Technical Strategic Plan 2023 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." (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ー①	Phase 3ー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 (around 2023) 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 steadily progressing, as shown by the facts that the images of the inside the pedestal was successfully captured for the first time during the internal investigations of Unit 1 in March 2023, milestones in reducing the amount of stagnant water in the reactor building were achieved, and the discharge of ALPS-treated water into the sea started in August. Preparations to start the final phase of Phase 2 are currently underway including trial retrieval of fuel debris in the second half of fiscal 2023. From Phase 3-[1] onward, 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 fuel debris retrieval in scale and the formulated analysis plan.

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).

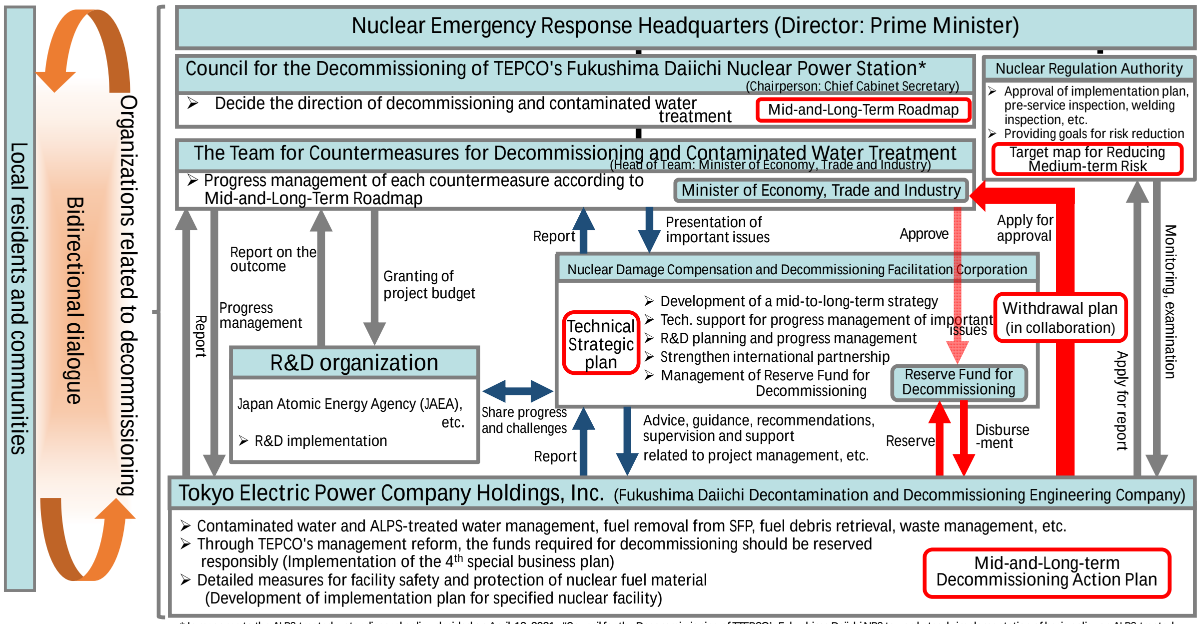
- Providing a solid technical basis for the Mid-and-Long-term Roadmap and contributing to its smooth and steady implementation, and consideration of revisions

- 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 The NDF and TEPCO jointly prepare a Withdrawal Plan for Reserve Fund.

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

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 according to the Policy fir 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).

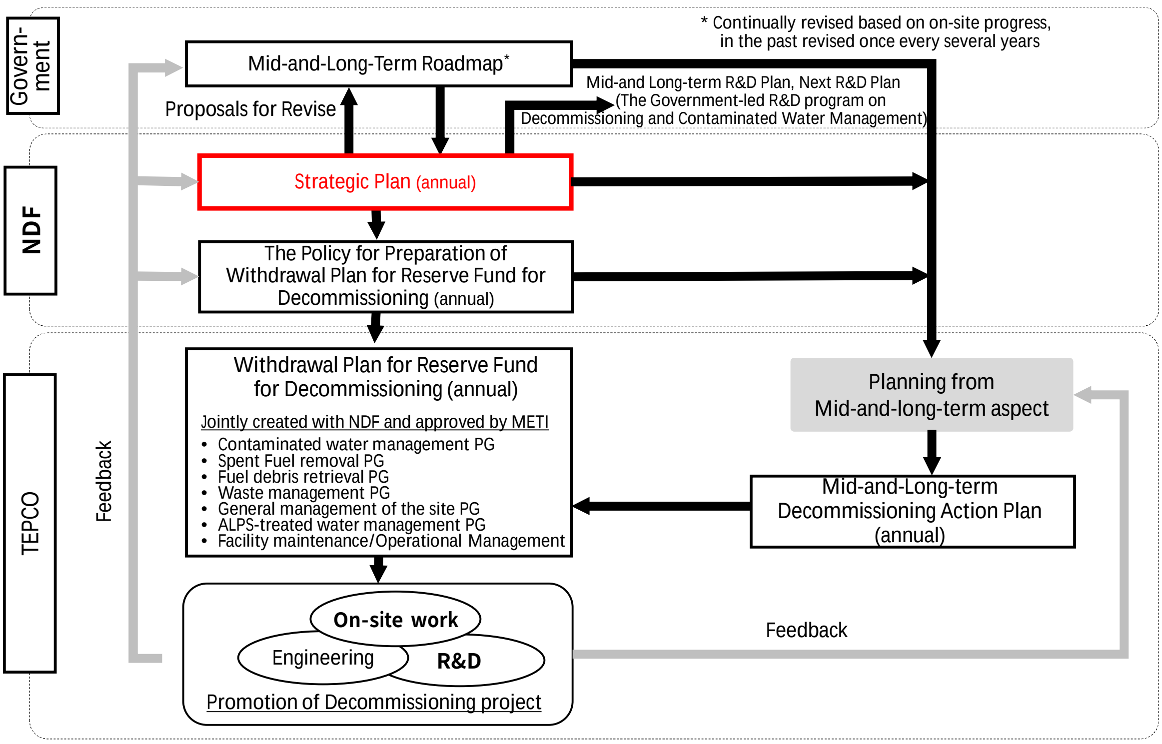


Fig. 3 Positioning of the Technical Strategic Plan based on the Reserve Fund

1.2 The Technical Strategic Plan 2023

The Technical Strategic Plan 2023 consists of six chapters and characteristically features below:

- Unit 1; Investigation and evaluation for the integrity of the pedestal
- Unit 2; Preparatory works related to trial retrieval (internal investigation and fuel debris sampling)
- Unit 3; Examination of selecting the retrieval methods toward further expansion of fuel debris retrieval in scale
- Efforts toward the discharge of ALPS-treated water into the sea
- Enhancement of analysis system

Including the above, the major changes in the Technical Strategic Plan 2023 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

- The SED assessment[1] has been 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 2023. The most notable changes since the end of March 2022 include decreasing of Hazard Potential as the progress of the transfer work of the ALPS slurry stored in the HIC, which exceeded the standard for integrated absorbed dose, and the review of Requiring Level for Safety Management for "contaminated structures in buildings, etc." in light of the newly identified on-site conditions.
- For some time, the immediate target has been to reduce the "Requiring Level for Safety Management" of risk sources and bring them into "region of sufficiently stable management". To clarify the direction of its specific measures, the Technical Strategic Plan 2023 presents how "Requiring Level for Safety Management" can be reduced from each perspective by breaking down "Requiring Level for Safety Management" into two components (a component related to the containment of the facility and a component related to the long-term stability of risk sources).

Chapter 3 Technological strategies toward decommissioning of the Fukushima Daiichi NPS

(1) Fuel debris retrieval

- This section stated that, as a result of the internal investigation of Unit 1 conducted in March 2023, a great deal of information was obtained, including the height of deposits outside the pedestal and the status of deposits and fallen objects located at the bottom of the pedestal.

[1] 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.

- With regard to “Further expansion of fuel debris retrieval in scale”, the Technical Strategic Plan 2022 described the study processes, the overview and examples of issues of the two methods discussed (partial submersion method and submersion method), and the policy for further action, based on the studies of the methods until the first half of 2022. In the Technical Strategic Plan 2023, the description was completely revised, and the six factors that make it difficult to retrieve fuel debris, which should be taken into account when proceeding with the evaluation of retrieval methods were identified, as well as the issues and action policies for each of these factors were described in each of partial submersion method (water injection into RPV), partial submersion method option (RPV filling and solidification) and submersion method (shell method).
- As this selection of retrieval methods is an extremely important decision that will determine the success or failure of decommissioning over the medium-to long-term, it is necessary for TEPCO, the government and NDF to cooperate in the study process. Therefore, this section states that "The Sub-committee for Evaluation of Fuel Debris Retrieval Method" has been established from February 2023 to perform expert and intensive studies and evaluations on the technical feasibility of each method, business continuity of the project[2].
- In the Technical Strategic Plan 2022, the issues for each technical requirement were comprehensively described as the Section 3.1.2.6, there were duplicated descriptions with the previous section. The Technical Strategic Plan 2023 describes research and development items regarding further expansion of fuel debris retrieval in scale currently being implemented in the Project of Decommissioning, Contaminated water and Treated water Management.

(2) Waste management

- This section states that, since the studies on analysis have progressed, which is an important element in advancing waste management, TEPCO formulated an analysis plan in March 2023 with the aim of characterizing of solid waste and optimizing its storage/management to review processing/disposal methods for solid waste.
- Based on this analysis plan and other materials, new targets for analysis were set, and new action policies are described according to the fields of “characterization”, “storage/management” and “processing/disposal”.

(3) Contaminated water and treated water management

- As the prospect for reducing the amount of contaminated water generated to 100 m^3/day or less to the average rainfall by the end of 2025 is becoming clear, and the reduction of the amount of stagnant water in reactor buildings to about half of that at the end of 2020 has been achieved, in the Technical Strategic Plan 2023, new target (about 50 to 70 m^3/day by

[2] Indicators for determining whether decommissioning is a sustainable project over the long term. Examples are costs, processes, availability of workers, and social receptivity.

the end of FY 2028) has been set and the policy for efforts to achieve this has been newly added.

- The Technical Strategic Plan 2022 describes what needs to be done towards the start of discharging ALPS-treated water into the sea, as well as the strategies for issues to be addressed after the start of discharging. The Technical Strategic Plan 2023 summarizes the results of the efforts that have been made toward the discharge of ALPS-treated water (e.g. establishment of a cross-checking system, selection of 29 nuclides to be measured and evaluated) and describes the issues and policies to be addressed in the future.

(4) Fuel removal from spent fuel pool

- Regarding the removal of high-dose equipment, the Technical Strategic Plan 2022 described its significance and stated that the removal plan and process of high-dose equipment should be fully considered in the design of fuel handling facilities. Considering the progress of the plan, the issues and the need for action of site bunker capacity were added.
- For the dry storage of spent fuel on high ground, the Technical Strategic Plan 2022 stated that studies should be conducted with reference to overseas findings, including handling of fuel with damaged cladding tubes. The Technical Strategic Plan 2023 describes the issues and policies to be taken when studying the application of concrete casks (which have been stored overseas but not in Japan), which were newly announced in the Mid-and-Long-term Decommissioning Action Plan 2023.

Chapter 4 Analysis strategy for promoting decommissioning

- Previous Technical Strategic Plans have mainly stated the analysis of fuel debris. Given the fact that studies on analysis have progressed and analysis plans have been drawn up, the scope of analysis has been expanded to include other than fuel debris, and the issues and action policies are described.
- The descriptions of the studies of analysis plans and the development of analysis/evaluation methods are enhanced as new items, and the activity policies of the “Analysis Coordination Meeting” and “Analysis Support Team” are also stated as new efforts to secure human resources.

Chapter 5 Efforts to facilitate research and development

- Regard to the implementation structure for the Project of Decommissioning, Contaminated water and Treated water Management, the Technical Strategic Plan 2022 included points to be noted and necessary initiatives (RFI (Request for Information), project review) with a view to shifting from the International Research Institute for Nuclear Decommissioning (hereinafter referred to as “IRID”)-centered structure to a new structure. In the Technical

Strategic Plan 2023, it is stated that the new structure, based on the needs of TEPCO, has been shifted to a system in which research institutions, manufacturers and others are the main implementers.

- In order to continue and further strengthen the good practices of the functions performed by IRID, specific measures being undertaken by the NDF such as RFIs and specific details of project reviews are stated.

Chapter 6 Activities to support our technical strategy

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

- In the Technical Strategic Plan 2022, the key items to be strengthened by TEPCO were described: Safety and Operators' Perspectives, promulgation of "Safety First", and Owner's engineering capabilities (project management capability, engineering capability based on safety and operators' perspectives). The Technical Strategic Plan 2023 describes the need to expand "Investigation capability at the upstream side of the project" as a capability that owners should have, considering the progress of TEPCO's studies.
- For "coexistence of reconstruction and decommissioning", this section includes the consideration of integrating and reorganizing Fukushima Daini NPS and its head office functions into the Fukushima Daiichi Decontamination and Decommissioning Engineering Company, which is being promoted by TEPCO.

(2) Strengthening international cooperation

- In Subsection 6.2.2.1, "Integrating and giving back wisdom and knowledge from around the world", the previous descriptions are summarized in 3 strategies (Specifically, (1) strengthen cooperation with counterparts, (2) expand the scope of information gathering, and (3) return results).
- In Subsection 6.2.2.2, "Maintaining and developing the international community's understanding, interest and cooperation in decommissioning", 2 strategies ((1) approach to experts; (2) approach to the general public) are described to gain international understanding based on the experience obtained from the response to ALPS-treated water.

(3) Local community engagement

- In relation to the creation of regional industrial and economic infrastructure, the "Medium-to-Long-Term Outlook in the Decommissioning" has been prepared since September 2020 with the aim of increasing the participation of local companies. From FY2022 the candidate work orders involving local companies have been clearly indicated in the "Medium- to-Long-Term Outlook in the Decommissioning". This section states that it is necessary to continue and expand measures to facilitate the participation of local companies.

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

2.1 Basic policy for the decommissioning of the Fukushima Daiichi NPS

<Basic policy for the decommissioning of the Fukushima Daiichi NPS>

Continuously and quickly reduce the risks arising from the radioactive materials caused by the accident that do not exist in normal nuclear power plants

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

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

Accordingly, the basic policy for the decommissioning of the Fukushima Daiichi NPS is “to continuously and quickly reduce the risks arising from the radioactive materials caused by the accident that do not exist in normal nuclear power plants” by taking measures specifically designed to reduce risks. Generally, the following measures are effective for reducing risks at facilities where an accident has occurred; ① Improving the containment functions of the damaged facilities; ② Changing the properties and form of the contained radioactive materials to be more stable; and ③ Strengthening monitoring and control over the equipment to better prevent or mitigate the occurrence or propagation of abnormalities. In order to achieve these measures in an integrated way, in addition, ④ Collecting radioactive materials from the damaged facilities or insufficient containment conditions and placing them in more robust storage is effective.

