blue	Blue	Blue	Yellow	Grey
In-building concrete	S5	Yellow	Blue	Grey	Blue	Blue	Blue	Yellow	Grey
Rubbles, etc.									
Rubble metal	S6	Yellow	Green	Green	Green	Yellow	Blue	Yellow	Red
Rubble concrete	S7	Yellow	Green	Green	Green	Yellow	Blue	Yellow	Green
Miscellaneous flammable solid waste, fallen trees									
Flammable materials (e.g., fallen trees, protective clothing)	S8	Yellow	Green	Green	Green	Blue	Blue	Red	Grey
Secondary waste generated by water treatment									
Sorption vessel (1) (KURION, SARRY)	S9	Yellow	Green	Grey	Grey	Yellow	Blue	Yellow	Grey
Sorption vessel (2) (mobile purifier)		Grey	Green	Grey	Grey	Yellow	Blue	Grey	Grey
Multi-nuclide removal equipment (1) (Slurry)	S10	Yellow	Green	Green	Green	Yellow	Blue	Yellow	Grey
Multi-nuclide removal equipment (2) (Sorption)		Yellow	Green	Grey	Grey	Yellow	Blue	Red	Grey
Multi-nuclide removal equipment (3) (Used column)		Yellow	Green	Yellow	Green	Grey	Grey	Grey	Grey
Waste sludge	S11	Yellow	Green	Green	Green	Yellow	Blue	Yellow	Grey
Filter	S12	Grey	Green	Yellow	Yellow	Blue	Blue	Grey	Grey
Concentrated liquid waste	S13	Yellow	Green	Yellow	Green	Grey	Blue	Grey	Grey
Waste generated from debris retrieval									
Waste generated from fuel debris retrieval	S14	Grey	Grey	Grey	Grey	Grey	Grey	Grey	Grey
Contaminated soil, etc.									
Contaminated soil	S15	Yellow	Green	Green	Green	Yellow	Blue	Yellow	Blue

- (Green) Phase in which the feasibility as a practical technology has been confirmed, and engineering-related examinations can be made to comply with preceding/succeeding fields.
- (Yellow) Phase in which the feasibility as an element technology has been confirmed, and the compatibility with preceding/succeeding fields can be examined.
- (Red) Phase in which the feasibility as element technology is being confirmed.
- (Blue) Phase in which technological examinations in each field have not started, but the technological difficulty is low and individual waste stream examinations can start.
- (Grey) Phase in which technological examinations in each field have not started or the conditions for starting them have not been met.

The policy on determining when to start examinations for individual waste streams was summarized below, based on the status of development and examination of technology in each individual solid waste field.

■ Concept of determining the start of individual waste stream examinations (Table A 14-2)
  - ✓ Each field ranging from characterization to disposal has not been evaluated in terms of the “phase in which technological examinations in each field have not started or the

conditions for starting them have not been met" or the "phase in which the feasibility as element technology is being confirmed." Evaluations and examinations by field are possible, and evaluations on upstream and downstream impact are possible as well.

Table A 14-2 Examples of solid waste which examination of individual waste stream may be initiated

Solid waste (Individual waste stream)	Stream number	Solid waste management							
		Radioactive waste management							Recycling
		Characterization	Temporary storage	Pretreatment /Treatment	Preconditioning storage	Conditioning	Predisposal storage	Disposal	
Rubbles, etc.									
Rubble metal	S6								
Rubble concrete	S7								
Secondary waste generated by water treatment									
Multi-nuclide removal equipment (1) (Slurry)	S10								

Solid waste for which consideration of individual waste streams may be initiated.

Attachment 15 Previous initiatives for the discharge of ALPS-treated water into the sea

(1) The course of events behind the discharge of ALPS-treated water into the sea

With regard to the disposal method of ALPS-treated water, a report published in February 2020 after more than six years of comprehensive discussions at expert meetings[344,345] concluded that "discharge into the sea is more realistic." In response, the IAEA also assessed that it "has a scientific basis". After that, based on hundreds of exchanges of opinions with local governments, agricultural, forestry, and fishery companies, listening to opinions by deputy ministers of each ministry, and requests for written public opinions (more than 4,000 comments), the government finalized the basic policy[346] at the Inter-Ministerial Council for Contaminated Water, Treated Water and Decommissioning Issues in April 2021. In the basic policy, the basic concept for "coexistence of reconstruction and decommissioning," specific methods for discharging ALPS-treated water into the sea, and responses to the influence of reputational damage were summarized. The government also established the "Inter-Ministerial Council concerning the Continuous Implementation of the Basic Policy on Handling of ALPS Treated Water" to follow up on the implementation status of matters specified in the basic policy and implement additional measures flexibly.

Table A15-1 shows major initiatives toward the discharge of ALPS-treated water into the sea after the basic policy was announced. To date, the government has held six meetings with the Inter-Ministerial Council to compile immediate measures and a specific action plan and manage the progress. Since 2021, meetings of the task force on monitoring and measuring the marine environment and the Expert Meeting for Marine Monitoring have been held continuously to enhance marine monitoring. In October 2022, the ALPS-Treated Water Monitoring Symposium was launched for fishery product distributors and retailers to provide detailed explanations and dialogue on monitoring and other initiatives to protect food safety and security.

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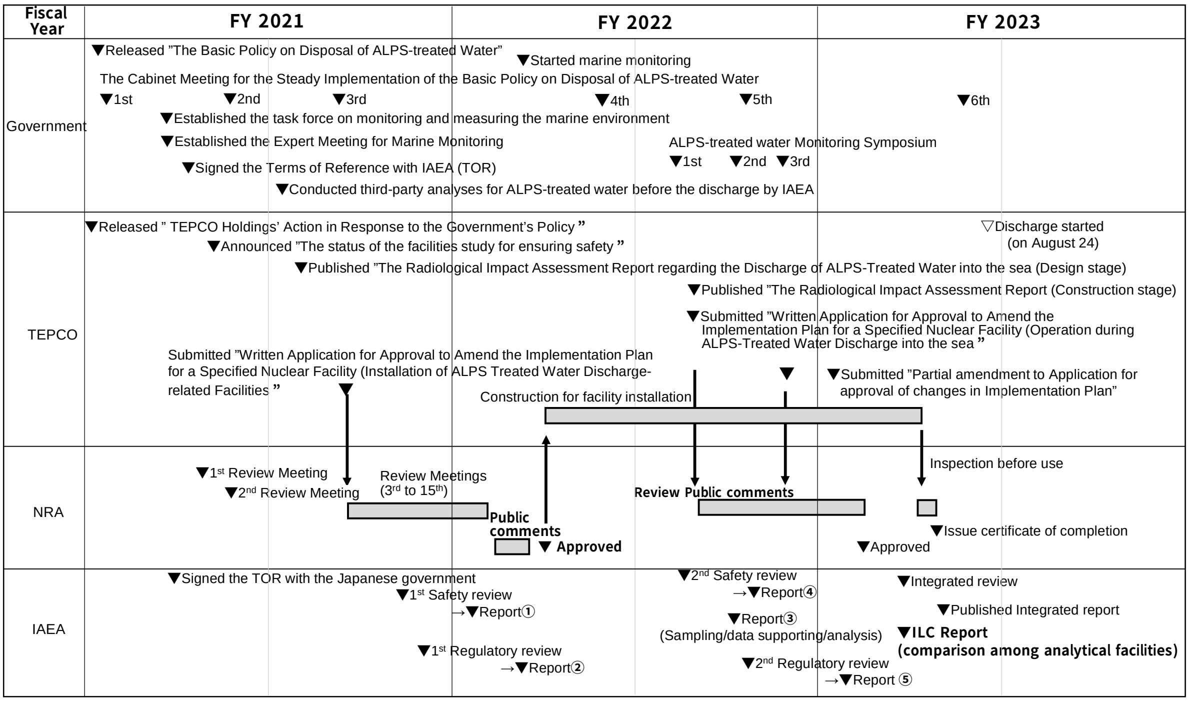
[344]Tritiated Water Taskforce Report, June 3, 2016

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

[346]Material 1: "Basic policy for disposing of treated water by multi-nuclide removal equipment at the TEPCO Fukushima Daiichi Nuclear Power Station (draft)," Inter-Ministerial Council for Contaminated Water, Treated Water and Decommissioning Issues (fifth meeting), April 13, 2021

Table A 15-1 Major initiatives for the discharge of ALPS-treated water into the sea



In light of the government's basic policy, TEPCO proceeded with detailed studies on the design and operation of ALPS-treated water dilution/discharge facilities and related facilities and submitted Application Documents for Approval to Amend the Implementation Plan for Fukushima Daiichi Nuclear Power Station Specified Nuclear Facility (installation of facilities related to the discharge of ALPS-treated water into the sea) to the Nuclear Regulation Authority (NRA) in December 2021 and obtained approval in July 2022.

Subsequently, TEPCO specified the organizational structure for the operation, maintenance, management of ALPS-treated water dilution/discharge facilities, and selected nuclides to be measured and assessed to verify whether the discharge standards are satisfied pre-discharge. It also revised the radiological impact assessment on humans and the environment based on the selected nuclides to be measured and assessed. Then, TEPCO submitted the Application Documents for Approval to Amend the Implementation Plan for Fukushima Daiichi Nuclear Power Station Specified Nuclear Facility (operation at the time of the discharge of ALPS-treated water into the sea) in November 2022. Reflecting the discussions at the Technical Meeting on the Examination of the Implementation Plan of the Measures for the Specified Reactor Facilities held subsequently by the NRA, the Application Documents for Approval to Amend the Implementation Plan were partially revised from February to April 2023 and approved in May of the same year.

With regard to ALPS-treated water dilution/discharge facilities, full-scale construction, including an undersea tunnel, began in August 2022 and was completed in June 2023. The facilities subsequently received a pre-service inspection by the NRA and a certification of completion in July.

Based on the Terms of Reference with the government, the IAEA has conducted reviews on safety, regulations, sampling, and analyses associated with handling ALPS-treated water and published the reports for each review, and the comprehensive report that summarizes those reviews in July 2023. The IAEA concluded that:

- the approach to the discharge of ALPS-treated water into the sea, and the related activities by TEPCO, the NRA, and the Japanese government are consistent with the relevant international safety standards, and
- the discharge of ALPS-treated water into the sea that TEPCO is currently planning would have a negligible radiological impact on humans and the environment.

At the meeting of the “Inter-Ministerial Council for Contaminated Water, Treated Water and Decommissioning Issues (sixth meeting)” and the sixth “Inter-Ministerial Council concerning the Continuous Implementation of the Basic Policy on Handling of ALPS Treated Water” held in August 2023, the entire government confirmed the status of initiatives to date on safety assurance and reputational damage countermeasures related to the disposal of ALPS-treated water, and the ALPS-treated water was discharged into the sea on August 24, based on the proposed exact timing of the discharge of ALPS-treated water into the sea.