Since the accident, these diverse measures for risk reduction have been taken with careful preparations aimed at preventing accidents and radioactive exposure of workers (Attachment 3).

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

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

- Aim to complete fuel removal from the spent fuel pools of Units 1 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 fuel debris retrieval in scale, which will be full-scale decommissioning work, will be promoted. Even though more than about twelve 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 fuel debris retrieval in scale, it is necessary to improve the ability to observe conditions inside the PCVs where changes in these risks are likely to occur. Therefore, despite the high degree of difficulty, consideration should be given to expanding the type and number of monitoring targets, while taking into account the current purpose of the monitoring parameters and the number of monitoring devices in the PCVs and difficulties in on-site operation. For example, the dust concentration in the PCVs is expected to increase with fuel debris retrieval work in the case of further expansion of fuel debris retrieval in scale. If the dust concentration in the PCVs can be measured in a phase of preceding trial retrieval and gradual expansion of fuel debris retrieval, and the correlation between the location and scale of the retrieval operations and the dust concentration can be determined, it is possible to reduce the uncertainty associated with retrieval operations and improve work efficiency while maintaining an appropriate safety margin.

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

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

2.1.1.1 Risk reduction

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

・ Gaseous and dusty radioactive materials

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

・ Liquid radioactive materials

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

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

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

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

At the PCV bottom, 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 4). 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.

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

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

- Ensure that trial retrieval will be carried out while obtaining knowledge so that it can be utilized in subsequent gradual expansion of fuel debris retrieval and further expansion of fuel debris retrieval in scale.
- Proceed with designing, manufacturing, and installing systems related to retrieval methods.
- 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 that does not hinder the above operations.

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

2.2 Concept of reducing risks caused by radioactive materials

2.2.3 Quantitative identification of risks

The term “risk” has various meanings depending on the field or situation in which it is used. In general, in the context of appropriate risk management, “risk” can be understood as an expectation value of the negative impact of an event. In other words, the magnitude of a risk (risk level) posed by a subject (risk source) can be expressed as the product of the level of impact and the 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 5). The name of this “Requiring Level for Safety Management” was “Safety Management” until the Technical Strategic Plan 2022, and although the name has been revised in the Technical Strategic Plan 2023, the definition and other details remain unchanged. 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.

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 2023. 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 2023. In particular, the most notable changes since the end of March 2022 include the transfer of Hazard Potential level of “ALPS slurry (to be transferred to other HICs)” to 'ALPS slurry' resulting from the progress of the transfer of ALPS slurry stored in HICs that exceeded the standard for integrated absorbed dose, and a review of the Requiring Level for Safety Management for “contaminated structures in buildings, etc.” considering the retention of hydrogen that entered into the system connected to the PCV at the accident. Regarding the latter, as a result of piping integrity assessment under the assumption that a hydrogen explosion should occur, Requiring Level for Safety Management were increased based on the fact that the S/C of Unit 3 and the high-pressure coolant injection system (hereinafter referred to as 'HPCI') exceeded the elastic deformation range. However, the evaluation is based on conditions that do not take into account the attenuation of the pressure wave from the hydrogen explosion caused by the contained water in S/C. It is unlikely that the S/C will immediately leak water from these systems, even if the elastic deformation range is exceeded, it must undergo plastic deformation to rupture[3]. Because the PCV internal investigation of Unit 1 revealed the partial loss of concrete in pedestals, TEPCO will evaluate the effects on the Requiring Level for Safety Management of fuel debris and contaminated structures in buildings in the future, referring to the ongoing seismic evaluation of pedestals.

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[4]. In considering the station-wide risk reduction strategy for the Fukushima Daiichi NPS, the above-mentioned SED is a quantitative indicator of risks attributable to radioactive materials at a certain time, and is an effective method for prioritizing risk sources for risk reduction. In considering risk reduction strategies for the Fukushima Daiichi NPP as a whole, the SED described above quantifies the risk caused by radioactive materials over a certain time cross-section and is an effective method

[3] Tokyo Electric Power Company Holdings Inc., “Response based on the hydrogen retention event at the Unit 1 RCW (Evaluation of the impact of hydrogen retention event)”, The 10th Technical meeting on the review of the implementation plan for specific nuclear facilities, Material 2-1, June 5, 20231

[4] 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..

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 the facilities containing risk sources that were not expressly considered before, investigations and examinations are being conducted in consideration of external events such as earthquakes, tsunamis, and rainwater. Once information on the risk sources has been identified through investigation and review, those that have been determined to be prioritized and addressed in the same manner as major risk sources will be evaluated for risk levels in the future. (Attachment 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[5] 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[6]. 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[7], with its epicenter off the coast of Fukushima Prefecture, lowering of the PCV water levels at Units 1 and 3, and sliding of tanks on site exceeding the sliding amount evaluated at the time of tank installation were observed. At the time of the earthquake on March 16, 2022, with its epicenter off the coast of Fukushima Prefecture, a lowering of the PCV water levels at Units 1 and 3 was observed and the over-turning of containers in the temporary storage area was confirmed[8]. 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

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

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

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

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

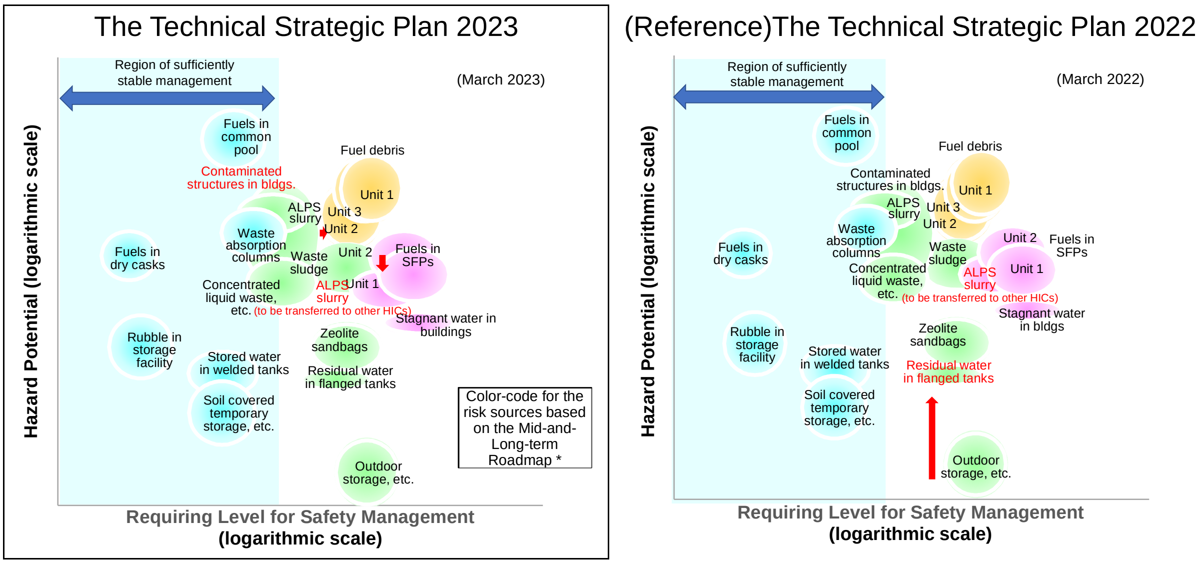
advance the consequences of and the necessity of countermeasures against beyond-design-basis events in existing/new systems.

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

Table 1 Major risk sources at the Fukushima Daiichi NPS

Fuel debris		Fuel debris in RPVs/PCVs in Units 1 to 3
Spent fuel	Fuel in SFPs	Fuel assemblies stored in the spent fuel pools (SFPs) in Units 1 and 2
	Fuel in the Common Spent Fuel Storage Pool	Fuel assemblies stored in the Common Spent Fuel Storage Pool
	Fuel in dry casks	Fuel assemblies stored in dry casks
Contaminated water, etc.	Stagnant water in buildings	Contaminated water accumulated in the reactor buildings of Units 1 to 3, process main building and high-temperature incinerator building, and sludge containing α-nuclides at the bottom of buildings of Units 1 to 3
	Zeolite sandbags	Zeolite, etc. in sandbags placed on the basement floors of the process main building and high-temperature incinerator building
	Stored water in welded tanks	Strontium-treated water and ALPS-treated water, etc. 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

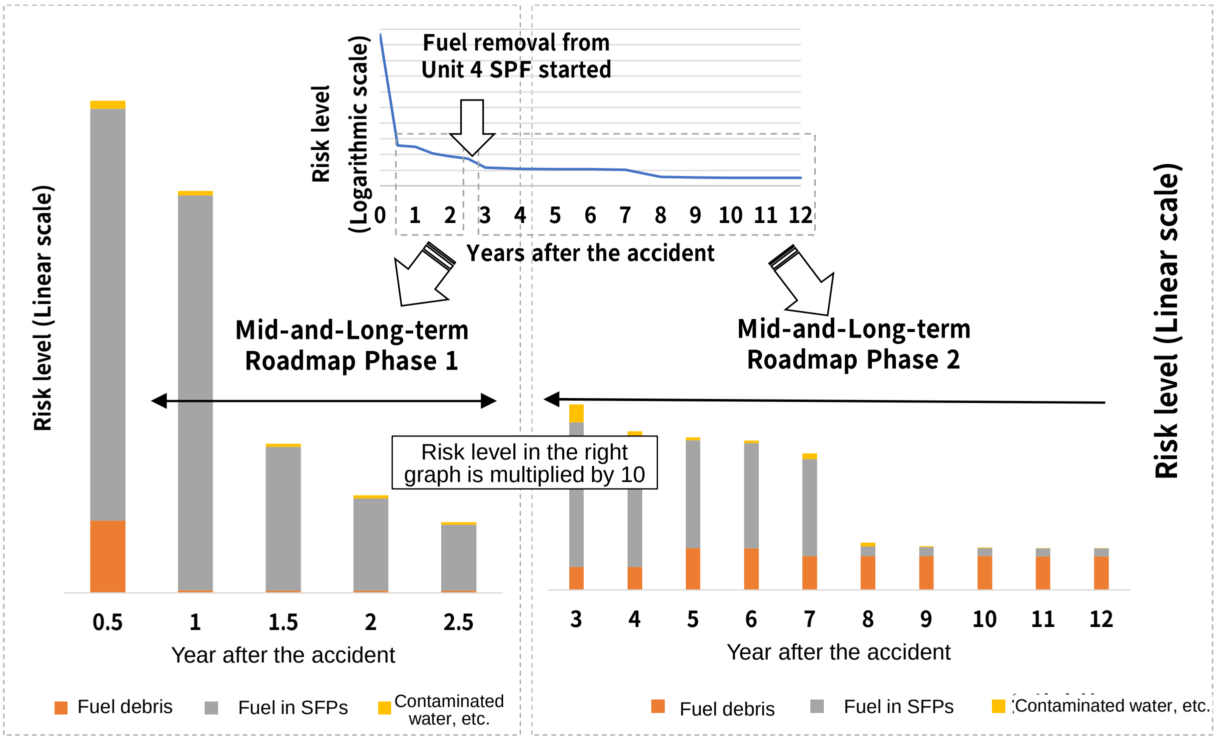
Contaminated structures, etc., in the buildings	Structures, pipes, components, and other items (shield plugs, standby gas treatment system pipes, etc.) inside the reactor buildings and PCVs/RPVs that are contaminated with radioactive materials dispersed due to the accident; and activated materials generated 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 2022 (as of March 2022), the origin of the arrow indicates the location reported in the Technical Strategic Plan 2022. 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. For the “contaminated structure in buildings”, Requiring Level for Safety Management increased, reflecting the retaining hydrogen that flowed into the system connected to the PCV at the accident.

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 margin before the risk becomes apparent is increased.

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 allowable 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 (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 the 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 2022. 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 2022. 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[9]. 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 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.

[9] 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.

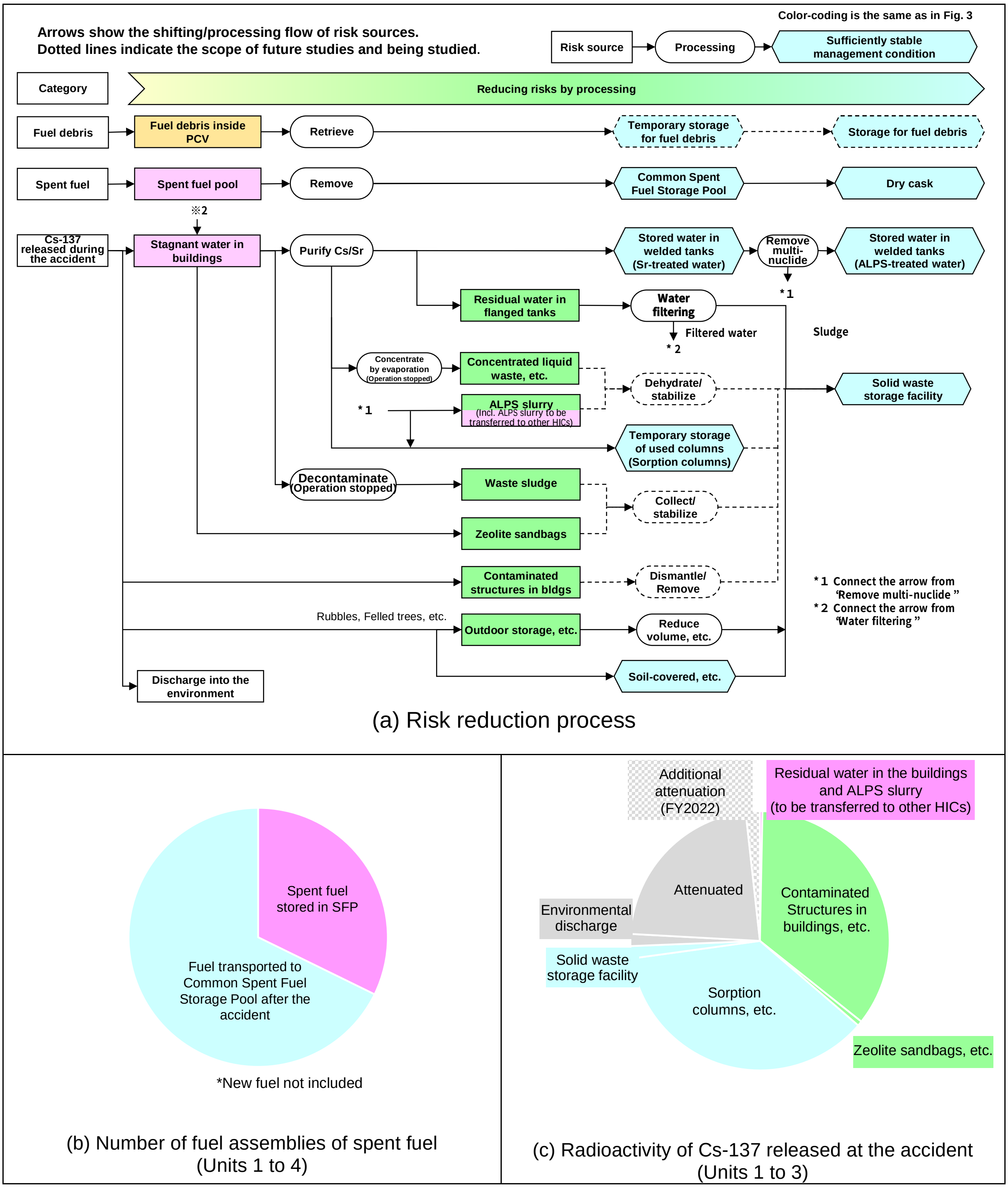


Fig. 6 Risk reduction process for major risk sources and the progress (as of March 2023) (1/2)