(2) Overview of the facilities for the discharge of ALPS-treated water into the sea

Fig. A15-1 shows a conceptual diagram of facilities for discharge into the sea, published by TEPCO[347]. These facilities consist of processes from Purification, Analysis/Confirmation, and Dilution to Discharge. The key facilities and procedures are shown below.

① Measurement/confirmation facility

After homogenizing by circulating and agitating the ALPS-treated water in the measurement/confirmation facility, the water is sampled and analyzed to confirm that (1) the concentrations of radionuclides other than tritium are purified to ensure that they are reliably below the regulatory limits for discharge (the sum of the ratios to regulatory concentrations limits of radionuclides other than tritium must be less than 1), that (2) the tritium concentration is below 1 million Bq/L, that (3) the nuclides to be removed[348] are not significantly present, and that (4) there are no water quality problems.

② Diluting facility

[347]98th meeting of the Committee on Oversight and Evaluation of Specified Nuclear Facilities, Material 2-2: “Installation of New ALPS Treated Water Dilution/Discharge Facilities and the Related Facility,” March 14, 2022

[348]This is 1/40 of the regulatory concentrations limit (60,000 Bq/L) and approximately 1/7 of the World Health Organization's (WHO) Guidelines for drinking-water quality (10,000 Bq/L).

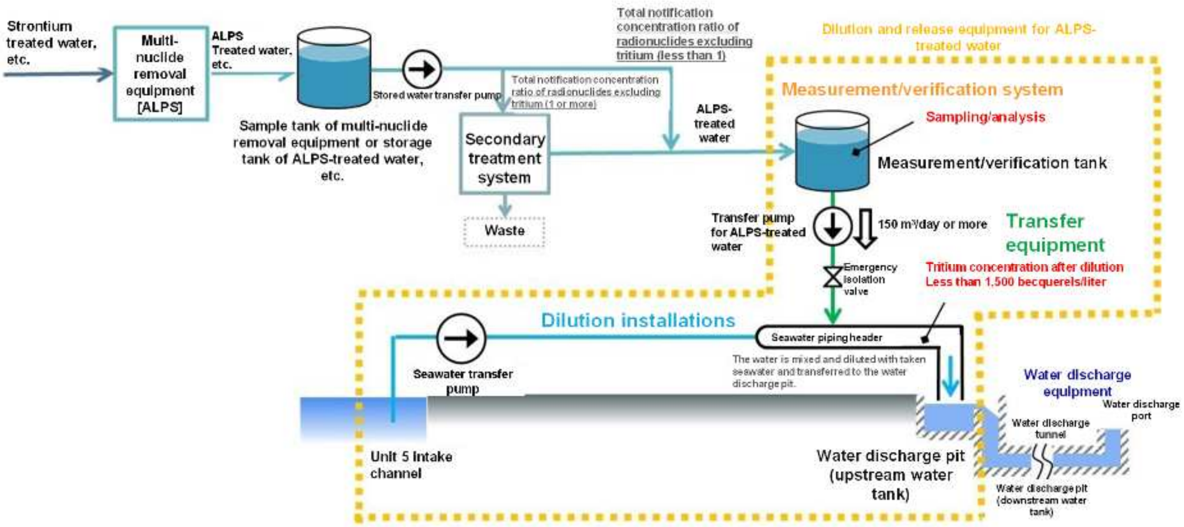
ALPS-treated water confirmed to meet regulatory standards is mixed and diluted using seawater so that the tritium concentration is less than 1,500 Bq/L[349]. The tritium concentration after dilution by seawater will be monitored in real time by the flow rate of the ALPS-treated water and the seawater to dilute and confirmed in both rates.

③ Intake/discharge facility

In order to avoid the impact of radioactive material in the harbor, for the water intake facility, the seawall was constructed at the intake channel open ditch of Units 5 and 6, as well as a part of the permeation prevention works of the North Breakwater was removed in order to take water for dilution from outside the port. The discharge facility discharges ALPS-treated water via the undersea tunnel (approx. 1 km) to prevent discharged water from recirculating into the seawater that is taken in.

④ Measures in the event of abnormality

If the seawater pump to dilute the water to be discharged shuts down, the emergency isolation valves shall be closed promptly to stop the discharge. The discharge shall also be stopped for surveillance of the situation if the values that exceed the criterion level to suspend discharge are confirmed in the marine monitoring.



(Source: TEPCO)

Fig. A 15-1 Conceptual drawing of discharge facilities

[349]This is 1/40 of the regulatory concentrations limit (60,000 Bq/L) and approximately 1/7 of the World Health Organization's (WHO) Guidelines for drinking-water quality (10,000 Bq/L).

(3) ALPS-treated water analysis and evaluation structure, and selection of target nuclides

Fig. 29 of the main part shows the structure for ALPS-treated water analysis and evaluation. In addition to its own analysis (outsourced to Tokyo Power Technology Ltd.) before the discharge into the sea, TEPCO performs analyses by outsourcing them to an ISO/IEC 17025-certified[350] independent external organization (KAKEN) to determine whether to discharge, according to regulatory standards. The JAEA Okuma Analysis and Research Center (Radioactive Material Analysis and Research Facility Laboratory-1) also conducts analysis every time before the discharge, in accordance with the government's basic policy.

The NRA conducts safety inspections to verify whether TEPCO is developing structures for analyzing nuclides to be measured and assessed in accordance with the Implementation Plan and is properly implementing quality assurance activities related to analysis. In addition, the NRA has commissioned the JAEA's Nuclear Safety Research Center to analyze ALPS-treated water and independently verify the analytical quality provided by TEPCO.

Led by the IAEA, the IAEA and other analytical institutions in third countries are also continuously engaged in inter-laboratory comparison (ILC), thereby supporting ALPS-treated water analysis data submitted by TEPCO and verifying analysis quality.

The target nuclides to be measured and evaluated before the discharge of the ALPS-treated water into the sea were selected after re-examining the nuclides that could be contained in the contaminated water before being treated by cesium sorption apparatus, ALPS and other systems in significant amounts, based on knowledge of decommissioning and buried facilities at nuclear power plants in Japan. A flow for selecting target nuclides, as Fig. A15-2 shows, was established. This was achieved based on experts' opinions, by combining inventory evaluation, measured data of nuclide concentrations in the stagnant water in buildings, and study of the physical and chemical properties of nuclides. Consequently, based on this procedure, 29 nuclides (excluding tritium) shown in Table A15-2 were selected as nuclides to be measured and evaluated[351]. When discharging ALPS-treated water into the sea, it is necessary to confirm that the sum of the ratios to the regulatory concentration limits of the selected nuclides to be measured and evaluated is less than 1. Of the 62 nuclides to be removed by ALPS, 39[352] excluded from the measurement and evaluation are independently measured and evaluated before the release to prevent any reputational damage, thereby confirming that they are not contained in significant amounts. The number of nuclides to be measured and evaluated was 29 until the 3rd discharge in FY 2024 as shown in Table A15-2, but it was increased to 30 from the 4th discharge in FY 2024 due to addition

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

[351] Partial Revision of the "Application Documents for Approval to Amend the Implementation Plan for Fukushima Daiichi Nuclear Power Station Specified Nuclear Facility," February 20, 2023

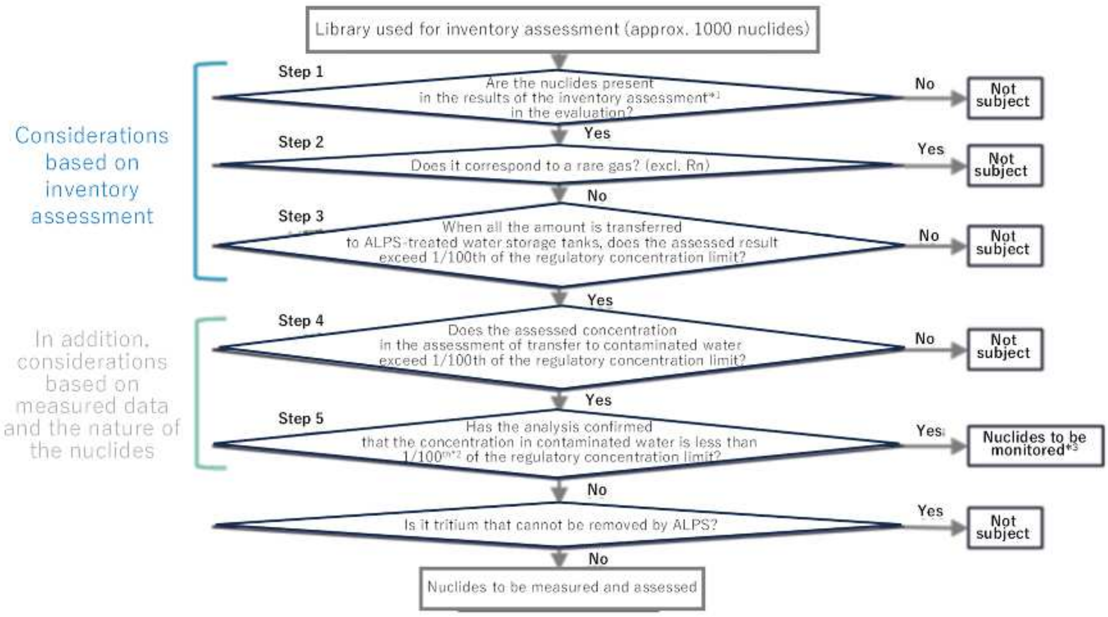
[352] The 29 nuclides selected include six nuclides (C-14, Fe-55, Se-79, U-234, U-238, and Np-237) that are not included in the 62 nuclides to be removed by ALPS. Therefore, out of 62, the nuclides excluded from measurement are 62 − (29 − 6) = 39.

of cadmium-113m among the six nuclides to be monitored[353]. This decision was made based on the selection flow shown in Fig. A15-2 after cadmium-113m was detected at concentration greater than 1/100 of the regulatory concentration limit during the analysis of contaminated water prior to ALPS treatment conducted in February 2024. Accordingly, the number of nuclides TEPCO voluntarily measures and evaluates prior to discharge into the sea to confirm no presence in significant amounts has become 38 by excluding cadmium-113m. The water in which cadmium-113m was detected was contaminated water prior to ALPS treatment, and TEPCO has been voluntarily assaying 39 nuclides including cadmium-113m in treated water prior to discharge into the sea, confirming that the concentration of cadmium-113m is less than 1/500 of the regulatory concentration limit every time, and there is no problem in the safety of the ALPS-treated water that was discharged

Some selected nuclides to be measured and evaluated may be removed from measurement/evaluation targets in the future, as a result of decay of the radioactive materials. Evaluations made by calculating this decay indicate that 5 nuclides will be excluded from the target in the next decade. Some nuclides to be measured and evaluated were also evaluated using core inventory evaluation results. There thus is a need to periodically reevaluate the inventory, and, based on the results, review the nuclides to be measured and evaluated as per the steps for their selection.

Similarly, 18 of the 39 nuclides, which TEPCO voluntarily confirmed are not contained in significant amounts, were determined to be excluded from the step 1 inventory evaluation when selecting nuclides to be measured and evaluated, and no significant amount has ever been confirmed in the previous six releases. The necessity of measuring and evaluating the nuclides thus needs to be examined.

[353] The six nuclides (chlorine-36, niobium-93m, niobium-94. molybdenum-93, cadmium-113m, and barium-133) that have been confirmed not to be present in contaminated water at significant concentrations in past analyses but may be present in contaminated water theoretically



*1: The decay period in the inventory assessment is appropriately set according to when the selected results are to be used (initially set to 2023 (12 years after the accident)).
*2: Nuclides that have been detected in the past are checked using the maximum detection value, and nuclides that have never been detected are checked using the minimum detection limit.
*3: Nuclides to be continuously checked for significant presence in contaminated water

(Source: TEPCO)

Fig. A 15-2 Flow to select nuclides to be measured and evaluated

Table A 15-2 Nuclides to be measured and evaluated and their quantification methods

No.	Nuclides	Quantification method	Detection limit*1 (Bq/L)	*No.*	Nuclides	Quantification method	Detection limit*1 (Bq/L)
1	C-14	Beta-ray measurement after chemical separation	1.50E+00	16	Ce-144	Gamma-ray nuclide analysis	3.80E-01
2	Mn-54	Gamma-ray nuclide analysis	2.60E-02	17	Pm-147	Evaluated from the radioactivity concentration of representative nuclides (Eu-154)	3.30E-01
3	Fe-55	Beta-ray measurement after chemical separation	1.90E+01	18	Sm-151		1.30E-02
4	Co-60	Gamma-ray nuclide analysis	2.30E-02	19	Eu-154	Gamma-ray nuclide analysis	7.40E-02
5	Ni-63	Beta-ray measurement after chemical separation	9.10E+00	20	Eu-155	Gamma-ray nuclide analysis	2.60E-01
6	Se-79	Beta-ray measurement after chemical separation	8.80E-01	21	U-234	Evaluated as included in total alpha radioactivity	2.80E-02
7	Sr-90	Beta-ray measurement after chemical separation	3.90E-02	22	U-238		
8	Y-90	Radiative equilibrium with Sr-90	3.90E-02	23	Np-237		
9	Tc-99	ICP-MS measurements	2.10E-01	24	Pu-238		
10	Ru-106	Gamma-ray nuclide analysis	2.50E-01	25	Pu-239		
11	Sb-125	Gamma-ray nuclide analysis	9.60E-02	26	Pu-240		
12	Te-125m	Radiative equilibrium with Sb-125	3.60E-02	27	Pu-241	Evaluated from the radioactivity concentration of representative nuclides (Pu-238)	7.80E-01
13	I-129	ICP-MS measurements	1.00E-02				
14	Cs-134	Gamma-ray nuclide analysis	3.30E-02	28	Am-241	Evaluated as included in total alpha radioactivity	2.80E-02
15	Cs-137	Gamma-ray nuclide analysis	3.40E-02	29	Cm-244		

*1: Example of the values measured by TEPCO in tank water analysis for measurement and confirmation prior to the 7th discharge (reported on June 26, 2024)

(4) Strengthening and enhancing marine monitoring

In order to ensure and systematically conduct detailed radiation monitoring related to the accident at the Fukushima Daiichi NPS, the government established the Monitoring Coordination Council under the Nuclear Emergency Response Headquarters, chaired by the Minister of the

Environment, and formulated a comprehensive monitoring plan.[354] Based on this plan, relevant ministries, municipalities, and business operators will cooperate to conduct monitoring.

Given the "Basic Policy on the Disposal of ALPS-treated water," which was decided by the government in April 2021, incorporated the strengthening and expansion of marine monitoring, "the Monitoring and Measurement Task Force on Marine Environment" led by the Ministry of the Environment and the "Marine Monitoring Expert Meeting on ALPS-treated water" were established under the Monitoring and Coordination Council in the same year, and initiatives have been undertaken to strengthen marine monitoring (Fig. A15-3). In March 2022, the comprehensive monitoring plan was revised based on expert advice, and in April, marine monitoring began before discharge into the sea. According to this, in addition to TEPCO, the Ministry of the Environment, the NRA, and Fukushima Prefecture are also supposed to monitor the same marine areas independently in marine areas near the Fukushima Daiichi NPS. A framework has been established for each of them, including TEPCO, to conduct monitoring to increase objectivity and transparency. Initiatives are also underway to promptly analyze the tritium concentration of seawater in a set location both during and for a certain period following the end of the discharge into the sea, and then to publish the results through a preliminary report.

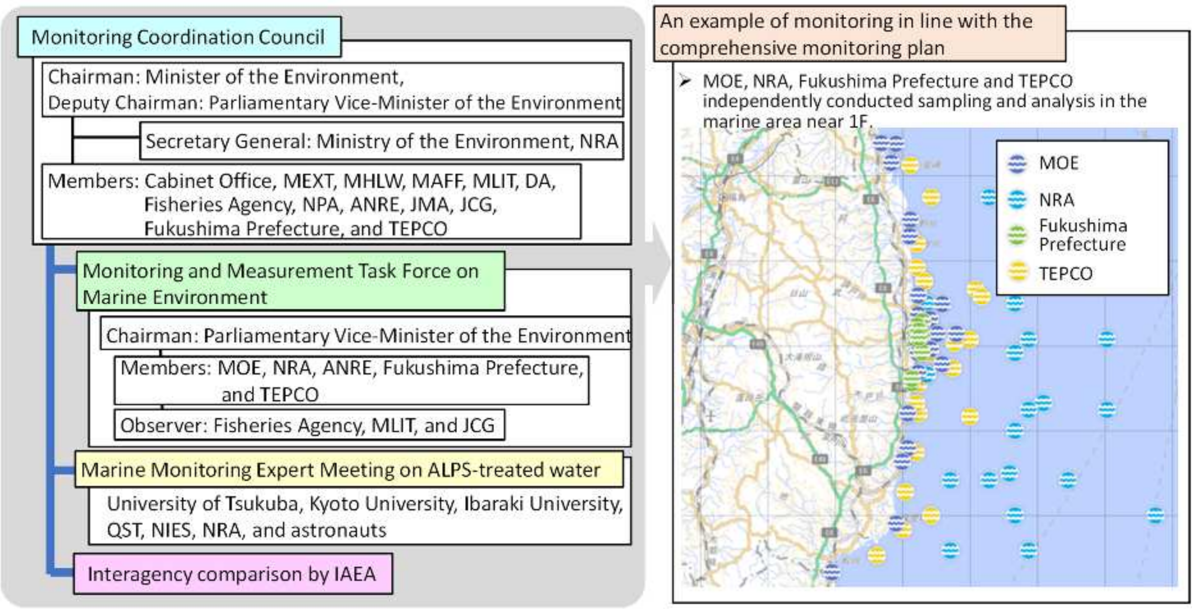


Fig. A 15-3 Framework for discussion and implementation system for marine monitoring (Monitoring Coordination Council material[355], compiled by NDF with reference to TEPCO website[356] and other material etc.))

[354] https://radioactivity.nra.go.jp/cont/ja/plan/meetings/204_01_20240321.pdf
[355] The Ministry of the Environment Website, https://www.env.go.jp/content/000120258.pdf
[356] TEPCO Website, https://www.tepco.co.jp/decommission/progress/watertreatment/monitoring/

In addition, to maintain and improve the reliability and transparency of marine monitoring data, analysis of supporting data and interlaboratory comparison (ILC) were conducted by the IAEA. In the ILC result report[357] on radionuclide analysis of seawater, seabed soil and fish, published in June 2022, the sampling methods of the participating Japanese analytical institutions (10 institutions, including TEPCO and the JAEA) were evaluated as adequate, highly accurate, and competent. The IAEA's comprehensive report also assessed that “Enhanced environmental monitoring by TEPCO and the Japanese government to deal with the discharge of ALPS-treated water has a clearly defined plan”.

To prevent reputational damage, it is important to expedite analysis and disseminate information on monitoring results that is easy to understand in a timely manner. Marine monitoring requires sophisticated analytical techniques and long-time measurements to detect extremely low concentrations of radionuclides. To expedite the analysis, in addition to the development of pretreatment technologies for concentrating radionuclides, operational initiatives are being undertaken, such as the disclosure of preliminary data from short-time analysis and final data from long-time analysis at different times.

To disseminate easy-to-understand information on analysis results, TEPCO publishes web pages on its Treated Water Portal Site that display monitoring results simply using visual elements and provides the latest information to domestic and international audiences in multiple languages (English, Chinese, and Korean). TEPCO also launched the Overarching Radiation-monitoring data Browsing System in the coastal ocean of Japan (ORBS) website in March 2023 to provide a quick view of the analysis results of each party[358].

Since multiple organizations, including TEPCO, the Ministry of the Environment, the NRA, and Fukushima Prefecture, conduct sampling and analysis as marine monitoring, it is important to operate the system continuously so that these pieces of data are disclosed promptly and transparently.

To ensure that initiatives related to the discharge of the ALPS-treated water into the sea proceed smoothly, in August 2023, TEPCO strengthened its systems. For example, the company established the “ALPS-treated Water Integrated Countermeasure Project Team” under the direct control of the President, which oversees all relevant internal departments, and the “Response Team on the Impact of ALPS-treated water,” responsible for centrally handling information dissemination, reputational countermeasures, and compensation, not only in Fukushima but also in various regions across the country.

Moreover, initiatives are being undertaken to disclose the on-site situation in a timely and easy-to-understand manner through communication on various occasions, such as visits and briefing sessions, and through information dissemination via various media, such as the website (Treated

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[357]IAEA Website, https://www.iaea.org/sites/default/files/22/06/2022-06-21_japan_ilc_2021_report_v4.2.pdf
[358]Launch of the Overarching Radiation-monitoring data Browsing System in the coastal ocean of Japan (ORBS), March 13, 2023

water portal site). As an example, a single page has been newly published on the treated water portal site to summarize the status of each facility for discharging ALPS-treated water into the sea. On the "Status of dilution and water discharge facilities" page, real-time data on seawater and ALPS treated water flow rates, tritium concentration in diluted ALPS treated water, etc., can be checked at a glance. These data are also available on the IAEA website.