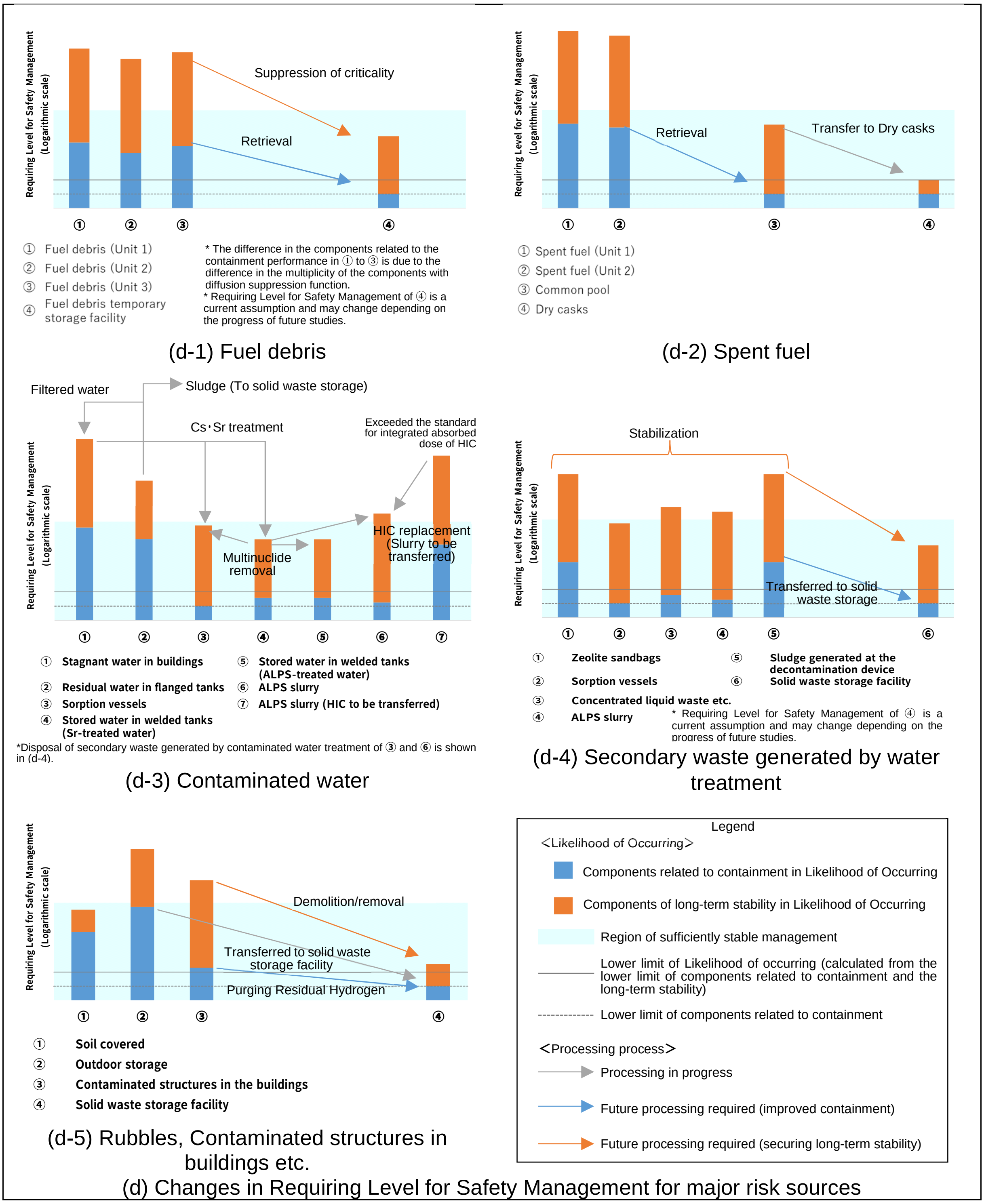


Fig. 6 Risk reduction process for major risk sources and the progress (as of March 2023) (2/2)

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

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”, a large amount of atypical, unsealed radioactive material will be handled in an incomplete containment state in a situation where there are large uncertainties in the radioactive material and containment barrier conditions, and where on-site access and instrumentation to reduce these uncertainties are also restricted. Therefore, it is necessary to assume a wide range of possibilities (cases) and to check that it is possible to ensure safety for them as the starting point for all considerations. At the same time, with regard to “safe”, it is important not to prolong the work period considering the risks over the entire work period, and it is necessary to avoid excessive safety measures out of proportion to the risks and to take sensible safety measures (ALARP[10]). It is important that this perspective on “safety” (the safety perspective) is reflected in the consideration of decommissioning 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 (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[11] engineering” 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

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

[11] 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.

process. Lastly, the section refers to the importance of ALARP judgment. Moreover, the relationship between these points and aforementioned Five guiding principles of risk reduction will be discussed.

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 the safety perspective 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, "Conducting extensive assessments on safety matters associated with methods and devices when reviewing any project and, upon verifying that necessary and sufficient levels of safety have been ensured, taking into account factors such as technical reliability, reasonableness, speed, and actual site applicability in a comprehensive manner to decide which methods or devices to use, and which safety measures to apply consequently".

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

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 with a certain operational scale, while ensuring safety in criticality. To this end, fuel debris retrieval operators should be aware of the signs of criticality that change with each work step as significant fluctuations of measured value. Even if cutting and other work of sufficient magnitude to cause noise, identifiable and significant fluctuations in measured values are performed with relatively small subcriticality, it is possible to take action by maintaining subcriticality or identifying signs of criticality through operations based on design and actual measurement values. In other words, as described above, in environments with significant uncertainties, the development of detection technologies to enable operational responses will become even more important.

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

  To cope with significant uncertainties, 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[12]。

2.3.1.4 ALARP judgment based on safety

For safety, there is a minimum level of safety standards that must be met before the relevant retrieval method/equipment can be used. After satisfying this minimum level, what level of safety achieved should be optimized between the safety level to be achieved and resource required (project cost, duration workers' radiation dose, etc.) to determine the retrieval method/equipment to be adopted. 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 (operators' perspective)", and "examining and discussing at projects (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 ALARP judgement made by the project based on the safety perspective will be linked to the 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. The concept is to ensure a minimum level of safety and to consider project perspectives such as "Proven", "Efficient", and "timely" as factors in ALARP decisions.

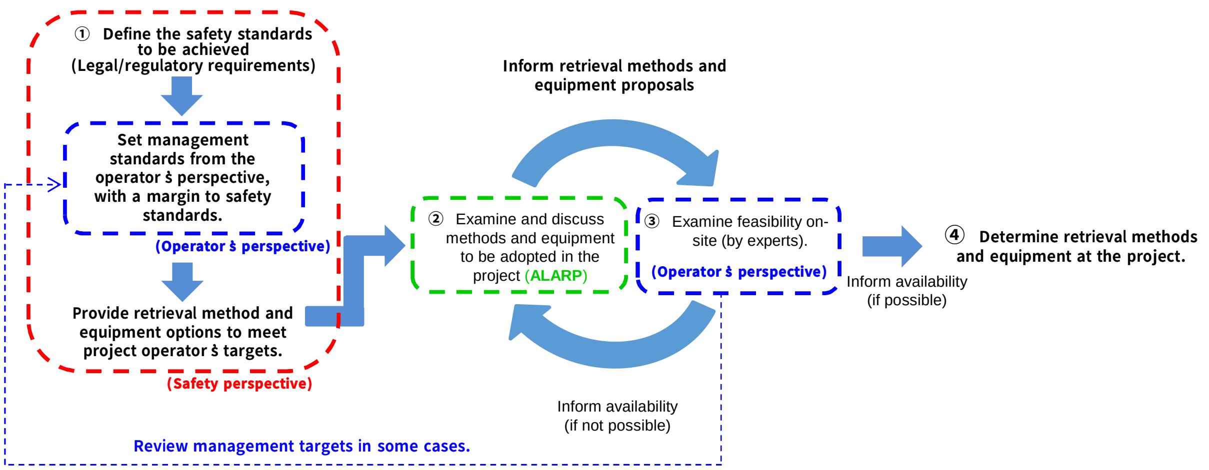


Fig. 7 ALARP centered on safety (conceptual diagram)

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

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 with existing knowledge, assumptions of an extremely large safety margin and wide range of technical options will be needed. Thus, extension of the work period or the risk of rework will be unavoidable. As a result, the feasibility or predictability of the entire project may be reduced, leading to a delay in the entire decommissioning, a rise in the decommissioning cost, or increased radiation exposure of workers.

However, considering the environment with an already high radiation level, further deterioration of containment barriers, and the possibility of future major natural events (such as earthquakes or tsunamis), it is necessary to immediately improve the state of such risks and reduce uncertainties. Therefore, a “sequential type approach” is important where the whole operation is divided into several stages, “operation at first stage” is implemented for which practical safety can be ensured, and then the information obtained there is utilized in the next stage. With this approach[13], 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[14]. The information obtained at each stage of operation and testing is utilized in the design of subsequent stages. This approach reduces uncertainties in the operations in subsequent stage as well as improve the reliability of safety assurance and rationalize design.

TEPCO should actively introduce an approach like this into actual engineering and project management[15].

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 these knowledge, TEPCO has decided to reduce the water injection amount for Unit 2 while maintaining continuous water injection.

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.

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

[14] 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.

[15] 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

- 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.
- 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 limit the increase in the risk level during decommissioning as much as practicably possible by thorough preparations as achieved through application of the concept of ALARP.

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, cost, and worker's exposure needed for relevant preparations and work, while giving priority to limiting the risks involved in the decommissioning work (Attachment 7).

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) The trial retrieval process in Unit 2 is under review to improve work safety and reliability during retrieval, and trial retrieval will begin in late FY 2023. Continue the series of operations, including the gradual expansion of fuel debris retrieval, to acquire the knowledge and experience necessary for further expansion of fuel debris retrieval in scale (for the fuel debris targeted for retrieval, see Attachment 8).

(3) With regard to the further expansion of fuel debris retrieval in scale, consideration will be given to the methods including those for containing, transferring, and storing of fuel debris, 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

PCV internal investigations were performed from February 2022 to March 2023 using a submersible boat-type access investigation vehicle (hereinafter referred to as “submersible ROV”), which can be equipped with various measurement sensors. The submersible ROV is inserted into the PCV through the PCV penetrating part X-2 (hereinafter referred to as “penetration X-2”) to access the basement floor outside the pedestal (Fig. 9). Detailed visual observation, measurement of deposit thickness, detection and evaluation of deposit debris (neutron flux level, etc.), and 3D mapping measurements of deposits were conducted outside the pedestal from February 2022. Deposit sampling was also successful, and the plan is to analyze it in the future. In March 2023, the investigation by inserting a submersible ROV into the pedestal succeeded for the first time. As a result, much information was obtained, including the fact that there is missing concrete at the lower part of the pedestal, the condition of the deposits and fallen objects at the inner bottom of the pedestal, and the condition of the upper structures, such as the control rod drive (hereinafter referred to as “CRD”) housings (Fig.10). The main findings are as follows.

(a) Outside the pedestal, deposits are distributed over a wide area from the vicinity of the pedestal opening (worker access opening). They are relatively high near the pedestal opening and become gradually lower as it approaches penetration X-2 through which the submersible ROV is inserted.

(b) As for the deposits outside the pedestal, powdery and sludgy deposits are thin in general, shelf-like deposits exist near the pedestal opening, and the inside is hollow.

(c) Thermal neutron flux and Eu-154 were detected at all survey points outside the pedestal, and no correlation was observed between the distance from the pedestal opening and the height of the deposit for these values. Therefore, it is presumed that materials released from fuel debris (derived from fuel debris) exist extensively in the survey areas.

(d) There are deposits of nearly uniform height and some upper structures, such as CRD housings, at the inner bottom of the pedestal.

(e) A lump that appears to be solidified molten materials adheres to the upper CRD housings.

(f) The vicinity of the worker access opening and almost the entire inner wall of the pedestal have lost their lower concrete.

Following the discovery of the partial loss of concrete in the pedestal, based on the discussion during the 12th NRA meeting on May 24, 2023, the NRA directed TEPCO, (1) with the assumption that the pedestal cannot be expected to provide support, to evaluate the impact of dust scattered at the site boundary, including the case where the RPV sinks and the PCV has an opening equivalent to the main steam pipe; (2) to consider possible countermeasures regardless of the evaluation results; and (3) to evaluate the structural impact on the RPV and the PCV in the event of subsidence of the RPV due to loss of support functions[16]. In response to this directives in (1) and (2), TEPCO assumes that it is unlikely to cause large-scale damage based on the results of the strength evaluation of the pedestal, at the same time, TEPCO is evaluating the impact of external exposure, supposing the pedestal's RPV support function deteriorates to form a large opening in the PCV. As a result of evaluating conditions inside the PCV by setting conservative conditions, TEPCO considers that there is no significant risk of radiation exposure[17]. In addition, although it is not considered to pose a significant risk of radiation exposure, further safety measures such as mobile response and enhancement of PCV containment function are being considered[17]. These evaluations by TEPCO were reported by the NRA at the NRA Committee and approved on the spot[18]. In response to directive (3), TEPCO conducted a strength evaluation assuming Ss900 of the earthquake ground motion, and evaluated that the inner skirt of the RPV pedestal foundation and the stabilizer/the bulkhead of the pedestal superstructure could not be damaged on a large scale because they could support seismic loads[19]. In response to this evaluation, the NRA

[16] May 24, 2023, meeting minutes, interview on future actions based on the status of the Fukushima Daiichi Nuclear Power Station Unit 1 pedestal

[17] The 108th meeting of the Study Group on Monitoring and Assessment of Specified Nuclear Facilities, Material 2-1, "Status of response to the directives on future responses based on the situation of the Unit 1 pedestal" (TEPCO)

[18] The 24th Nuclear Regulation Authority Committee in FY 2023 "Material 2: Response to the situation of Unit 1 pedestal at the TEPCO's Fukushima Daiichi Nuclear Power Station, (NRA).

[19] The 109th meeting of the Study Group on Monitoring and Assessment of Specified Nuclear Facilities, Material 2-1, "Status of response to the directives on future responses based on the situation of the Unit 1 pedestal" (TEPCO)

recognized that there are limitations to conducting evaluations that reflect the actual situation after the accident because the premises and input values for the evaluation must be set based on assumptions, and concluded that it is difficult to confirm the validity of the evaluation. However, the NRA expressed the views that the structural integrity of the reactor building as a whole can be sufficiently maintained even if extreme events are assumed[20]. With regard to the environmental impact, the NRA also offered the view that it has confirmed that the aforementioned TEPCO's evaluation remains conservative and maximized, and this NRA's view was also accepted at the NRA Committee[20].

The retention of hydrogen which flowed into the inside at the accident was observed during the drainage of high-radiation-dose equipment (Reactor Building Cooling Water System (hereinafter referred to as "RCW")) to improve the on-site environment (reduce radiation dose) in the reactor building. Therefore, operations are carried out while carefully reducing and monitoring the hydrogen concentration.

b. Unit 2

After completing the manufacture and confirmation tests of the arm-type access equipment in the UK in June 2021 (hereinafter referred to as "robot arm") for use in trial retrieval, the equipment was brought to Japan and has been undergoing performance confirmation tests, verification tests in simulated environment of actual machine (hereinafter referred to as "mock-up tests"), and training in the following facilities.

- Domestic factory from July 2021 (Kobe)
- Naraha Center for Remote Control Technology Development (NARREC), the JAEA from February 2022

Modification and verification of the control software for the robot arm and improvement of some devices, which are newly required as a result of these tests, are implemented, and verification of the required functions of the robot arm alone is in progress. In addition, as on-site preparatory work, installation of the isolation chamber for the hatch opening of the existing PCV penetrating part X-6 (hereinafter referred to as "penetration X -6") began in November 2021. During the installation, countermeasures were implemented against damage to the rubber box of the isolation chamber (damage due to contact during installation work of isolation chamber), bending of the guide roller (impact of the earthquake occurred on March 16, 2023), misalignment of the shielding door (impact of the earthquake occurred on March 16, 2023), and damage to the pressing mechanism parts (insufficient margin of design intensity), then, the installation of isolation chamber was completed in April 2023. Currently, removing the flange bolt and opening the hatch of the penetration X-6, and removing the deposits inside the penetration are in progress, these works should be implemented safely and carefully.

[20] The 37th Nuclear Regulation Authority Committee in FY 2023 "Material 2: Response to the situation of Unit 1 pedestal at the TEPCO's Fukushima Daiichi Nuclear Power Station (second meeting)", (NRA).

A plan for the gradual expansion of fuel debris retrieval is also underway, and the retrieval device will be improved by increasing the weight capacity and enhancing accessibility 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[21] 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. Designing of the retrieval device, the first storage facility is in progress (Fig. 12).

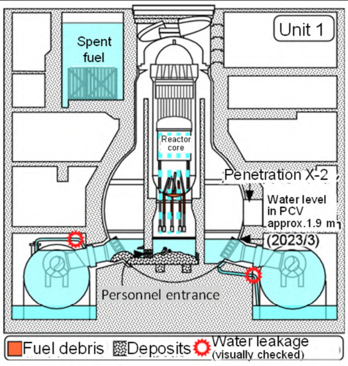
c. Unit 3

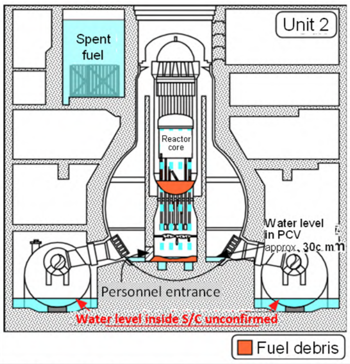
For the further expansion of fuel debris retrieval in scale, TEPCO has performed the conceptual study on retrieval methods, many challenging issues have been identified with respect to methods proposed for discussion. The actual site applicability and technical feasibility associated with measures for mitigating these issues are being verified. In FY 2023, evaluation including business continuity[2] is underway, with continued issue studies of each method. In addition, since February 2023, the Sub-Committee for the Evaluation of Fuel Debris Retrieval Methods has been established under the Decommissioning Strategy Committee, a committee of NDF, technical feasibility and business continuity in each of fuel debris retrieval method are being studied and evaluated technically and intensively. (For details, refer to 3.1.3.4)

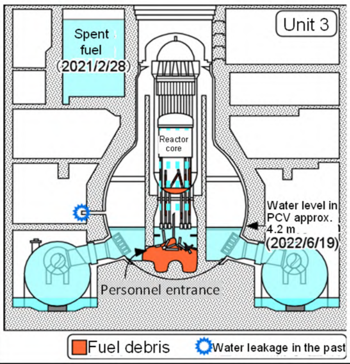
Moreover, due to the high-water level in the PCV, the plan is to lower the PCV water level, taking into account the conducting of the PCV internal investigation and the improved seismic resistance of the S/C. In the reactor water injection shutdown tests in June 2022, the PCV water level became almost stable when water injection was resumed and adjusted after it was determined that the PCV water level fell below the lower end of the new PCV thermometer/water level gauge. Therefore, it is estimated that the leakage point was located below the lower end of the thermometer/water level gauge[22]. Installing a water gauge at a lower position than the current one is under discussion to further reduce the PCV water level in the future. In parallel to this, the operation of the PCV water intake facility began in October 2022, which takes water from the S/C bottom for replacement with the reactor injection water, and efforts are being made to improve the S/C water quality to reduce the PCV water level.

[21] As the study progressed, the name was changed because TEPCO decided to store retrieved fuel debris at storage facilities instead of temporarily storing it in temporary storage facilities.

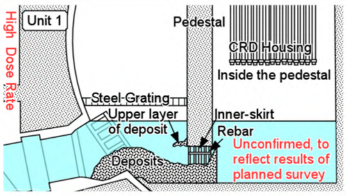
[22] Tokyo Electric Power Company Holdings Inc., Fukushima Daiichi Decontamination and Decommissioning Engineering Company, July 19, 2022, “Completion of Fukushima Daiichi NPS Unit 3 reactor water injection shutdown tests”



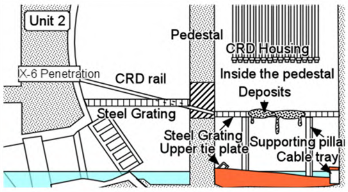


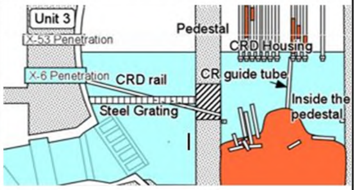


	Unit 1	Unit 2	Unit 3
Core region	・Little fuel debris remains.	・Little fuel debris remains. (Partially intact fuel might exist in the peripheral region)	・Little fuel debris remains.
At the RPV lower head	・A small amount of fuel debris is present. ・A small amount of fuel debris is present inside and on 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.
On-site radiation dose *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 inside surface of the pedestal.





	Unit 1	Unit 2	Unit 3
Information on the access route to fuel debris*2	・The D/W bottom outside the pedestal is accessible from the upper side of the steel grating. ・Condition around the CRD rail connecting into the pedestal from the penetration X-6 has not been observed.	・No large obstacles have been observed on the CRD rail and around the pedestal entrance. ・The bottom inside the pedestal is accessible through the pedestal entrance.	・The bottom inside the pedestal is accessible through the pedestal entrance.
Information on the condition of structures around the access route	・At personal entrance, the inner rebar and inner-skirt are exposed, and the PCW system piping is missing. ・A deposit approx. 1.0 m thick has been observed around the personal entrance of outside the pedestal (condition, e.g. cavities, of the deposit inside could not be confirmed) ・No significant damage has been observed on the wall surface outside the pedestal on the steel grating upper side. ・Neutron and Eu-154 gamma rays were detected from 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 penetration X-6, 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 penetration X-6 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 penetration X-6.

(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

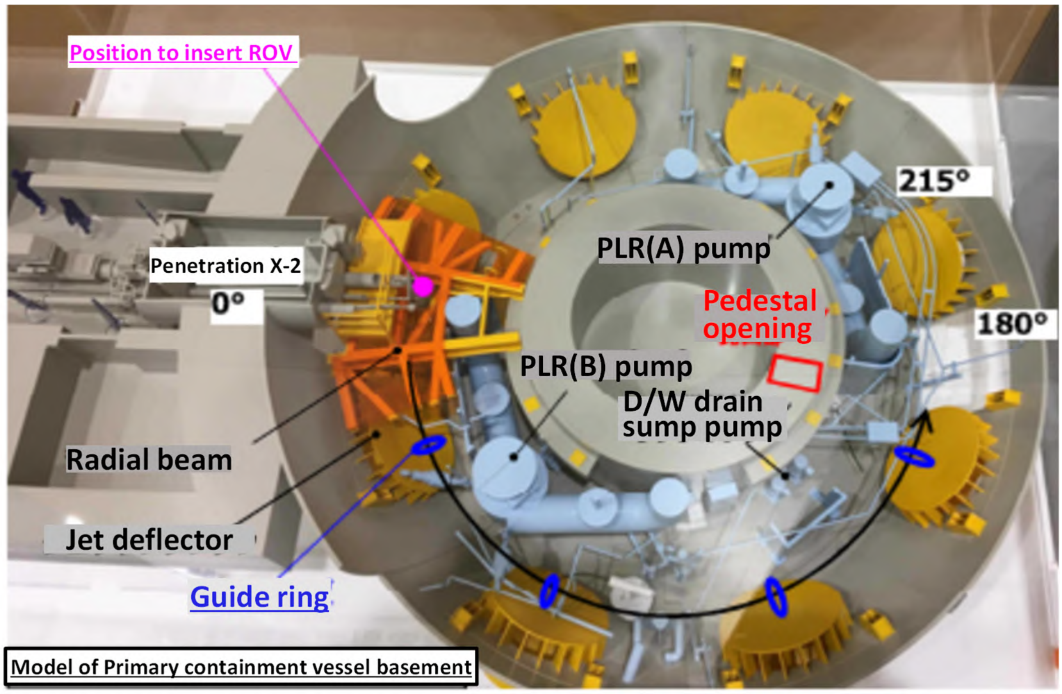
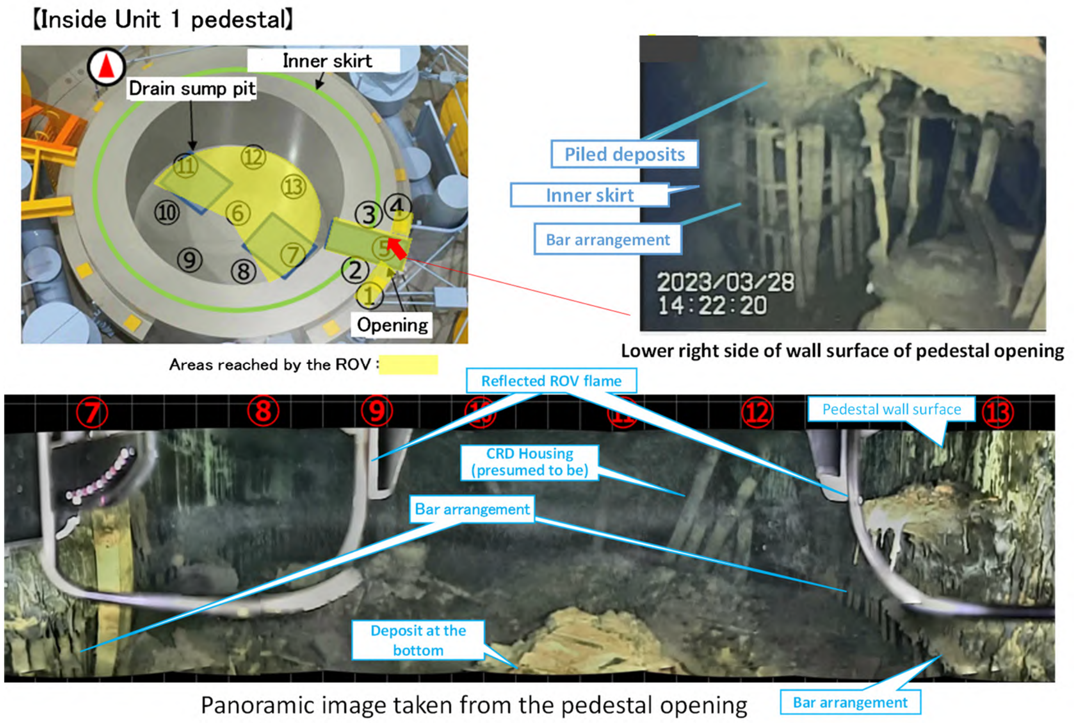


Fig. 9 Scope of internal investigation for Unit 1 PCV (Outside the pedestal on the basement floor of the PCV from 0 to 215 degrees, pedestal opening and inside the pedestal)[23]

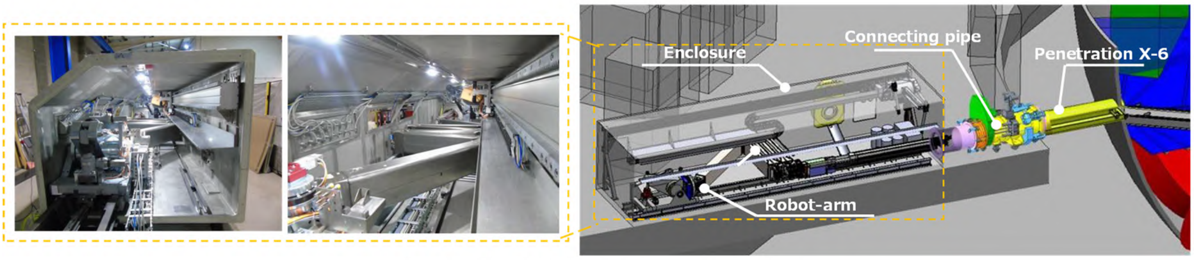


"Progress of internal investigation for Unit 1 PCV (second half)", Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water, April 27, 2023, IRID/Tokyo Electric Power Company Holdings Inc.