(5) Simulation of discharge into the sea

The amount of tritium in the tank-stored treated water decreases approximately 5% on an annual basis from decay of the radioactive materials as well as discharge into the sea. A discharge was simulated by considering these changes, assuming that the amount of in-tank tritium would drop to zero at the end of 2051 and with a setting that minimizes the amount of tritium discharge into the sea[359]. The simulation was made with the aim of showing that the discharge of ALPS-treated water can be completed by the end of 2051 within an annual scope of 22 trillion Bq, and it does not show the planned value of annual tritium release post-FY 2024. Table A 15-3 shows the conditions that were used in the simulation.

Table A 15-3 Conditions used in the simulation

Common condition

Annual tritium release (Less than 22 tn Bq/yr)	Set the total amount of tritium to be released so that the discharge into the sea would be completed in FY 2051 within a scope that does not impact the site use plan.
Fiscal year when simulation of discharge starts	FY 2023 (simulation by fiscal year)
ALPS treated water flow rate	Maximum approx. 460m³/day
For-dilution seawater flow rate	Approx. 340,000 m³/day (2 seawater transfer pumps)
ALPS treated water Discharge process	Approx. 30K m³ in the K4 tank used as a measurement/confirmation facility, in the order of low tritium concentration. Then, discharge another tank and new ALPS-treated water by prioritizing the ones with lower tritium concentration as much as possible.
Decay of tritium	Consider with a half-life of 12.32 years (approx. 5.5% decrease in one year), and the decay of the radioactive materials for new tritium generation as well
Generation of ALPS-treated water	120m³/day in FY2023, 110m³/day in FY2024, 100m³/day in FY2025 90m³/day in FY2026, 80m³/day FY2027, 70m³/day FY2028 to FY2051
Number of days discharged	292 (80% availability factor)

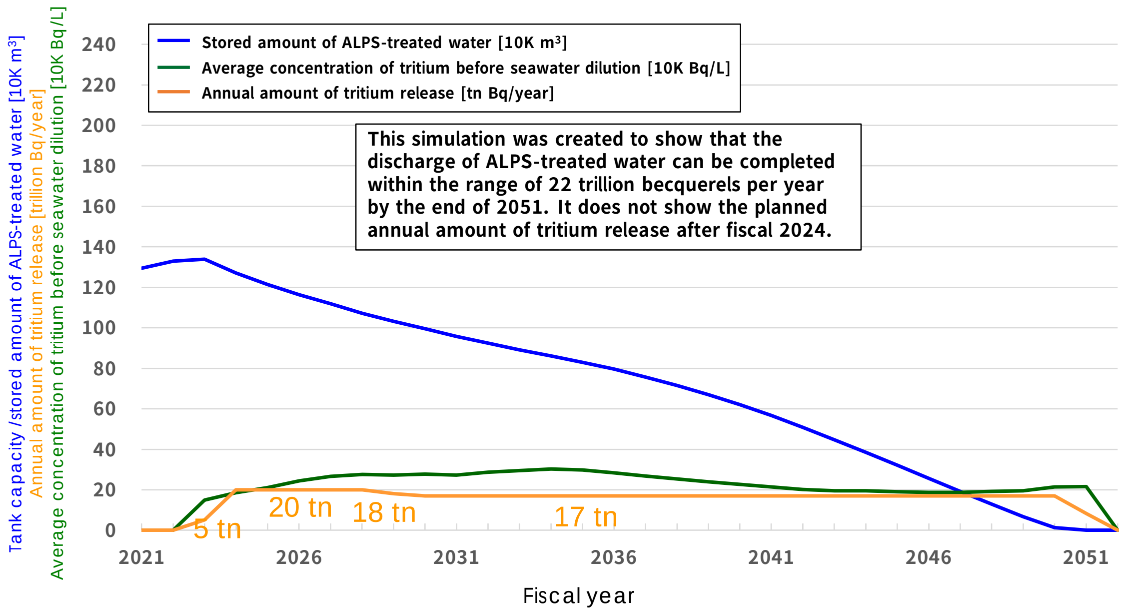
Parameters

Case	A (Case with the highest total amount of tritium)	B (Case with the lowest total amount of tritium based on current information)
Tritium concentration of ALPS-treated water treated daily	589 thousand Bq/liter (Dec. 23, 2022; max. of FY 2022)	254 thousand Bq/liter (Apr. 8, 2022; min. of FY 2022)
Total amount of tritium in building (as of Mar. 31, 2023)	Approx. 1,020 trillion Bq (All 3,400 trillion Bq at the time of the accident remained in buildings/tanks)	Approx. 80 trillion Bq (Estimated from the volume and concentration of stagnant water in buildings)

(Source: TEPCO)

359 Material 1: "The Status of the Discharge of ALPS-Treated Water into the Sea,", Committee on Countermeasures for Contaminated Water Treatment (27th), January 30, 2024.

Here, Fig. A 15-4 shows the simulation results of the case with the largest total amount of tritium in parameter A. As the blue line in the figure shows, the results indicate that even with the highest total amount of tritium, the discharge of ALPS-treated water can be completed by the end of 2051 within an annual tritium discharge of 22 trillion Bq.



(Source: TEPCO)

Fig. A 15-4 Results of ocean discharge simulation (Case with the highest total amount of tritium)

Attachment 16 Individual Action plans of relevant organizations pertaining to analysis

Agency for Natural Resources and Energy, TEPCO, the JAEA and NDF

Core measures① : Efforts for Securing Human Resource

Measure 1: Securing Human Resources

Efforts to date	Short-term Efforts (in the next two years)	Mid-to long-term Efforts (around 10 years)
【TEPCO】 ・Organized the requirements for analytical personnel (Analytical Technician, Analytical Manager, and Analytical Worker) ・Organized analysis system focusing on fuel debris, waste and bioassays. 【JAEA】 ・Hire new employees (new graduates and mid-careers), including people with skills and experiences.	【TEPCO】 ・Secure the personnel necessary to review the analysis plan. ・Secure the necessary personnel to implement the analysis plan. 【JAEA】 ・Hire new employees (new graduates and mid-careers), including people with skills and experience. [Continued]	【TEPCO】 ・Secure the personnel necessary to review the analysis plan. [Continued] ・Secure personnel necessary for conducting analysis at a comprehensive analysis facility (new graduates/mid-careers). 【JAEA】 ・Utilize and develop experienced personnel throughout JAEA ・Hire new employees (new graduates and mid-careers), including people with skills and experiences. [Continued]

Measure 2: Human Resource Development

Efforts to date	Short-term Efforts (in the next two years)	Mid-to long-term Efforts (around 10 years)
【TEPCO】 ・Organize the requirements necessary for analytical personnel and to build analytical technology focusing on fuel debris, waste and bioassays. ・Develop analytical technicians through OJT at external analytical organizations including JAEA to develop analytical personnel. ・Train analysis workers by utilizing training support by external organizations, etc. 【P】	【TEPCO】 ・OJT for potential analytical technicians will begin at JAEA. ・Development of analysis managers/analysis workers will begin by utilizing training support provided by external organizations.	【TEPCO】 ・Develop analytical technicians. [Continued] ・Continue training to maintain analytical technology by gaining on-site experience at JAEA, and through OJT in 1F by analytical technicians already trained. ・Maintain analytical capability in 1F to ensure analytical managers/analytical workers required for achieving the analytical plan by continuing education.
【JAEA】 ・Provided training at TEPCO 1F and private analytical laboratories. ・Provided OJT in the JAEA Ibaraki area and Okuma Building 1. ・Engaged in research and development in the Project of Decommissioning, Contaminated water, and Treated water Management, and the World Intellegence Project.	【JAEA】 ・Provide OJT in the JAEA Ibaraki area and Okuma Building 1. [Continued] ・Engaged in research and development in the Project of Decommissioning, Contaminated water, and Treated water Management, and the World Intellegence Project. [Continued] ・Examine a training system for analytical personnel for the entire JAEA. ・Secure and train human resources by forming analysis technology network utilizing laboratories in the Ibaraki area and universities and have them verify analyses performed and advance analytical technologies.	【JAEA】 ・Provide OJT in the JAEA Ibaraki area and Okuma Building 1. [Continued] ・Engaged in research and development in the Project of Decommissioning, Contaminated water, and Treated water Management, and the World Intellegence Project. [Continued] ・Build a training system for analytical personnel for the entire JAEA to develop more advanced human resources.

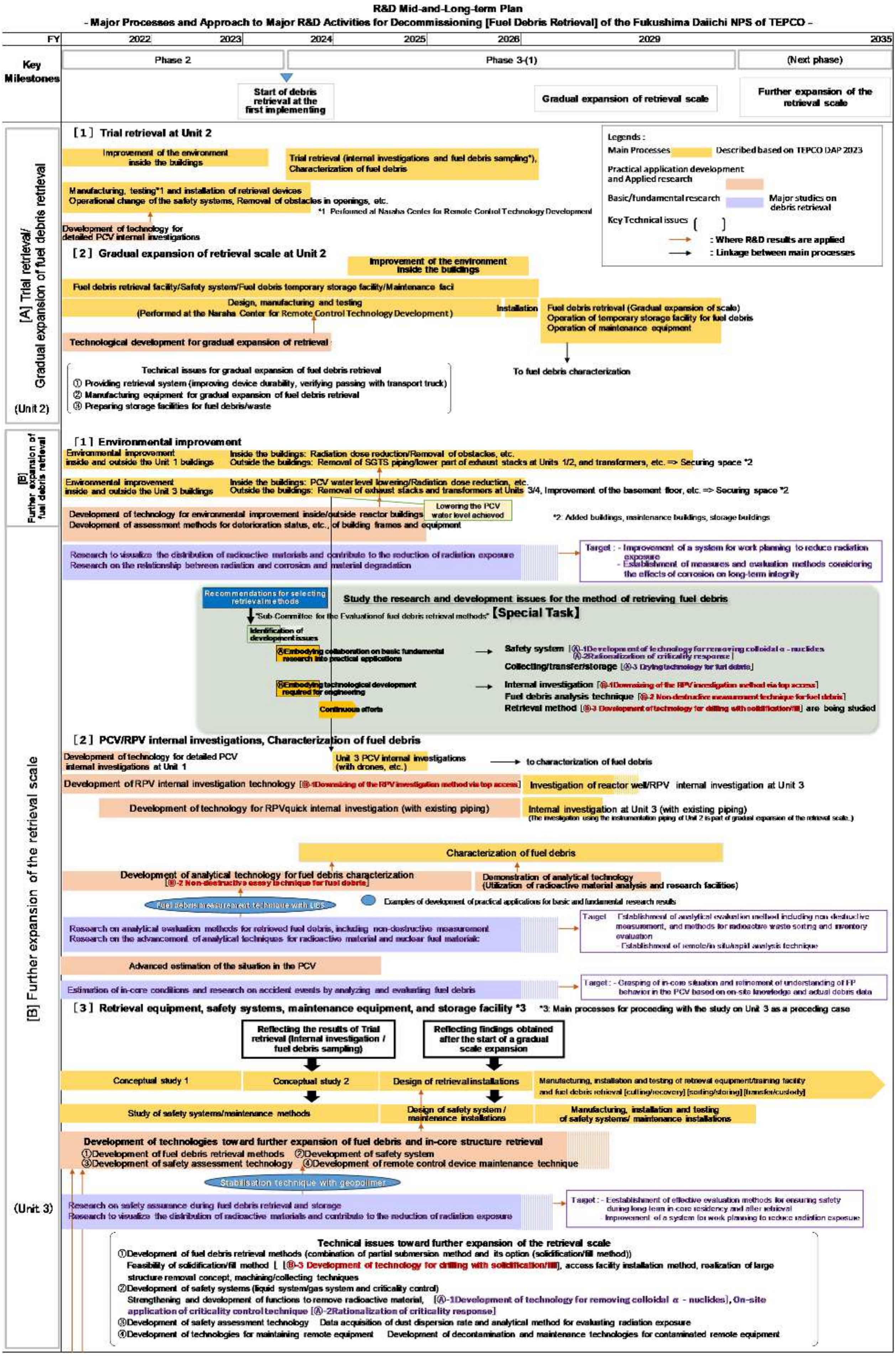
Measure 3: Support for Human Resource Development