Fig. 10 Results of the internal investigation for Unit 1 PCV[24]

[23] "Progress of internal investigation for Unit 1 PCV", Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water, February 24, 2022, IRID/Tokyo Electric Power Company Holdings Inc.

[24] "Progress of internal investigation for Unit 1 PCV (second half)", Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water, April 27, 2023, IRID/Tokyo Electric Power Company Holdings Inc.



Photo：Robot arm and Enclosure

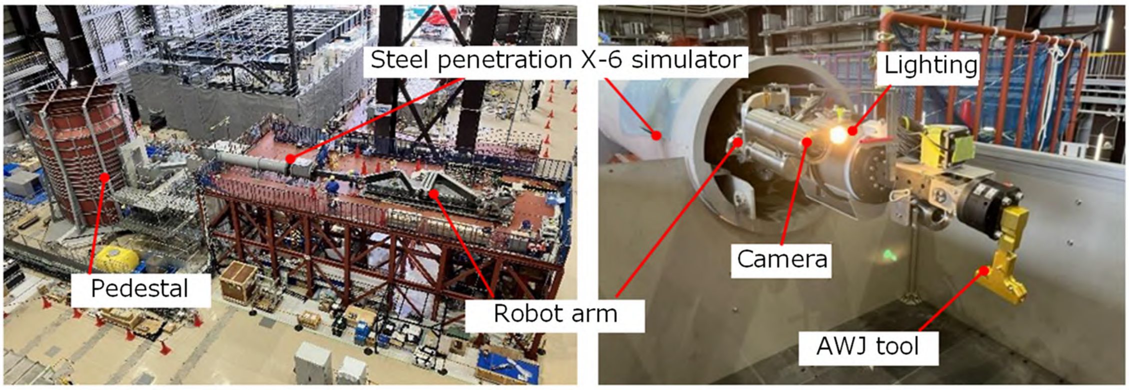
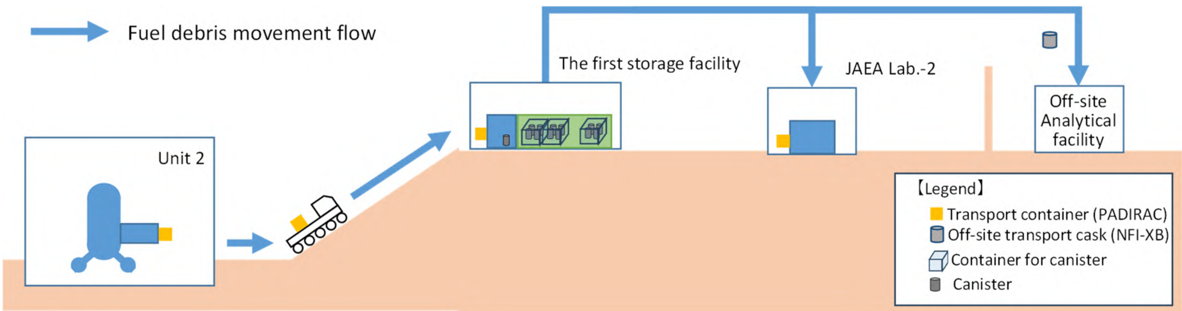


Photo: Status of performance verification test of the robot arm passing through the penetration X-6
(Testing facility in Naraha Center for Remote Technology Development (JAEA))

(Prepared by NDF based on TEPCO and IRID materials)

Fig. 11 Image of fuel debris retrieval system[25]
(Trial retrieval and gradual expansion of fuel debris retrieval)



(TEPCO material edited by NDF)

Fig. 12 Conceptual drawing from retrieval to storage of fuel debris
(Gradual expansion of fuel debris retrieval)

3.1.3 Key issues and technical strategies to realize them

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 fuel debris retrieval in scale.

[25] "Preparation of PCV Internal Investigation and trial retrieval operation for Unit 2", Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water, June 29, 2023, IRID/Tokyo Electric Power Company Holdings Inc.

TEPCO established Toso Mirai Technology Company (Decom. Tech) in October 2022 to engage in the basic design and R&D of systems and installations for the further expansion of fuel debris retrieval in 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 fuel debris retrieval in scale
- 3.1.3.5: Status of accident analysis activities
- 3.1.3.6: R&D status

3.1.3.1 Fuel debris retrieval strategies in each Unit

(1) A common strategy for each unit

- Since each unit has many areas where direct visual information is unavailable, the issue is conducting further internal investigations to gain diverse information. Assuming further expansion of fuel debris retrieval in scale, the investigation will proceed while developing and updating the internal investigation plan in the future to clarify which areas should be prioritized. Technology development for this purpose is underway, so the direction of the fuel debris retrieval strategy should be verified based on the acquired information to avoid regressing in engineering 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).

- With a view to business continuity, 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
  - ✓ 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 fuel debris retrieval in 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, 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 part of the upper structures, such as CRD housings, at the inner bottom of the pedestal.
  - ✓ The concrete near the pedestal opening (worker access opening) and the inside wall of the pedestal is missing at the entire circumference.
- 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

- Preparations for trial retrieval are 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 fuel debris retrieval in 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 pool has been completed and there is little interference with other operations, and working environment of the reactor building will be improved faster than Unit 1, retrieval methods are being examined for further expansion of fuel debris retrieval in scale ahead of other Units. The actual site applicability and technical feasibility should be studied for the issues and risks associated with the 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.

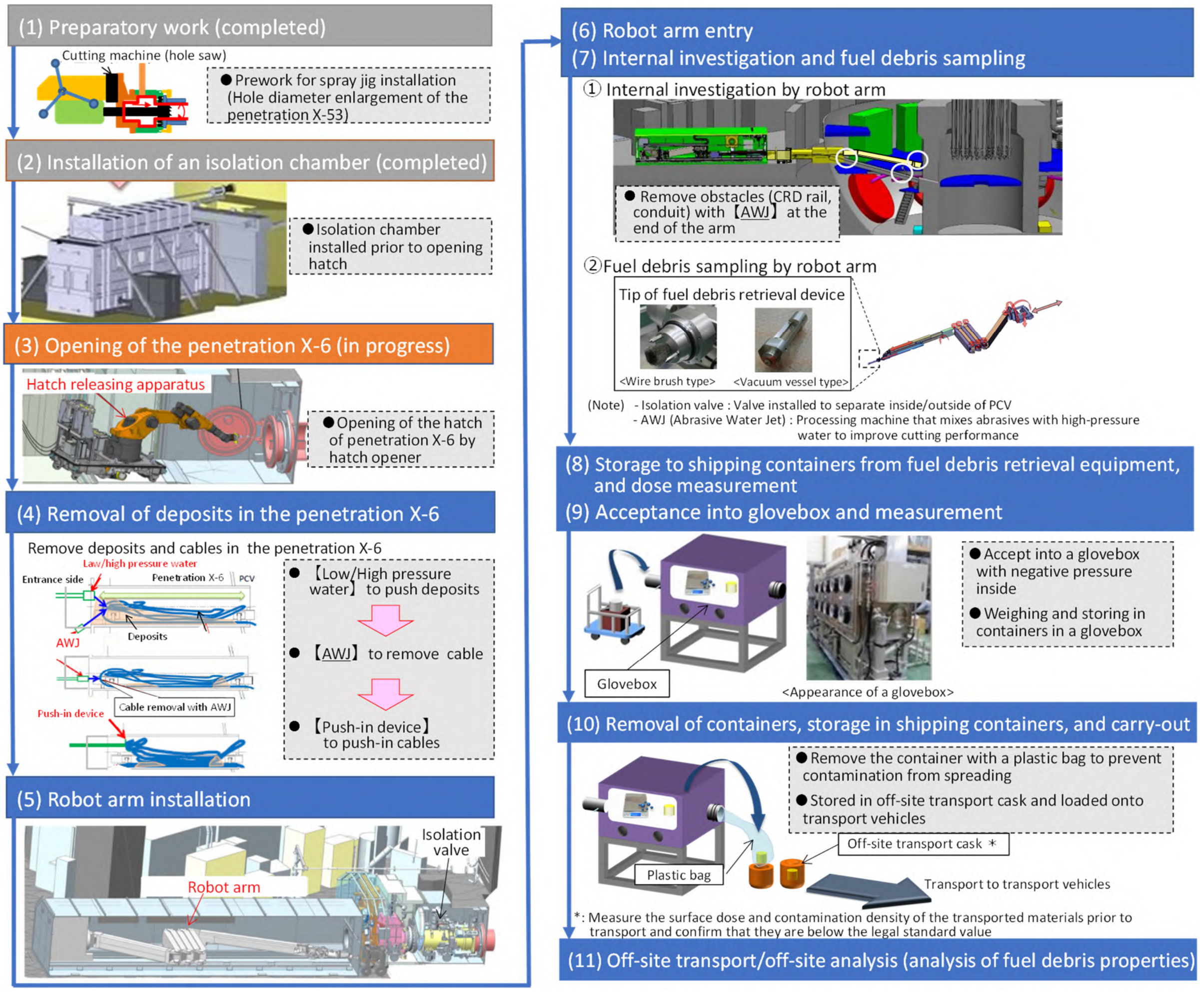
3.1.3.2 Trial retrieval (Internal investigation and fuel debris sampling)

The trial retrieval, which is under preparation at Unit 2, is intended to access the inside of the pedestal from outside the PCV for further internal investigations and collect small amount of fuel debris.

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 retrieval in 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. 13). 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.



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

Since February 2022, mock-up testing of the newly developed robot arm have 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 are newly required as a result of these tests, are almost completed, and verification of whether the requirements of the robot arm alone are satisfied is in progress. In the future, there are plans for mock-up tests and training on the entire system combining the robot arm and the enclosure.

The issues for on-site applications with uncertainty 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, and the works of removing the flange bolt and opening the hatch of the penetration X-6, and removing deposits inside the penetration are underway. After that, the plan is to continue the installation of the penetration X-6 connection structures and enclosure (with the built-in robot arm, etc.) in order to establish an access route.

During the installation of the isolation chamber, it took time to take countermeasures against damage to the rubber box of the isolation chamber (damage due to contact during installation work of isolation chamber), bending of the guide roller (impact of the earthquake occurred on March 16, 2023), misalignment of the shielding door (impact of the earthquake occurred on March 16, 2023), and damage to the pressing mechanism parts (insufficient margin of design intensity). In particular, it is regrettable that the design did not adequately consider 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 it. It is important to be prepared in advance in order to flexibly respond to such events that differ from the prior assumptions.

Furthermore, given the adhering condition of the bolts, difficulty in deposits removal may be also a concern inside the penetration X-6, so it is necessary to study in advance a method that enables fuel debris retrieval even if the deposits inside the penetration cannot be completely removed. TEPCO is also considering the use of a telescopic device that has been used in past investigations and confirmed to be accessible to the bottom of the pedestal as a method to complement the internal investigation and trial retrieval by the robot arm (Fig. 14).

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 this event will be a challenge. 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 fuel debris retrieval in scale.

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

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

  In light of a dust dispersion event caused by an abrasive water jet (hereinafter referred to as "AWJ") to construct access routes for PCV internal investigation in Unit 1, measures such as removal of deposits by low-pressure water cleaning, and dispersion control by spray curtains have been prepared to prevent dust dispersion due to removal of deposits inside the penetration X-6. It is confirmed that due consideration has been given to safety measures in the operation procedures, such as monitoring dust concentration and gradually expanding operations. While placing the highest priority on ensuring safety, the issue is to set an appropriate operational value for dust concentration control that will not significantly extend the process due to operation constraints.

- Considerations in project management

  The project should proceed while paying attention to the process 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

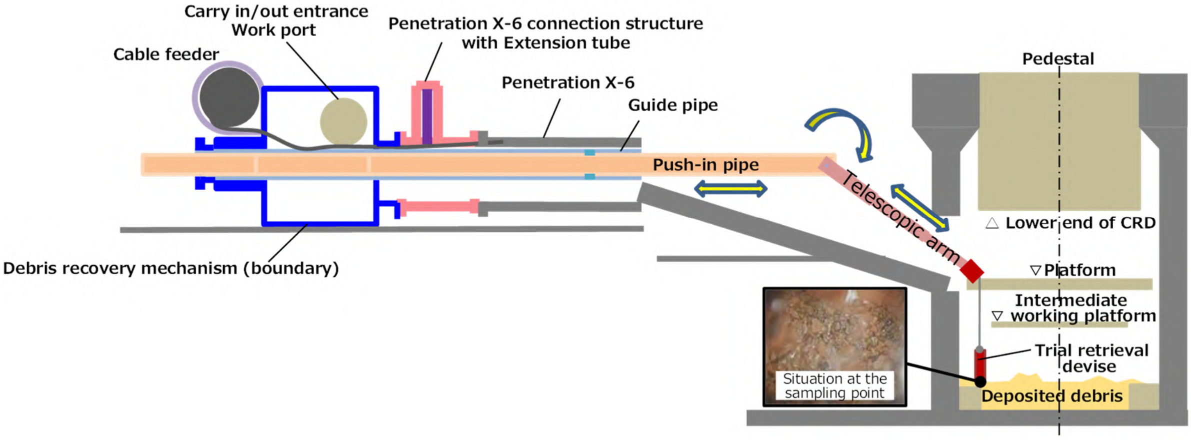
  In the PCV internal investigation using a robot arm, following will be ascertained; the state of existing structures, and the distribution of deposits inside the pedestal (3D data), the distribution of gamma rays and neutron counts at the bottom and on the platform. However, since more structures and 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 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.

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



(Source: TEPCO)

Fig. 14 Conceptual drawing of telescopic device to complement robot arm

3.1.3.3 Gradual expansion of fuel debris retrieval

Preparations of gradual expansion of the 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 fuel debris retrieval in 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, 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[26] 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.

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

  Since the work period is on 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 the further expansion of fuel debris retrieval in 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

[26] 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.

leveraged in project and construction management for the further expansion of fuel debris retrieval in scale in the future.