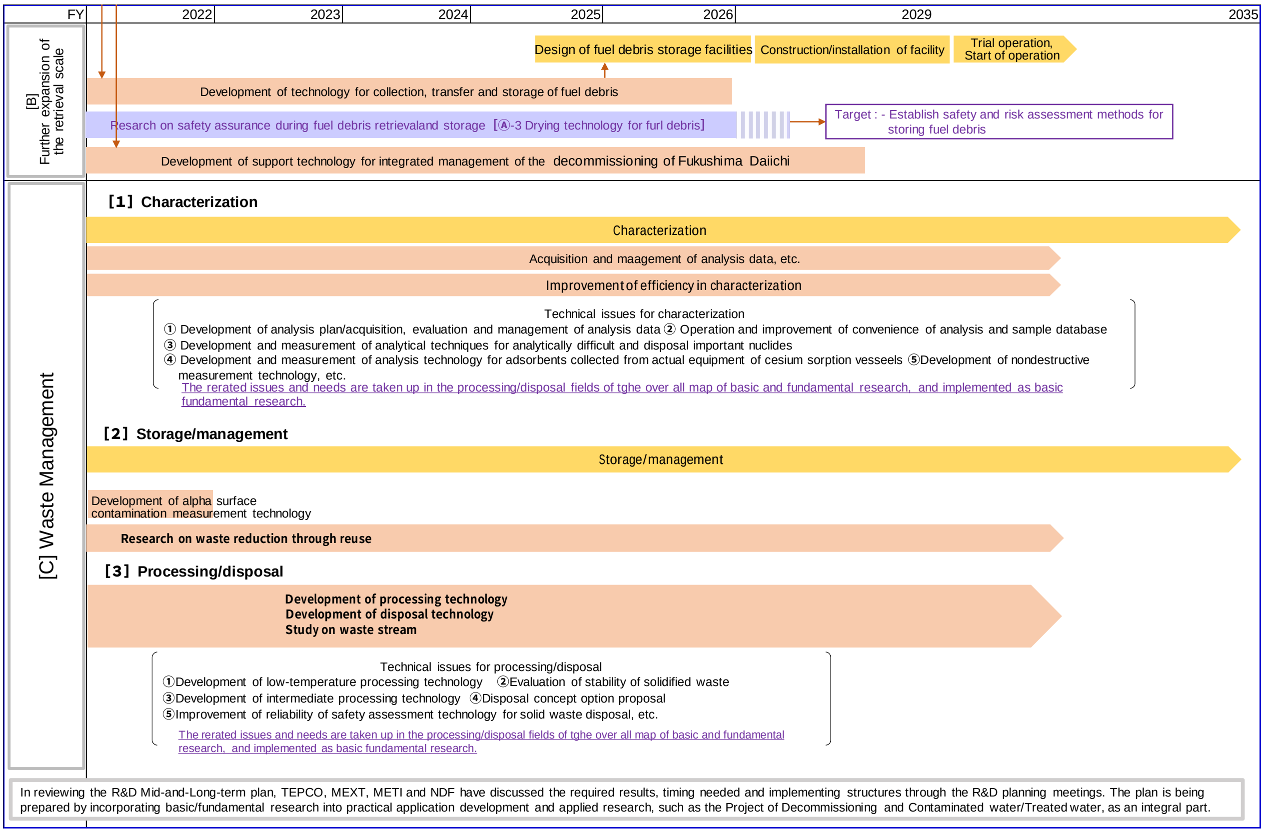
Efforts to date	Short-term Efforts (in the next two years)	Mid-to long-term Efforts (around 10 years)
【JAEA】 ・The acceptance of the analytical engineer candidate of Tokyo Electric Power Co. was examined and adjusted in JAEA Ibaraki district and Okuma Building 1. 【NDF】 ・An analysis coordination meeting was organized to provide advice on problems related to the analysis plan and analysis related to the decommissioning of the Fukushima Dai-ichi NPS, and an analysis support team was organized to discuss and review solutions to problems.	【JAEA】 ・At the JAEA Ibaraki area and Okuma Building 1, candidates for analytical technicians from TEPCO will be accepted to participate in research and development. 【NDF】 ・Advise on TEPCO's analysis plan at the analysis coordination meeting. ・The analysis support team will establish working groups as necessary to address new analysis issues, and review and advise on how to resolve these issues. ・The "Fuel debris analysis evaluation and study Working Group (WG) is being established with young or middle-ranked researchers as the main members. The WG will discuss the results of fuel debris analysis and future data acquisition, and train analysis evaluators.	【JAEA】 ・At the JAEA Ibaraki area and Okuma Building 1, candidates for analytical technicians from TEPCO will be accepted to participate in research and development. [Continued] 【NDF】 ・Advise on TEPCO's analysis plan at the analysis coordination meeting. [Continued] ・The analysis support team will establish working groups as necessary to address new analysis issues, and review and advise on how to resolve these issues. [Continued] ・Strengthen cooperation between TEPCO and the analysis community and, in cooperation with them, support TEPCO to develop the capacity to take the initiative in coordinating and executing analysis plans.

Core measures② : Efforts to Develop Analytical Facilities		
Measure 4: Development and Operation of Analysis Facilities		
Efforts to date	**Short-term Efforts (in the next two years)**	**Mid-to long-term Efforts (around 10 years)**
【TEPCO】 ・Conceptual study was completed and design study (basic design) was started on the improvement of the comprehensive analysis facility. 【JAEA】 ・Waste samples and internal investigation samples were analyzed, licenses for fuel debris analysis were aquired, and analytical equipment in the Ibaraki area was introduced. ・Okuma Building 1 started operation. ・Construction of Okuma Building 2 has started.	【TEPCO】 ・Design studies (basic design/detailed design) will be conducted on the improvement of the comprehensive analysis facility, and approval will be obtained. 【JAEA】 ・Analytical R&D will be conducted at the Ibaraki area and Okuma Building 1 complementarily, which is utilized for human resource development. ・The analysis will be performed in Okuma Building 1, and the necessity of enhancing the analysis capability (equipment and personnel) will be examined. ・Okuma building 2 will be constructed. [Continued]	【TEPCO】 ・For the comprehensive analysis facility, approval will be obtained and construction will be completed with a view to its steady completion in the latter half of the 2020s. 【JAEA】 ・Analytical R&D will be conducted at the Ibaraki area and Okuma Building 1 complementarily, which is utilized for human resource development. [Continued] ・Analysis will be continued in Okuma Building 1, and the capability for analysis will be enhanced as necessary. ・The target for completion of construction in FY2026, operation of Okuma Building 2 will be started.
Measure 5: Development of tequniques to expand analytical capabilities		
Efforts to date	**Short-term Efforts (in the next two years)**	**Mid-to long-term Efforts (around 10 years)**
【Agency for Natural Resources and Energy】 ・Necessary measures are being taken for the stable operation of the Okuma Analysis and Research Center. 【NDF】 ・In the Project of Decommissioning, Contaminated water and Treated water Management, development of analysis and estimation technology to grasp the properties of fuel debris and R&D on processing and disposal of solid waste have been conducted. 【JAEA・NDF】 ・In the OECD/NEA project, the accident progress, estimation of condition inside the reactors, and preliminary study of fuel debris analysis were made.	【Agency for Natural Resources and Energy】 ・Necessary measures are taken for the stable operation of the Okuma Analysis and Research Center. [Continued] 【NDF】 ・In the Project of Decommissioning, Contaminated water and Treated water Management, the necessary technologies will be developed for speeding up, automation, and labor saving of analysis. Non-destructive measurement technology for fuel debris, which is different from the conventional technology, will be examined and developed as necessary. ・Develop and enhance analytical technology (speed-up, automation, and labor saving) are implemented for both fuel debris and solid waste. The obtained analytical data are reflected into fuel debris retrievalv and considerations of storage/managemente and processing/disposal of waste. ・Confirm skills of solid waste analysis. ・Based on the proposals of the Analysis Coordination Meeting and the Analysis Support Team, technical development for solving analysis issues will be conducted as necessary.	【Agency for Natural Resources and Energy】 ・Necessary measures are taken for the stable operation of the Okuma Analysis and Research Center. [Continued] 【NDF】 ・Development and upgrading of analytical technology (speed-up, automation, labor-saving) will be conducted for both fuel debris and solid waste, and the acquired analytical data will be incorporated into examininaiton for fuel debris retrieval, waste storage/management, and processing/disposal.
【JAEA】 ・The development of analytical tequniques for samples and nuclides that are difficult to measure. ・The development of the analysis planning method (DQO process) which sets the analysis point statistically is being performed. ・R&D on new analytical tequniques (ICP-MS/MS, SIMS, etc.) are conducted to improve the accuracy, simplify and accelerate analysis of fuel debris.	【JAEA・NDF】 ・Through the OECD/NEA project, discussions will be made on fuel debris properties and damage conditions inside the reactors to absorb global knowledge and disseminate international information. 【JAEA】 ・The development of analytical tequniques for samples and nuclides that are difficult to measure. [Continued]	【JAEA・NDF】 ・Regarding fuel debris properties, global knowledge will be absorbed through OECD/NEA projects, etc. to use for decommissioning and disseminate information internationally. 【JAEA】 ・The development of analytical tequniques for samples and nuclides that are difficult to measure. [Continued] ・Develop and verify necessary analytical tequniques based on the analysis plan. [Continued]