As various remote-control devices will be used for handling fuel debris in the first storage facility, 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 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 fuel debris retrieval in scale

Toward the further expansion of fuel debris retrieval in scale, TEPCO should take responsibility for examining the methods based on the viewpoint that “fuel debris retrieval is an important process in decommissioning, and its retrieval in a reliable manner affects the success/failure of the decommissioning project”, and from a comprehensive standpoint in anticipation of technical feasibility as well as business continuity. Therefore, this section describes in detail the procedure for examining the methods. (As a reference, changes in considerations on retrieval methods in the previous Technical Strategic Plans are shown in Attachment 9.)

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 Lack of on-site information
Due to the restrictions in [1] and [2] above, it is difficult to obtain on-site information (and prospects are uncertain), and discussions must be based on the presumed conditions.

④ Building containment barriers
If 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 constructed, it requires containment performance, including seismic resistance according to the site conditions.

⑤ Criticality control

An external force, such as a process during retrieval, will cause a movement or change the form of fuel debris currently in a subcriticality condition. In order to properly assess the impact caused by such a change in state, it is necessary to incorporate on-site information (fuel debris composition, distribution, neutron flux, etc.).

⑥ Waste management

Solid waste newly generated as a result of decommissioning work must be considered in accordance with the Basic Concept of Solid Waste presented in the Mid-and-Long-term Roadmap. In particular, it is necessary to reduce the amount of solid waste generated as much as possible to reduce the overall burden of solid waste management.

Therefore, the following should be considered when examining and evaluating methods.

(1) Considerations when examining retrieval methods

- Appropriate establishment of requirements for ensuring safety

  Given an unusual environment different from normal reactors, to ensure safety, the optimal approach to safety (ALARP) should be implemented throughout the entire project, not to prolong the work period. For this reason, it is important to perform an impact assessment 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 several scenarios of fuel debris retrieval by each unit and to clarify several paths from start to completion in this retrieval method examination. The intention of this study on fuel debris retrieval scenarios is to estimate in advance 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 ad narrow down the paths to take according to the information obtained afterward.

In considering several paths, it is necessary to control potential risks 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 risk level and risk measures.

- Clarification of requirements

  As for the further expansion of fuel debris retrieval in 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

  If the developed retrieval method has even one potential technical issue or if an issue that was overlooked in construction work, retrieval work, or maintenance becomes apparent, the work may be derailed and it may not be possible to proceed. To prevent this, issues should be identified through systematic and exhaustive methods at the design stage. For this purpose, 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 check the actual site applicability and technology feasibility based on the Five guiding principles (safe, proven, efficient, prompt, and field-oriented), the methods related to business continuity, 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.

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. Many challenging issues have been identified with respect to methods proposed by the end of FY 2021. In FY 2022, the actual site applicability and technical feasibility associated with measures for mitigating these issues were verified. In FY 2023, issue studies of each method are continued and evaluated including business continuity. In addition, preparation work such as yard maintenance, which becomes necessary regardless of the retrieval method, has been identified and summarized to have it take shape as soon as possible. Selecting a specific method is an extremely important decision to determine the success or failure of decommissioning over the medium to long term. Thus, not only TEPCO but also the national government and NDF must cooperate to comprehensively examine and evaluate technological feasibility, with safety as a major prerequisite. To this end, since February 2023, the Sub-Committee for the Evaluation of Fuel Debris Retrieval Methods has been established under the Decommissioning Strategy Committee, a committee of the NDF, to conduct technical and intensive study and evaluation on the technical feasibility and business continuity for each method of fuel debris retrieval.

The followings are the overview and the issues of the partial submersion method ((Water injection into RPV), its option (RPV solidification)) and submersion method (shell structure). The outline of each method is only an example and is not definitive.

3.1.3.4.1 Overview of and issues with the partial submersion method

3.1.3.4.1.1 Overview of and issues with the partial submersion method (water injection into RPV)

(1) Overview of the proposed partial submersion method (water injection into RPV)

The partial submersion method (water injection into RPV) is a method for retrieving debris exposed in the air or immersed at a low water level while pouring water into the RPV. (Fig. 15)

Previous examinations have been conducted on the top and side access methods alone, but this retrieval method does not use either method alone but rather combines them. This makes it possible to share the safety and pre-transfer treatment systems installed in the additional building to streamline the entire facility. The roles of the top and side access are as follows: the top access will be the main route to retrieve debris inside the RPV and the pedestal, based on the fact that a large working opening can be taken and that access is possible in a linear direction. In contrast, the side access route will be used to retrieve from outside the pedestal, which is not easily accessible from the top. Regarding side access, safety measures, are implemented inside/outside the pedestal ahead of the top access, such as criticality control due to the accumulation of cutting particles during fuel debris fabrication and preventing heavy objects from falling from the RPV. Duplexed containment barriers will be constructed to prevent radioactive dust dispersion and the spread of contamination during retrieval. The primary containment barrier comprises PCVs and other structures while the secondary containment barrier comprises reactor buildings and other structures. In addition, a gas phase containment system is installed at the primary and secondary containment barriers to achieve active containment through difference pressure control inside and outside the containment barriers.

The retrieved fuel debris is transported to the additional building connected to the reactor building, where pre-transfer treatment is performed. Storage in transfer containers and inspection including hydrogen concentration measurements are carried out in pre-transfer treatment. The transfer containers are transferred from the additional building to a pre-storage treatment facility to analyze, sort, and dry fuel debris as pre-storage treatment. They are then stored in storage containers and stored in storage facilities.

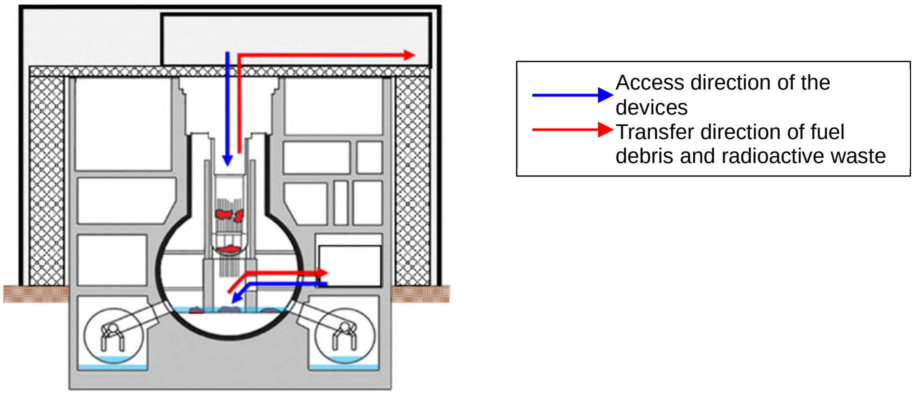


Fig. 15 Example of the proposed partial submersion method (water injection to RPV)
(Conceptual drawing of combination of top access and side access)

(2) Issues with the proposed partial submersion method (water injection to RPV)

For the proposed partial submersion method (water injection to RPV) described in (1) above, the issues and the possible measures were summarized according to the abovementioned factors ① to ⑥ that make fuel debris retrieval difficult.

- For factor ① (extremely high radiation dose in PCVs and RPVs), the issue is that all operations will be conducted using remote control devices because it is inaccessible to humans. After identifying the required operations including what is expected to be done, such as fuel debris retrieval and removal of obstacles in PCVs, the function, structure, and general safety requirements (radiation resistance, water resistance, temperature range, remote inspection/maintenance, remote operability, ensuring field of views, protective mechanisms such as collision avoidance and automatic shutdown in case of abnormalities, high reliability and appropriate redundancy, etc.) of equipment should be established.
- For factor ② (high radiation dose in reactor buildings), although some works in buildings can be implemented manually, in such cases, the issues are careful exposure control as well as environmental improvement (decontamination and shielding). Operations using remote control devices are another issue in high radiation dose areas where dose reduction is difficult. Because establishing an access route for retrieval will be conducted by remotely, the same measures will be required as with factor ①.
- For factor ③ (insufficient on-site information), the issue is that the retrieval method must be considered based on the uncertainty of on-site information due to the limited results of the

on-site survey. Therefore, in addition to obtaining on-site information through internal investigations, remote control devices and work procedures should be considered to allow for flexible response in cases where the on-site situation still cannot be identified.

- For factor ④ (building containment barriers), it is necessary to support a heavy cell with a shielding function or retrieval devices on a platform for top access, and the issues are their seismic feasibility and airtightness of the interface with existing structure. As a countermeasure, it is necessary to assess the validity of seismic conditions as well as study measures for reducing the upper load and examination of structure to ensure airtightness. In addition, because existing structures such as reactor buildings and PCVs are used as containment barriers facilities, the issue is to examine airtightness and seismic resistance in consideration of the fact that they are damaged by the accident and the aging deterioration. In view of long-term use in the future, it is necessary to monitor, investigate, and assess damage, deterioration, and corrosion conditions, and by taking these into account, it is also necessary to continuously check the earthquake resistance and structural integrity.
- For factor ⑤ (criticality control), the issue is to have criticality control (monitoring, criticality prevention, impact mitigation measures) take shape appropriately for the on-site conditions. Measures should be considered from both a design and operational perspectives. Design measures to be considered include the use of multiple monitoring means (rare gas concentration monitors, neutron detectors, etc.), setting limits on cutting operations (criticality prevention), and installing systems capable of injecting neutron absorbers (impact mitigation). Meanwhile, as operational measures, the amount of state change is assessed (monitored), and when a condition approaching criticality is detected, criticality is prevented by stopping operations, adding neutron absorbers, and determining whether operations can be resumed. In the future, accumulating and evaluating the information obtained during on-site operations (fuel debris composition, distribution, neutron flux, etc.) will make it possible to validate the initial design.
- For factor ⑥ (waste management), the issue is handling a large amount of waste, such as dismantled buildings and excavated soil in areas that interfere with new structure construction (such as platforms to support cells for top access, additional buildings, etc.). A plant-wide waste storage plan should be developed to verify that the waste to be generated can all be stored.

Countermeasures against these issues are under discussion, and the actual site applicability, technical feasibility, and business continuity will be evaluated.

3.1.3.4.1.2 Overview of and issues with the partial submersion method option (RPV filling and solidification)

Among factors related to the proposed partial submersion method (water injection into RPV), to reduce the difficulty of issues associated with factors ① and ②, it is effective to minimize and simplify operations using remote control devices and attended operations in the reactor building. Moreover, based on factor ④, a method that can mitigate the impact of damage to the existing structures and the deterioration of airtightness and strength due to aging degradation is desirable. For factor ⑤, reducing the possibility of criticality by suppressing the movement and form change of the fuel debris associated with operations is possible. As a possible measure to achieve this, partial submersion method option (RPV filling and solidification) is considered. An overview of this option and related issues are described below.

(1) Overview of the partial submersion method option (RPV filling and solidification)

The partial submersion method option (RPV filling and solidification) is a retrieval method where the pedestal bottom, RPV, reactor well, etc. are physically stabilized by solidifying with fillers, and then excavates, and retrieves fuel debris with fillers. (Fig. 16)

The method for retrieving fuel debris and removing other objects inside the RPV and pedestal is as follows; first, filler materials are injected into the bottom of the pedestal by side-access, then the filler materials are injected from the reactor well into the RPV and pedestal by top-access to solidify, and then excavate to the bottom of the pedestal by top-access for retrieval of fuel debris. For fuel debris outside the pedestal, filler materials are injected, a casing is installed, and then fuel debris is retrieved by excavation. In order to reduce the amount of waste generated due to filling, there is also an option of not filling the core and pedestal, but only the upper part of the RPV head and the lower part of the pedestal from the reactor well, and then installing a casing for recovering fuel debris from the upper part of the RPV to the bottom of the pedestal to recover fuel debris by drilling. There is also an option of not filling the core and pedestal, filling only the upper part of the RPV head and the lower part of the pedestal from the reactor well, installing a casing for recovering fuel debris from the upper part of the RPV to the bottom of the pedestal, and recovering fuel debris by drilling.

The drilling section would be supplied with water to fluidize the crushed fuel debris, which would be transferred together with filling material to a filter-type recovery container for circulation recovery.

Duplexed containment barriers will be constructed to prevent radioactive dust from dispersing and stop contamination from spreading during retrieval. Similar to the partial submersion method (water injection into RPV), the primary containment barrier comprises PCVs and other structures while the secondary containment barrier comprises reactor buildings and other structures. However, compared with the partial submersion method (water injection into RPV), since the filler covers fuel debris and other materials, the containment performance is expected to become stronger. In addition, a gas phase containment system is installed at the primary and secondary containment barriers to achieve active containment through difference pressure control 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 (water injection into RPV) and submersion (shell structure) methods.

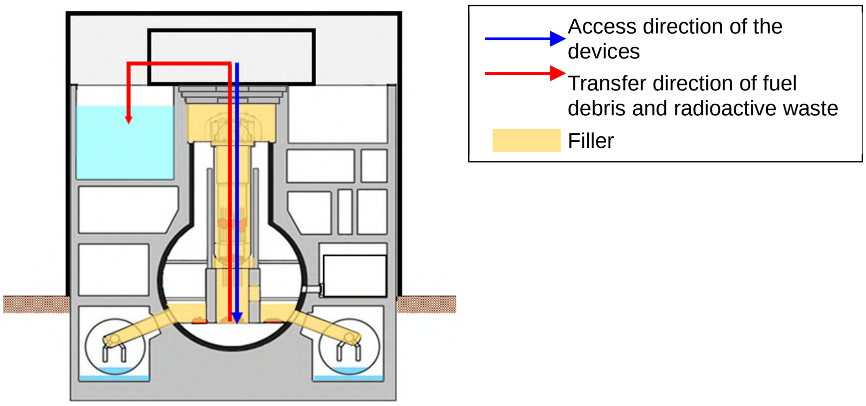


Fig. 16 Overview of the partial submersion method option (RPV filling and solidification)

(2) Issues with the partial submersion method option (RPV filling and solidification)

For the proposed partial submersion method option (RPV filling and solidification) described in (1) above, the issues and possible measures were summarized according to the abovementioned factors ① to ⑥ that make fuel debris retrieval difficult.