Core measures③ : Development of a framework for steady implementation of analysis		
Measure 6: Review of Analysis Plan and System		
Efforts to date	**Short-term Efforts (in the next two years)**	**Mid-to long-term Efforts (around 10 years)**
【TEPCO】 ・The analysis plan was formulated based on the analysis priority and the progress of the decommissioning event in the future, and the analysis system was examined accordingly.	【TEPCO】 ・Based on the analsis results and analysis needs of each fiscal year, annual analysis plan and necessary systems will be reviewed as a rule.	【TEPCO】 ・Based on the analsis results and analysis needs of each fiscal year, annual analysis plan and necessary systems will be reviewed as a rule. [Continued]
Measure 7: Coordination of Overall Processes related to collection of analytical samples, transportation, securing of facilities, etc		
Efforts to date	**Short-term Efforts (in the next two years)**	**Mid-to long-term Efforts (around 10 years)**
【TEPCO・JAEA・IRID】 ・ Debris samples from 1F were transported to JAEA Okuma Building 1. ・Samples were transported to facilities in Ibaraki area.	【TEPCO】 ・The content and schedule of sampling are reviewed and, in coordination with relevant organizations, necessary measures to secure sampling, transport and analysis facilities are taken. ・Based on the analysis plan, samples are transported to JAEA Okuma Building 1 and facilities in Ibaraki. [Continued]	【TEPCO】 ・The content and schedule of sampling are reviewed and, in coordination with relevant organizations, necessary measures to secure sampling, transport and analysis facilities are taken. [Continued] ・Samples are analyzed at the comprehensive analysis facility. ・Samples for which analytical tequniques need to be developed will continue to be transferred to JAEA facilities. [Continued]
Measure 8: Development, Review and Follow-up of Action Plans		
【NDF】 ・In the Technical Strategic Plan, the analysis strategy was expanded from the one centered on fuel debris to the overall analysis required for the overall decommissioning work at the Fukushima Dai-ichi NPS, and the action plan was prepared.	【NDF】 ・While following up with the Government on the progress made on the efforts described in the Action Plan, and the details will be reviewed and materialized in line with the revisions of the Technical Strategic Plan.	【NDF】 ・While following up with the Government on the progress made on the efforts described in the Action Plan, and the details will be reviewed and materialized in line with the revisions of the Technical Strategic Plan. [Continued]

Attachment 17 R&D medium-to-long-term plan

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2029
2035
[B] Further expansion of the retrieval scale
Design of fuel debris storage facilities
Construction/installation of facility
Trial operation, Start of operation
Development of technology for collection, transfer and storage of fuel debris
Resarch on safety assurance during fuel debris retrievaland storage［Ⓐ-3 Drying technology for furl debris］
Target : - Establish safety and risk assessment methods for storing fuel debris
Development of support technology for integrated management of the decommissioning of Fukushima Daiichi
[C] Waste Management
［1］Characterization
Characterization
Acquisition and maagement of analysis data, etc.
Improvement of efficiency in characterization
Technical issues for characterization
① Development of analysis plan/acquisition, evaluation and management of analysis data ② Operation and improvement of convenience of analysis and sample database
③ Development and measurement of analytical techniques for analytically difficult and disposal important nuclides
④ Development and measurement of analysis technology for adsorbents collected from actual equipment of cesium sorption vesseels ⑤Development of nondestructive measurement technology, etc.
The rerated issues and needs are taken up in the processing/disposal fields of tghe over all map of basic and fundamental research, and implemented as basic fundamental research.
［2］Storage/management
Storage/management
Development of alpha surface contamination measurement technology
Research on waste reduction through reuse
［3］Processing/disposal
Development of processing technology
Development of disposal technology
Study on waste stream
Technical issues for processing/disposal
①Development of low-temperature processing technology ②Evaluation of stability of solidified waste
③Development of intermediate processing technology ④Disposal concept option proposal
⑤Improvement of reliability of safety assessment technology for solid waste disposal, etc.
The rerated issues and needs are taken up in the processing/disposal fields of tghe over all map of basic and fundamental research, and implemented as basic fundamental research.
In reviewing the R&D Mid-and-Long-term plan, TEPCO, MEXT, METI and NDF have discussed the required results, timing needed and implementing structures through the R&D planning meetings. The plan is being prepared by incorporating basic/fundamental research into practical application development and applied research, such as the Project of Decommissioning and Contaminated water/Treated water, as an integral part.

Attachment 18 Past Research and Development initiatives in the Project of Decommissioning, Contaminated Water and Treated water Management

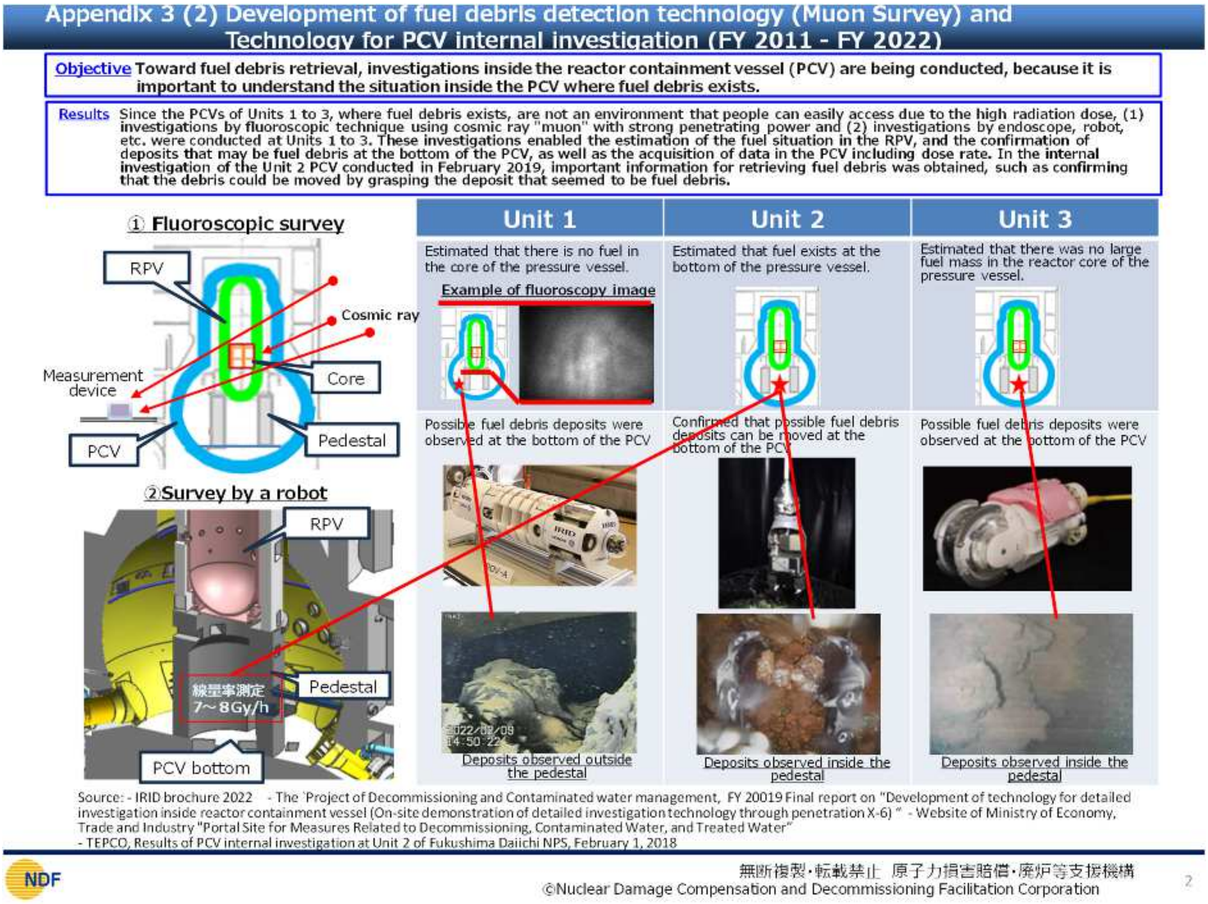
Japanese calendar (Fiscal year)	H23	H24	H25	H26	H27	H28	H29	H30	R1	R2	R3	R4	R5	R6
Western calendar (Fiscal year)	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
1. Contaminated water management														
1.1 Tritium separation technology														
1.2 Development and verification of high-performance multi-nuclide removal system														
1.3 Large-scale verification of frozen-soil impermeable wall														
2. Spent fuel management														
2.1 Evaluation of long-term integrity of fuel assemblies removed from SFPs														
2.2 Examination of methods for processing damaged fuel removed from SPFs														
3. Investigation inside the reactor, characterization of fuel debris, and internal investigation														
3.1 Investigation inside the reactor														
(1) Understanding inside the reactor by advanced accident progression analysis technology														
(2) Understanding inside the reactor utilizing the severe accident analysis code														
(3) Enhancement of the understanding inside the reactor by the accident progression and the actual data														
(4) Advancement of comprehensive understanding of state inside reactor														
3.2 Characterization of fuel debris														
(1) Characterization of fuel debris using mock-up debris and development of fuel debris processing technologies														
(2) Property analysis of actual debris														
(3) Grasping properties of fuel debris														
(4) Development of techniques for characterizing and analyzing fuel debris														
(5) Development of analysis and estimation techniques for characterization of fuel debris														
(6) Estimation of characteristics for aging degradation of fuel debris														
(7) Improvement of analytical accuracy of fuel debris and development of technology for estimating thermal behavior														
(8) Development of sorting technology for fuel debris and radioactive waste														
(9) Establishment of measurement control measures for fuel debris														
3.3 PCV internal investigation														
3.4 RPV internal investigation														
3.5 Technologies for the detection of fuel debris (using muon)														
4. Environmental improvement														
4.1 Development of remote decontamination technology in the buildings														
(1) Development of remote decontamination technology for reactor buildings														
(2) Formulation of the comprehensive dose reduction plan														
4.2 Development of Integrity Assessment Techniques for Nuclear Reactor Pressure Vessels and Containment (Corrosion control technology, earthquake-resistance and impact evaluation technology)														
(1) Development of integrity evaluation technology for pressure vessels and containment														
(2) Development of seismic performance and impact assessment methods for pressure vessels and containment vessels														
4.3 Repair methods for leak spots in PCV (incl. closed water circulation construction technology)														
(1) Development of investigation and repair technologies (water sealing) toward water filling in PCV														
(2) Full-scale test of repair methods for leak spots in PCV														
(3)Development of PCV closed water circulation systems														
(4)Development of PCV closed water circulation systems (mock-up test)														
(5)Development of technologies for non-destructive detection of radioactive material deposited in S/C, etc.														
4.4 Environmental improvement of in the buildings (Removal of interferences, digitization of radiation sources, S/C electrolytic protection)														
(1) Development of corrosion inhibition technology for RPV and PCV														
(2) Development of technology for environmental improvement of inside the buildings														
5. Fuel debris retrieval														
5.1Technologies for gradual expansioin of fuel debris retrieval(Development of sampling technology)														
(1) Development of sampling technologies for retrieving fuel debris and in-core structures														
(2) Development of technologies for retrieving fuel debris to be gradually expanded in scale														
5.2.1 Retrieval method of fuel debris														
(1) Development of technologies for retrieving fuel debris and in-core structures														
(2) Advancement of retrieval method and system of fuel debris and in-core structures														
(3) Development of technology for retrieval of fuel debris and in-core structures														
(4) Development of basic technologies for retrieving fuel debris and in-core structures														
(4)-1 Development of fundamental technologies for retrieving fuel debris and in-core structures (development of visual and measurement technologies, and monitoring technology for retrieval of fuel debris)														
(4)-2 Development of fundamental technologies for retrieving fuel debris and in-core structures (cutting and Dust Collection Technology)														
(4)-3 Development of fundamental technologies for retrieving fuel debris and in-core structures (remote controlled laser cutting and dust collection)														
(4)-4 Development of fundamental technologies for retrieving fuel debris and in-core structures (development of a compact neutron detector)														
(5) Development of technology for retrieval of fuel debris and in-core structures (development of technology for dust collection system for fuel debris)														
(6) Development of technologies toward further expansion of the retrieval scale for fuel debris and in-core structures														
(7) Development of retrieval method of fuel debris														
(8) Development of technology for ensuring safety during the retrieval of fuel debris														
(9) Development of technology to control dispersion of fuel debris														
(10) Development of CRD housing cutting and removal technology														
5.2.2 Safety system														
(1) Development of criticality control technologies of fuel debris														
(2) Advancement of methods and systems for retrieving fuel debris and in-core structures (Development of technologies for establishing criticality control methods)														
(3) Development of safety systems (liquid and gas systems, criticality control technology) for establishing criticality control methods)														
(4) Development of safety system (data acquisition of dust scattering rate)														
(5) Safety system (Development of analytical technique for exposure assessment)														
5.3 Technologies for containing, transferring, and storing fuel debris														
5.4 Technologies for maintaining remote equipmen														
5.5 Support technologies for integrated management														
(1) Development of a continuous monitoring system inside the reactor containment														
6. Waste management														
6.1Research and development of processing and disposal of solid waste														