- For factor ① (extremely high radiation dose in PCVs and RPVs), the issue is to prevent leakage of contaminated water inside the cell or to the outside because the excavated debris is recovered in a state mixed with water. It is necessary to examine detection methods in case of leakage, measures to prevent the spread of contamination, and restoration methods after contamination.
- For factor ② (high radiation dose in reactor buildings), the issue is how to lay the filling hose because the filler materials are injected into the bottom of the pedestal via side-access. The study is expected to be based on past examples of internal investigations of the Unit 2 PCV, which has been accessed to the inside of the pedestal.
- For factor ③ (insufficient on-site information), an issue is that the uncertainty of site information must be considered in discussing the method. An issue unique to this option is the flow and solidification properties of the filler. Fillers need to be injected in the areas to be excavated and to the extent to improve excavation-ability, but better fluidity makes it easier for fillers to leak through openings. On the other hand, there are limitations in investigating the conditions inside the PCV and RPV, and it is difficult to identify the location and size of cracks in the PCV/RPV. Therefore, it is necessary to assess the flow and solidification characteristics of filler materials through tests and to consider the selection of filler materials and procedures that allow them to be filled appropriately under various conditions, as well as methods or alternatives to confirm that the filler has been completed. The development should be promoted after clarifying the functions required for fillers. Moreover, since fuel debris is covered with fillers, decay heat removal is also a challenge, including whether it is necessary. Although it is unclear how much decay heat is generated and from where, the possibility that the heat decay removal is inhibited should also be considered.

- As for factor ④ (building containment barriers), the issues are the seismic feasibility of the cell to be installed in the reactor building and on the operating floor and securing airtightness of the interface necessary for the cell, cover over the cell, and existing structures. As a countermeasure, seismic assessment should be carried out after specifying the equipment installed on the operating floor, and the structures to ensure airtightness should be examined. In the case of top-access in the partial submersion method (water injection into RPV), the cell requires a shielding function because the structures with high radiation doses are exposed to the air. In this option, however, they are not exposed. Thus, the shielding function required for the cell and other structures is expected to be reduced compared to the partial submersion method (water injection into RPV), and there is a possibility that the platform supporting the cell, retrieval equipment, etc., will become unnecessary. In addition, because existing structures such as reactor buildings and PCVs are used as containment barriers, another issue is to examine the airtightness and seismic resistance in consideration of the fact that they have been damaged by the accident and of the aging degradation. Given long-term use in the future, similarly to the partial submersion method (water injection into RPV), it is necessary to monitor, investigate, and assess damage, deterioration, and corrosion conditions and continuously verify seismic resistance and structural integrity. If fillers can be used as expected, the impact due to aging degradation is expected to be mitigated.
- For factor ⑤ (criticality control) has the same issue as with the proposed partial submersion method (water injection to RPV). Measures specific to this option include, for example, limiting the size of the fuel debris recovery line to a size that will not cause criticality and adding neutron absorbers to the filler materials in advance. However, after clarifying the possibility of criticality, it is necessary to evaluate the impact of exposure should a criticality occur and consider necessary countermeasures in detail.
- As for factor ⑥ (waste management), the issue is that a large amount of fillers are used for excavation and recovery, and all of them must be treated as radioactive waste. For this reason, reducing the filling range should be considered, a plant-wide waste storage plan should be developed to verify that the waste to be generated can all be stored. In addition, although the origin of the recovered excavation powder is clear if the excavation site is identified, the method of sorting fuel debris and waste should also be considered, especially since the excavation powder recovered from the vicinity of fuel debris is a mixture of fuel debris, structures, and fillers.

3.1.3.4.2 Overview of and issues with the submersion method (shell structure)

(1) Overview of the proposed submersion method (shell structure)

The submersion method (shell structure) involves enclosing the entire reactor building with a new structure, called a shell structure, as containment barriers, flooding the reactor building, and retrieving fuel debris. (Fig. 17)

Fuel debris inside the RPV and inside/outside the pedestal will be retrieved via top-access. Operations outside the pedestal will be performed from inside the pedestal via worker access opening in the basement.

The shell structure is established to enclose the entire reactor building, and it is filled with enough water to flood the reactor building inside. It has a three-layer structure, with 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 through difference pressure control inside and outside the containment barriers.

The pre-transfer treatment of the retrieved fuel debris is carried out underwater until it is stored in a shielded container, and then the container is cleaned, drained, capped, and inspected in the air. To ensure a hydrogen concentration below the flammable limit for the radioactive decomposition of water contained in the transfer container, the amount of hydrogen generated should be measured beforehand, and the amount stored should be limited. The transfer containers are transferred from the shell structure to a pre-storage treatment facility to analyze, sort, and dry fuel debris as a pre-storage treatment. They are then stored in storage containers and stored in storage facilities.

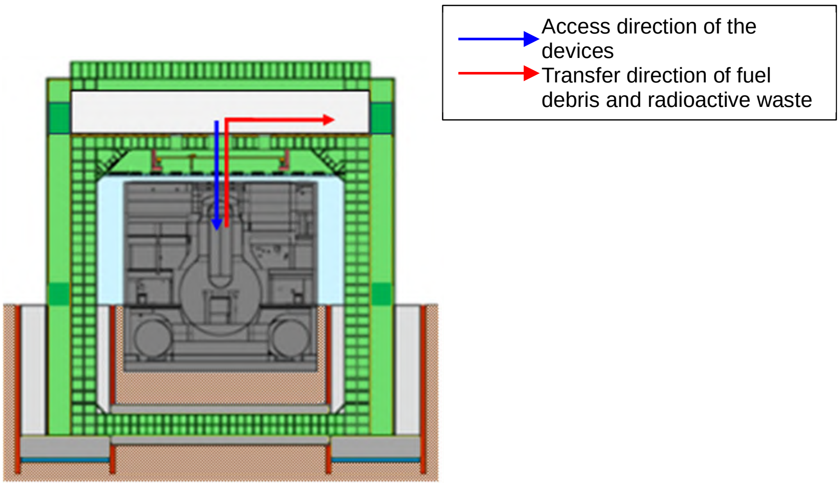


Fig. 17 Example of the submersion method (Shell structure)
(Conceptual drawing of the shell structure)

(2) Issues with the proposed submersion method (shell structure)

For the proposed submersion method (shell structure) described in (1) above, the issues and possible measures were summarized according to the abovementioned factors ① to ⑥ that make fuel debris retrieval difficult.

- For factor ① (extremely high radiation dose in PCVs and RPVs), effect of the water shielding by submersion allows a person to approach the middle working framework on which the retrieval work is carried out in the Shell structure. However, since all work inside the PCV/RPV will be performed remotely, it is necessary to take similar measures to the ones in the proposed partial submersion method (RPV water injection).
- For factor ② (high radiation dose in reactor buildings), in some of the preparatory work prior to the installation of the Shell structure, such as rerouting of reactor water injection facilities, work inside the reactor building is required. Since the operations are mainly manual, careful exposure control as well as environmental improvement are the issues, as in the case of the proposed partial submersion method (RPV water injection). In the event that remote work is required, it is necessary to take a response similar to that of the proposed partial submersion method (RPV water injection).
- As for factor ③ (insufficient on-site information), it is necessary to verify the conditions of soil contamination by doing sea-side sub-drain water and geological (boring) surveys around the reactor building to install temporary structures (pit, shield tunnel) for constructing the shell structure. However, the issue is that the possibility of soil contamination around the reactor building cannot be completely excluded. It is also necessary to examine construction feasibility, in advance, assuming that the excavated soil (including groundwater) is contaminated.
- For factor ④ (establishing containment barriers), in addition to studying the methods based on the uncertainty of on-site information, the issue is to assemble the bottom of the Shell structure into the space inside the shield tunnel with only the side access. The feasibility of welding work and inspection methods should be verified. Another issue is to prevent contaminated water from leaking outside the shell structure, which has three layers of containment barriers. It is necessary to study measures to detect leakage between the containment barriers and to recover from leakage. For the integrity of the temporary structures, surrounding ground, and shell structure during construction and earthquake, the prospects for feasibility have been confirmed through analysis and evaluation using the finite element method considering water pressure (internal water, ground water), earth pressure, seismic load, etc.
- For factor ⑤ (criticality control), the issues are the same as for the partial submersion method (water injection to RPV). In addition, as a countermeasure in case of criticality, the issues are the maintenance/management of boron concentration and the control of the supply of boric acid for a constant boric acid solution environment.
- For factor ⑥ (limiting waste amount generated), due to the construction of the Shell structure, the amount of waste such as demolished buildings and excavated soil, which interfere with

yard maintenance, will be enormous, and the same measures as those proposed for the partial submersion method (RPV water injection) will be necessary.

As with the partial submersion method, countermeasures against these issues are under discussion, and the actual site applicability, technical feasibility, and business continuity have been evaluated.

The above describes issues and measures for each method. While technical issues remain with each method, there are also complementary technologies (for example, the shielding effect from using fillers is a common element technology applicable to both the partial submersion and submersion methods).

In the future, it is desirable to extract elements with high technical feasibility, project continuity, and high effectiveness in solving issues out of technologies examined for each retrieval method, and combine them to proceed with examination to establish a more rational and feasible retrieval method.

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

Referring to the findings obtained through the PCV internal investigations and the analysis data of the collected deposit samples, TEPCO has been examining the estimation of RPV and PCV conditions to incorporate the results into planned on-site investigations and studies of fuel debris retrieval methods and storage management. On the other hand, there are still many places where internal investigation is not possible due to high radiation doses. Therefore, it is important to refine the information, such as the location and distribution of fuel debris and radiation dose distribution, through activities to improve understanding of the events during the accident, including analysis of the accident sequence in light of the on-site finding and solving pending issues in accident progression, and then incorporate them into the estimation of RPV and PCV conditions. Activities to improve understanding of the events during the accident and incorporate knowledge gained into decommissioning work will continue. Furthermore, 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. 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.

A list of the progresses 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 fuel debris retrieval in 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 a list of 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 3.1.3.6.8. 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 investigation inside the RPV

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) 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 (abrasive, etc.) were examined. As a result, AWJ with small nozzles and laser cutting were selected as candidate techniques. A verification test of remote workability from the operating floor using this fabrication equipment is scheduled for 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.

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. By FY 2023, the plan is to perform tests to verify the practical applicability of these investigation devices via lower access.

TEPCO is studying a simple investigation method in which a fiberscope with a small diameter and high radiation resistance is inserted into existing instrumentation piping (small-diameter piping) to access and investigate the inside of the RPV.

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 is developing elemental technologies to solve the issues from FY 2022.

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.

- The PCV should be accessed from the penetration X-6, etc. after the work environment in the reactor building is sufficiently secured.
- 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 improve functions for practical applications. 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 obstacles to be removed were selected, and the specifications of a remote-control device in accordance with the required functions were proposed and ended in FY 2022. Going forward, TEPCO’s engineering will promote development in order to actualize the proposal.

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 debris retrieval in the future, the challenge is to promptly assess the amount of radioactivity of the radioactive materials taken in and evaluate the radiation dose in order to consider more accurately improving protection functions against the intake as well as 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 is moving 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. Since FY2023, developing an internal radiation exposure dose assessment program has been underway through establishing a comprehensive internal radiation exposure dose assessment system using bioassays and external measurements, developing standards, and the continued technology development related to measuring and assessing internal radiation exposure doses.

3.1.3.6.4 Liquid treatment system (α-emitting nuclide removal technology)

Fuel debris retrieval may cause mixing and leaching of granular particulate or soluble alpha-ray emitting nuclides in higher concentrations than in the current contaminated water 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 in FY2023 include developing removal technologies that can accommodate colloidal α-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 the further expansion of fuel debris retrieval in 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.

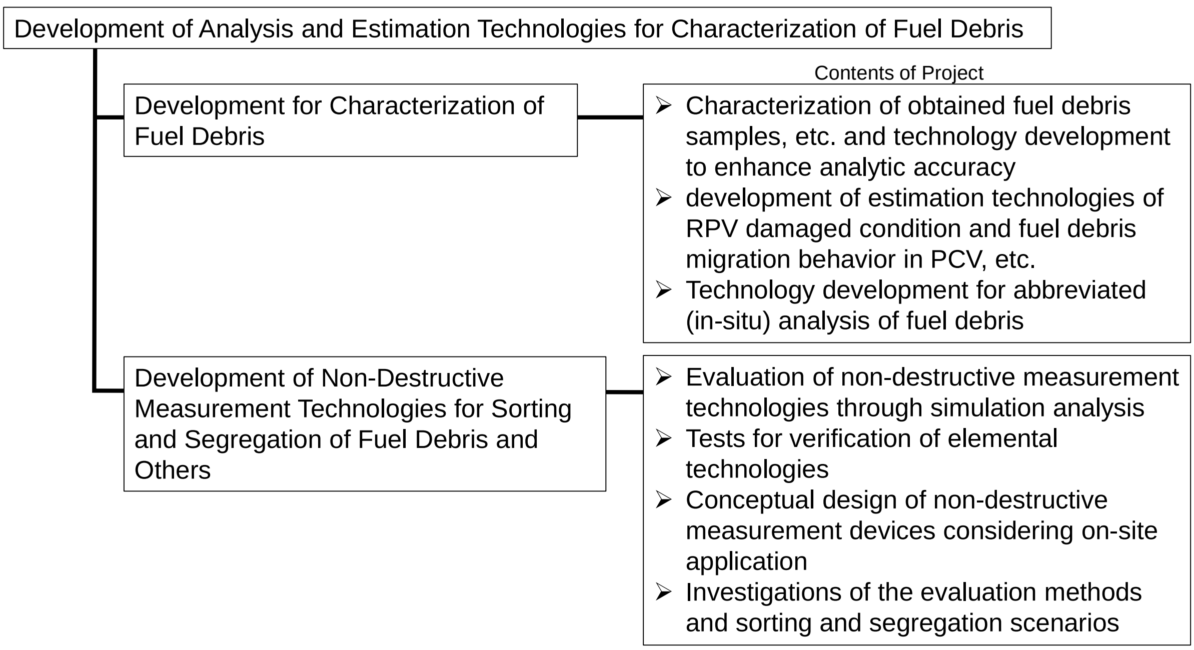
3.1.3.6.5 Analytical and estimation techniques for the characterization of fuel debris

The technical development necessary for analysis and estimation techniques for fuel debris characterization is in progress in the aim of contributing to developing methods for fuel debris retrieval and removal of in-core structures, and technology for the collection, transfer, and storage of fuel debris. Since FY 2023, as shown in Fig. 18, two primary focuses in these efforts are the “technology development necessary for fuel debris characterization” and the “development of the nondestructive measurement technology necessary for sorting”.

In the technology development necessary for fuel debris characterization, the plan is to analyze in hot lab facilities fuel debris samples, planned to be collected during trial retrieval in Unit 2, and the deposit samples collected during PCV internal investigation using the submersible ROV in Unit

1. Structural analysis and X-ray CT imaging of fuel debris from the Unit 2 of Three Mile Island Nuclear Power Plant (hereinafter referred to as “TMI-2”) accident are also planned to compare it with fuel debris at the Fukushima Daiichi NPS. In addition, severe accident progression analysis, material melting tests, and evaluation of relocation behavior of molten materials are underway, with a focus on damage to the reactor pressure vessel. A simple analysis technique is also being developed to promptly check whether fuel components are contained to reduce the burden of transporting samples to hot lab facilities when the amount of fuel debris retrieved increases in the future.