Legend
- End, moves to TEPCO's own technological developments
- Continueing

Link to the Project performance

*** Please refer to the link below for the link to the project results.**
Performance in FY 2013 and plans for 2014, The 4th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Wate, https://www.meti.go.jp/earthquake/nuclear/pdf/20140327_02/140327_02_025.pdf
Performance in FY 2014 and plans for 2015, The 15th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Wate, https://www.meti.go.jp/earthquake/nuclear/pdf/150226/150226_01_4_1_03.pdf
Performance in FY 2015 and plans for 2016, The 27th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Wate, https://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2016/pdf/0225_4_3a.pdf
Performance in FY 2016 and plans for 2017, The 39th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Wate, https://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2017/02/4-02-01.pdf
Performance in FY 2017 and plans for 2018, The 51st Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Wate, https://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2018/03/4-02.pdf
Performance in FY 2018 and plans for 2019, The 63rd Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Wate, https://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2019/02/4-1.pdf
Performance in FY 2019 and plans for 2020, The 75th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Wate, https://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2020/02/4-2-2.pdf
Performance in FY 2020 and plans for 2021, The 86th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Wate, https://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2021/01/4-1.pdf
Performance in FY 2021 and plans for 2022, The 98th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Wate, https://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2022/01/4-1-1.pdf
Performance in FY 2022 and plans for 2023, The 111th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Wate, https://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2023/02/4-1.pdf
Performance in FY 2023 and plans for 2024, The 123rd Meeting of the Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and Treated Wate, https://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2024/02/02/4-1-2.pdf
<List of the Projects Management Office for the Project of Decommissioning, Contaminated Water and Treated Water Management>
https://en.dccc-program.jp/
<Information Portal for the Research and Development for the Fukushima Daiichi Decommissioning>
https://www.drd-portal.jp/en/

Examples of studies (Internal investigation)



Attachment 19 Ongoing R&D activities

Classification	Name of R&D	Reason for selection	Result of development	Remaining challenge
R&D concerning fuel debris retrieval	PCV internal investigation	Environment conditions, such as the distribution of fuel debris, in-PCV status, and radiation dose, need to be confirmed to contribute to examinations related to the retrieval of fuel debris inside the PCV.	For the internal investigation of the PCV, where the situation was unknown due to high-radiation doses and high contamination, access devices (e.g., arm/telescopic-type devices and an underwater remotely operated vehicle) were developed and access routes were established with practical verification. The status inside/outside the pedestal in Unit 1, the status inside the pedestal in Unit 2 (including gripping investigation of deposits suspected to be fuel debris at the bottom), and the status inside the pedestal in Unit 3 were clarified.	For each unit, information needs to be obtained on areas where the in-PCV status is unknown. The challenge is to identify the status of damage at the RPV bottom in each unit, the status of deposits in the vent tube and S/C in Unit 1, and the status outside the pedestal in Unit 3.
	RPV internal investigation	Environment conditions, such as the distribution of fuel debris, in-RPV status, and radiation dose, need to be confirmed to contribute to examinations related to the retrieval of fuel debris inside the RPV.	The remaining state of in-RPV fuel was estimated through a survey using cosmic rays (muon) with a strong penetration force. The Unit 1 RPV has no fuel in its core, the Unit 2 RPV has fuel at its bottom, and no large fuel mass is at the Unit 3 RPV core. For investigation based on direct access into the RPV, investigation method by drilling the upper part, investigation method by drilling the side, a lower access investigation method, and an investigation method using existing piping were developed and device functionality was verified in preparation for practical application.	Since no direct footage or similar information of RPV internals is available for each unit, the challenge is to obtain the information inside the RPV as early as possible by promoting the development of techniques suitable for the on-site situation and TEPCO's engineering.
	R&D on characterization of fuel debris	To develop techniques necessary to quantitatively analyze fuel debris components and estimate fuel debris characteristics, and thereby contribute to the development of a retrieval method of fuel debris and in-core structures and technologies for collection, transfer, and storage of fuel debris.	Results include standardization of analytical methods that use mock-up debris for prompt and accurate fuel debris analysis, analysis of deposits and other substances obtained through PCV internal investigation, participation in OECD/NEA projects, and creation of 3D graphic images of the estimated internal PCV condition.	Analysis of fuel debris to be obtained at 1F and fuel debris from the Three Mile Island Nuclear Power Plant as a comparative sample, response to the increased size and quantity of samples, and the development of simple analysis techniques and non-destructive measurement techniques, in addition to the continued implementation of current efforts.
	Development of technology for work environmental improvement in reactor buildings	To develop technologies related to environmental improvement needed for safe and efficient work in the reactor building, where the state of damage caused by the accident remains unknown in some locations and radiation doses are still high, in view of the further expansion of fuel debris and in-core structure retrieval in scale.	Technologies to identify radiation sources using environmental survey data and to visualize the environment and radiation source distribution by digital technology have been developed for the formulation of a safe and efficient work plan, and a prototype was built in FY 2022. Development has been underway since FY 2023 to advance functions for practical applications. In FY 2024, actual site applicability is being evaluated.	The development of technologies for remote monitoring and removal work systems for the removal of high-radiation dose PCV-penetrating piping, etc., which could contain contaminated fluid, hydrogen, etc.
	R&D on the fuel debris retrieval method	Regarding the fuel debris retrieval method for further expansion of fuel debris retrieval in scale, technology development is needed for the devices, equipment, and systems required for establishing access routes to the PCV and fuel debris retrieval, on the assumption that the fuel debris retrieval work will be a remote operation in an environment with a high radiation dose, high contamination, and high uncertainty.	Side-access and top-access retrieval methods using the partial submersion method were developed, along with elemental technologies common to the side- and top-access methods. Development regarding the side-access method include a fuel debris recovery system, a cutting/dust collection system, technologies to remove obstacles, and remote-control support systems. Development regarding the top-access method including methods for cutting into large units and large transport devices. Remote decontamination and maintenance technologies and dust dispersion control materials during work were developed as elemental technologies common to the side- and top-access methods.	Specific design studies are underway in accordance with recommendations in the report of the Sub-Committee for the Evaluation of Fuel Debris Retrieval Methods, including formulation of retrieval scenarios and studies on the technical feasibility of the methods. Among the challenges newly identified through these studies, those that are determined to have a high need for new development and high technical difficulty need to be addressed.
	R&D on safety systems	To develop and test elemental technologies needed for ensuring safety during work, in view of the further expansion of fuel debris and in-core structure retrieval in scale.	(1) Development of technology to remove particles containing radionuclides from circulating cooling water, technology to remove soluble alpha-ray emitting nuclides in an environment simulating practical application, and technology to treat secondary waste. (2) Acquisition of data on the dust dispersion rate in dry conditions, for the purpose of understanding the basic behavior of dust dispersion in a moist environment during fuel debris retrieval. (3) Studies on the concept of an internal radiation exposure dose assessment program, investigation and examination on the acceleration of bioassay methods, and technical development for optimizing protective equipment.	(1) Technology to remove colloidal α-nuclides, testing of α-nuclide removal by using the actual stagnant water in buildings, etc. (2) Acquisition of data on the dust dispersion rate assuming the moist environment inside the PCV and the specific method of applying the data to safety assessment. (3) Development of an internal radiation exposure dose assessment program. (4) Development of technology to increase the promptness and efficiency of the analysis of nuclear fuel materials, difficult-to-analyze nuclides, etc.

Classification	Name of R&D	Reason for selection	Result of development	Remaining challenge
R&D concerning fuel debris retrieval	R&D on fuel debris containment, transportation, and storage	A system to contain, transfer, and store the retrieved fuel debris in safe, reliable, and reasonable manners is required to be developed.	Establishment of the basic specifications of the container and testing to demonstrate the structural integrity of the container. Examination of a prediction method of hydrogen generation from fuel debris stored in containers; and determination of a vent mechanism for the container and establishment of safe transfer conditions for the container by using the said prediction method. Development of drying technology applicable to the recovered fuel debris and studies on relevant drying systems.	Establishment of processes to safely, reliably, and reasonably transfer and store fuel debris in slurry or sludge form.
	Development of supporting technologies for integrated decommissioning management of 1F	The development of digital technology-based supporting technologies for integrated management is required in terms of safe, efficient, and continuous decommissioning of 1F over a long term.	A monitoring system was developed (including the identification of monitoring items, studies on monitoring methods, and identification of technical challenges and elements to be developed) for the continuous monitoring of environmental changes inside the PCV in the further expansion of fuel debris retrieval in scale from the viewpoint of the safety requirements and maintenance of throughput.	Examination of the overall concept of an integrated management supporting system and development of integrated management technologies based on digital technology (development of a database).
R&D concerning waste management	R&D for treatment and disposal of solid waste	Based on the prospects of processing/disposal method and technology related to its safety (hereinafter referred to as the “technical prospects”) presented in FY 2021, studies need to be conducted toward presenting appropriate measures concerning the specific overall management of the solid waste.	Technical knowledge and assessment methods were improved with respect to characterization, storage/management, and processing/disposal, which contributed to presenting on technical prospects. The following activities were also conducted to present appropriate measures concerning the overall management of the solid waste based on technical prospects: • Accumulation of analysis data and development to increase the efficiency of characterization • Development concerning technologies for volume reduction and reuse to reduce the amount of waste • Examination of challenges concerning the applicability of normal-temperature processing, studies on the stability of solidified waste produced by different processing technologies, etc. • Investigation on information and knowledge necessary to build the disposal concept and trials to enhance the reliability of safety assessment technologies	Accumulation of draft individual waste stream options and construction of technical knowledge necessary to bundle together, assess, and examine all draft individual waste stream options, toward presenting appropriate measures concerning the specific overall management of the solid waste.

Attachment 20 Selected subjects in the Nuclear Energy Science & Technology and Human Resource Development Project (the World Intelligence Project)

Selected subjects in the FY2024 Issue-solving Decommissioning Research Program (7 subjects)

Subject of proposal	Study representative [Organization]	Participating institution
Elemental development of chipsets for wireless data transmission featuring high radiation tolerance (baseband circuit development)	Masaya Miyahara [KEK]	Okayama University; Piezo Studio, Inc.
Elemental development of chipsets for wireless data transmission featuring high radiation tolerance (high-frequency analog circuit development)	Atsushi Shirane [Tokyo Institute of Technology]	Okuma Diamond Device Co., Ltd., Nagoya University, Hokkaido University
Development of laser deflection-detecting ultrasound broadband 3D imaging system that allows in-core visualization under high radiation dose and invisible environment	Hiroshige Kikura [Tokyo Institute of Technology]	Muroran Institute of Technology, The Institute of Applied Energy, Tamaura Lab, Japan Atomic Energy Agency (JAEA)
Ultrasonic visualization technology for spatial recognition under poorly visible and high radiation dose environment	Takahiro Hayashi [Osaka University]	Nihon University, Tohoku University
Development of 3D modeling method with radiation-resistant laser scanner and AI/image processing	Tomohiro Fukuda [Osaka University]	RIKEN, Kumonos Corporation
Data-driven on-site diagnostic technology: Microbiologically induced corrosion risk prediction to ensure long-term health	Satoshi Wakai [Japan Agency for Marine-Earth Science and Technology]	National Institute for Materials Science, Central Research Institute of Electric Power Industry, Nippon Steel Corporation, JAEA
Research on imaging methods for neutron sources, etc., to ensure the safety of debris retrieval	Nishiki Matsubayashi [Kyoto University]	Fukushima University, Tohoku University, JAEA

Selected subjects in the FY 2024 Research Personnel Development Decommissioning Research Program (2 subjects)

Subject of proposal	Study representative [Organization]	Participating institution
Research and education personnel development to integrate remote robotics and measurement technology for fuel debris retrieval	Takumi Saito [The University of Tokyo]	Fukushima University; Kobe University; Tohoku University; Kogakuin University; University of Aizu; Toyama National Institute of Technology, Toyama College; National Institute of Technology, Fukushima College; JAEA
Research personnel development revolving around the establishment of Severe Environment Engineering and Management (SEEM) studies and fuel debris research	Yutaka Watanabe [Tohoku University]	University of Fukui, Kyoto University, RIKEN, Tokyo Institute of Technology, Tousou Mirai Technology Co. Ltd., JAEA

Selected subjects in the FY2023 Issue-solving Decommissioning Research Program (7 subjects)

Subject of proposal	Study representative [Organization]	Participating institution
Development of a prototype radiation-resistant diamond neutron measurement system that requires no shielding	Junichi Kaneko [Hokkaido University]	High Energy Accelerator Research Organization (KEK), National Institute of Advanced Industrial Science and Technology (AIST), Nagoya University, Kyushu University, Japan Atomic Energy Agency (JAEA)
Development of an innovative n-γ scintillation detection system for simple non-destructive measurement	Kei Kamada [The University of Tokyo]	The University of Tokyo, AIST, JAEA
Study on physical and chemical alteration of constituent materials for understanding the damage behavior of reinforced concrete in pedestal sections	Go Igarashi [Nagoya University]	The University of Tokyo, Tohoku University, JAEA
High-speed 3D in-core environment modeling based on the amount of characteristic extraction from dynamic images	Keita Nakamura [Sapporo University]	Iwate Prefectural University, JAEA
Study on rational processing and disposal considering volume reduction of radioactive concrete waste	Kozaki Tamotsu [Hokkaido University]	University of Fukui, Central Research Institute of Electric Power Industry (CRIEPI), JAEA
Development of technology for exploration inside the piping in high background radiation environments	Tatsuo Torii [University of Fukui]	Osaka University, Kobe University, Tohoku University, Saitama University, JAEA
Research and development of remote optical measurement technology for estimation of PCV gas-phase leakage position and leakage amount	Tatsuo Shiina [Chiba University]	Institute for Laser Technology (ILT)

Selected subjects in the FY2023 international cooperative decommissioning research program (2 subjects)

Subject of proposal	Study representative [Organization]	Participating institution
Japan-UK Joint Research on Nuclear Energy: 2 subjects		
Challenges in visualization of fuel debris by innovative spectroscopic image analysis and verification by LIBS	Hiroaki Muta [Osaka University]	Nippon Nuclear Fuel Development Co., Ltd. (NFD), JAEA
Design and characterization of metakaolin-based geopolymers with various properties for fuel debris removal	Yogarajah Elakneswaran [Hokkaido University]	JAEA

Selected subjects in the FY2022 issue-solving decommissioning research program (6 subjects)

Subject of proposal	Study representative [Organization]	Participating institution
Practical Application of Innovative Alpha Dust Imaging Device and High Dose Rate Field Monitor	Shunsuke Kurosawa [Tohoku University]	Mitsubishi Electric Corporation, Kyoto University, JAEA
Establishment of Three-Dimensional Dose Diffusion Prediction Method and Development of In-Structure Investigation Method Using Gamma-Ray Transmittance Difference	Tatsu Tanimori [Kyoto University]	Fukushima SiC Application Technology Laboratory Co., Ltd., JAEA
Development of elemental technology for α contamination visualization hand foot cross monitor	Mikio Higuchi Hokkaido University	AIST, JAEA
Development of Radiation Field Mapping Observation System Using Solar Cells for Low Illumination with High Radiation Resistance	Yasuki Okuno [Kyoto University]	National Institute of Technology Kisarazu College, AIST, RIKEN, Japan Aerospace Exploration Agency, Tohoku University, and National Institute for Quantum Science and Technology (QST)
Development of a Passive Wireless Communication System that Can Communicate under Poor Conditions Caused by Obstacles	Hiroyuki Arai [Yokohama National University]	Niigata University, Nagoya Institute of Technology
Development and Evaluation of Real-Time 3D Position Positioning and Integration System Combining Wireless UWB and Camera Image Analysis	Kojiro Matsushita [Gifu University]	The University of Tokyo, LocationMind Corporation, National Institute of Technology Fukushima College, Nagoya University, JAEA

Selected subjects in the 2022 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 Embedded Systems Using Radiation-Resistant Processors	Takehiko Tsukahara [Tokyo Institute of Technology]	Kobe City College of Technology, Lancaster University
Exploration of Nano-Interface Phenomena on Dissolution and Agglomerative Dispersion of Alpha Microparticles Using Micro-Nanotechnology	Hajime Asama [The University of Tokyo]	Waseda University, JAEA, University College London

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, 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, 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, AIST, ATOX Co., Ltd., 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, TEPCO, 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, 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, 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., JAEA, University of Bristol
Navigation and control of a mechanical manipulator for fuel debris retrieval	Hajime Asama [The University of Tokyo]	RITECS Inc, JAEA, University of Sussex
Japan-Russia joint research on nuclear energy: 2 subjects (* Transferred to issue-solving decommissioning research program from FY2023)		
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, JAEA, Saint Petersburg State University
Sophistication of fuel debris criticality analysis technology using the non-contact measurement method	Toru Obara [Tokyo Institute of Technology]	AIST, National Research Nuclear University (MEPhI)

Selected subjects in the FY2020 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, CRIEPI, 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 [KEK]	Hokkaido University, AIST, Nagoya University, 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]	QST, National Institute for Materials Science (NIMS), 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, QST, 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, JAEA
Study on the rational treatment/disposal of contaminated concrete waste considering leaching alteration	Tamotsu Kozaki [Hokkaido University]	University of Fukui, CRIEPI, JAEA
Challenge to the advancement of debris composition and direct isotope measurement by microwave-enhanced LIBS	Yuji Ikeda [iLabo Co., Ltd]	JAEA

Selected subjects in the FY2020 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]	KEK, JAEA, Lancaster University

Selected subjects in the FY2019 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]	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]	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 [QST]	The University of Tokyo
Development of radiation-hardened diamond image-sensing devices	Shinya Omagari [AIST]	Hokkaido University

Selected subjects in the FY2019 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, JAEA
Fluorination method for classification of the waste generated by fuel debris removal	Daisuke Watanabe [Hitachi-GE Nuclear Energy, Ltd.]	Saitama University, JAEA
Development of a stable solidification technique for ALPS sediment wastes with apatite ceramics	Takehiko Tsukahara [Tokyo Institute of Technology]	CRIEPI, JAEA
Challenge to the investigation of fuel debris in RPV with an advanced super dragon articulated robot arm	Shuji Takahashi [Tokyo Institute of Technology]	JAEA

Selected subjects in the FY2019 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, 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., 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., JAEA
Development of extremely small amount analysis technology for fuel debris analysis	Yasuyoshi Nagai [Tohoku University]	Nagaoka University of Technology, NFD, Kyushu University, JAEA

Selected subjects in the FY2019 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, Russia National Research Nuclear University (MEPhI)
Study of corrosion and degradation of objects in a nuclear reactor by microorganisms	Akio Kanai [Keio University]	RIKEN, 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., 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 21 Major activities related to enhancing international collaboration

Table A 21-1 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 A 21-2 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 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 A 21-3 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 A 21-4 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 A 21-5 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