In fuel debris sample analysis, only a portion of the fuel debris to be retrieved is able to be characterized. Therefore, non-destructive measurement techniques necessary for sorting is under development, with a focus on the amount of nuclear fuel in the fuel debris. As the analysis involves the risk of spreading contamination and internal exposure, the aim is to measure the radiation emitted or transmitted from a sealed object in a container to determine the amount of nuclear fuel promptly without destroying it. Since fuel debris is a heterogeneous mixture of many nuclides and elements, such as neutron absorbers, which can interfere with measurements, a wide range of chemical compositions is reproduced through simulation analysis, and the effects of the inhibiting factors are verified by tests using existing test equipment. The conceptual design of the equipment and sorting scenarios are under discussion based on these results.



※ It does not strictly match the expression in the guidelines, since concise expression and comprehensibility were prioritized.

Fig. 18 Research topics and key activities in analysis and estimation technologies for fuel debris characterization

3.1.3.6.6 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 2022.[27] [28]

- Development of basic specifications for the container (storage cans)[26], such as height in consideration of handling of it, internal diameter, quality of materials and lid structure in light of work efficiency and maintaining subcriticality, etc., and demonstration of the structural integrity of the container by testing.
- Examination of a practical and rational prediction method of hydrogen generation from fuel debris stored in containers; determination of a vent mechanism for hydrogen gas release on the container lid by using the said prediction method and establishment of safe transfer conditions with consideration for the accumulation of hydrogen gas in transferring casks.
- Development of efficient drying technology applicable to fuel debris in unit cans[26], 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

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, research on storage technologies/types, narrowing down of candidates, and 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 fuel debris retrieval in 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, reliable, and rational 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 handling from transfer to storage operation have been in progress. From FY2023 onward, based on the study results in the Project of

[27] 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)

[28] 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)

Decommissioning, Contaminated Water and Treated Water Management and new findings on fuel debris properties and conditions in PCVs, the consideration on the previous study and evaluation results will be deepen and will be verified component tests. 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, reliable, and rational 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, equipment and installations are designed based on conservative assumptions of the properties of fuel debris in the studies by the Project of Decommissioning, Contaminated Water and Treated Water Management and by TEPCO. In the design of equipment and installations for the containing, transferring, and storage of fuel debris for the further expansion of fuel debris retrieval in 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 useful approach to determine the specifications of equipment and installations required for containing, transferring, and storing fuel debris, as well as their size, their layout, and the flow of fuel debris handling 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.

3.1.3.6.7 Data acquisition of dust dispersion rate

For the further expansion of fuel debris retrieval in 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, data on the dust dispersion rate in dry conditions were acquired to understand the basic effects of dust dispersion during fuel debris retrieval. The assumed environment during fuel debris retrieval is a wet environment in PCVs, and the acquisition of data on dust dispersion rates in such an environment for multiple retrieval methods has been in progress since FY 2023 based on the results obtained up to FY 2022. The acquired data are being organized systematically to serve as a technical basis for safety assessment during fuel debris retrieval in the future decommissioning work of the Fukushima Daiichi NPS.

3.1.3.6.8 Fuel debris retrieval method

For the fuel debris retrieval method for the further expansion of fuel debris retrieval in 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 will be 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 will be promoted to prevent re-criticality due to falls, dust dispersion, or equipment damage. TEPCO is in process of conducting a conceptual study to develop methods for the further expansion of fuel debris retrieval in scale to verify actual site applicability and technical feasibility of measures against the issues related to partial submersion and submersion methods (shell structure), 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 in case that TEPCO needs technical assistance. NDF will also check the progress of the project from an engineering perspective to confirm that the application of safeguards to systems 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.19.

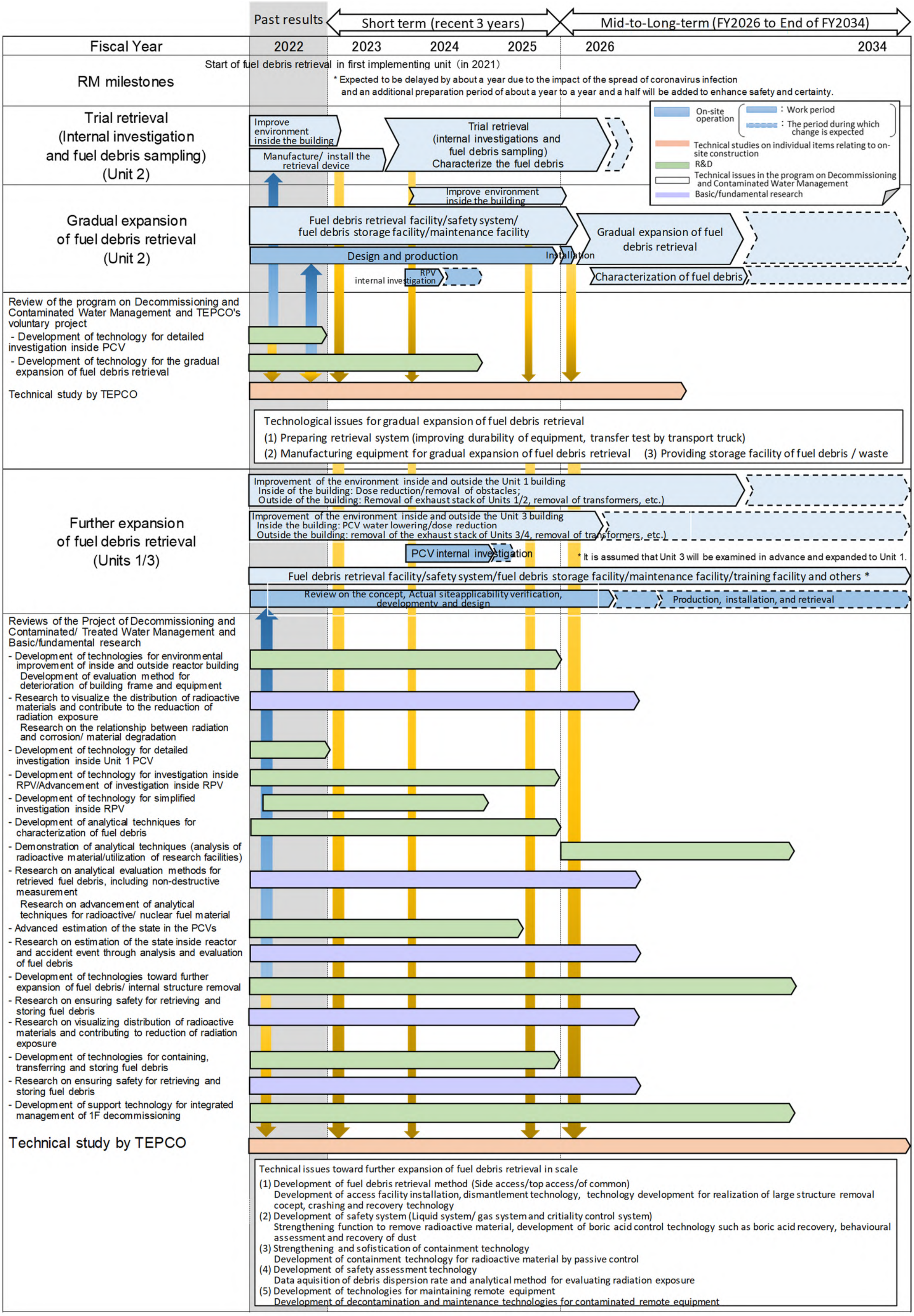


Fig. 19 Key technical issues and future plans on fuel debris retrieval (progress schedule)

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

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

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, and disposal. Definitions of terms related to radioactive waste management in the IAEA Safety Glossary Terminology are shown in Attachment 11, and classification and disposal of radioactive waste in Japan and abroad are shown in Attachment 12.

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 underway.

<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

[29] 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 reuse 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”.

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

⑦ Development of continuous operational framework

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

⑧ Measures to reduce radiation exposure of workers

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

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

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 2 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 reuse/recycling. Facilities needed to achieve this goal are under development (Attachment 13) and the processing plan[30] and transfer plan[31] related to this were examined.

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 reuse 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. 20)), and TEPCO has also been implementing initiatives corresponding to this concept.

Among the targets of reuse/recycling, concrete rubble is crushed and recycled as roadbed material on the premises of Fukushima Daiichi NPS after confirming that the surface dose rate is equivalent to the background radiation dose. In addition, such as by melting is under consideration as a decontamination method for recycling metal. The Project of Decommissioning, Contaminated Water and Treated Water Management is in progress to clarify the nuclide distribution behavior during melting and decontamination and examine validation 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 (scheduled installation of processing facility in FY 2026). Waste sludge will be collected from the underground storage tanks in the building, where it is currently

[30] 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.

[31] Assessment of the impact on receiving operations in terms of the impact of the completion time of the solid waste storage.

stored, dehydrated and then stored into containers, before being transferred to higher ground (starting in FY 2025).

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. As further goals from FY 2026 to FY 2034, it also shows the transition to a more stable condition (dehydration or solidification processing and storage in facilities with the required seismic resistance) is the conditions to be realized.

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 February 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.

Table 2 Status of solid waste storage/management

(a) Management status of rubble, fallen trees, used protective clothing, etc. (As of July 31, 2023)

Classification	Stored volume (m^3) / Storage capacity (m^3) (Percentage)
Outdoor storage (surface radiation dose rate ≤ 0.1 mSv/h)	302,200 / 397,900 (76%)
Outdoor sheet covered storage (surface radiation dose rate 0.1 - 1 mSv/h)	43,700 / 55,300 (79%)
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)	29,700/ 39,600 (75%)
Total	392,000 / 509,900 (77%)

Fallen trees

Classification	Stored volume (m^3) / Storage capacity (m^3) (Percentage)
Outdoor storage (trunks, roots, branches, leaves)	70,000 / 134,000 (52%)
Temporary storage pool (branches, leaves)	37,300 / 41,600 (90%)
Total	107,300 / 175,600 (61%)

Used protective clothing, etc.

Classification	Stored volume (m^3) / Storage capacity (m^3) (Percentage)
Temporary storage	20,000/ 25,300 (79%)

* 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 3, 2023)

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	5,608 / 6,500 (86%)
	2nd Cesium sorption apparatus		263	Number of vessels and filters	
	3rd Cesium sorption apparatus		18	Number of vessels and filters	
	HICs from multi-nuclide removal system		4,212	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		229	Number of vessels	

Waste sludge

Storage place	Stored volume (m^3) / storage capacity (m^3) (Percentage)
Sludge storage facility (indoor)	434 / 700 (62%)

Concentrated liquid waste

Storage method	Stored volume (m^3) / storage capacity (m^3) (Percentage)
Concentrated liquid waste storage tanks (outdoor)	9,468 / 10,300 (92%)

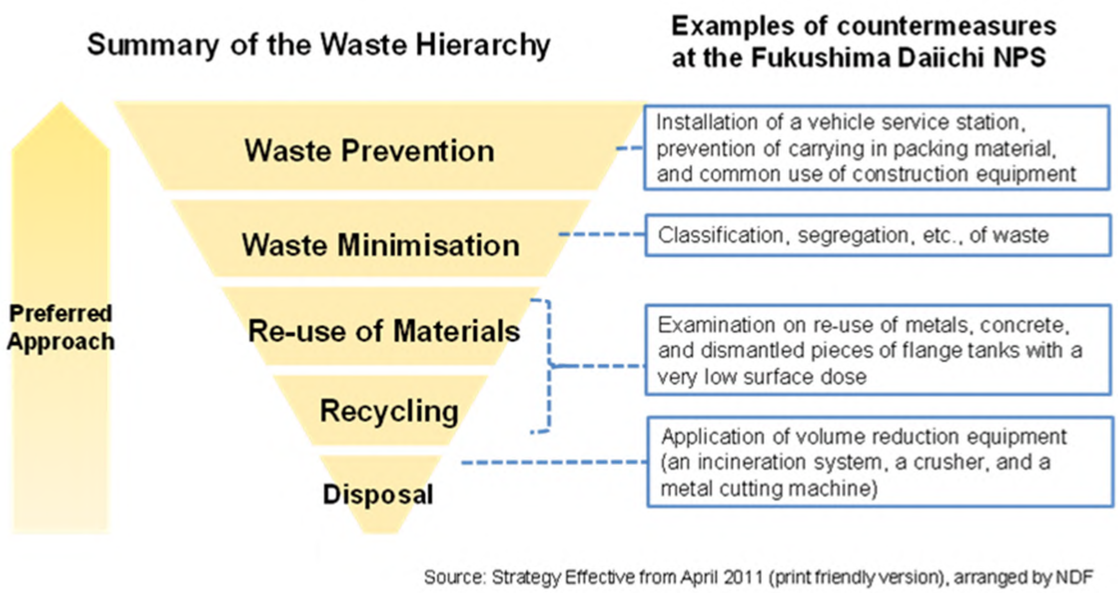


Fig. 20 Summary of waste hierarchy at the NDA, and countermeasures at the Fukushima Daiichi NPS

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 speed-up data acquisition, which have been studied, are being evaluated for feasibility and validity for use as standard analysis methods at the Radioactive Material Analysis and Research Facility Laboratory-1. Moreover, sampling of sorption from cesium sorption apparatus (KURION and SARRY) is in progress at the Fukushima Daiichi NPS site to obtain analytical data on high-activity waste.

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

As for the processing technology, while the prospects of the application as actual equipment of normal-temperature processing technology were confirmed through full-scale tests, further discussions 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, verification of the applicability of pyrolysis processing and other interim processing technologies to detoxifying organic substances and inactivating reactive/corrosive substances is underway. Studies are also being underway on the following possibilities as a preliminary study to address anticipated issues flexibly and rationally in the immediate decommissioning work.

- The bulk solidification technologies without segregating a large amount of miscellaneous rubble which is difficult to segregate and may contain hazardous materials etc.
- The technology to process slurry dehydrates and their containers together which simplifies the preceding process when processing slurry dehydrates after stabilization to eliminate the need for development related to removal from container.

Concerning disposal technology, the necessary information and knowledge are being investigated to develop measures that meet the needs of the disposal concept for waste, for which review of the waste stream is underway. A storyboard on the progression of important events in disposal facilities is under development to identify critical scenarios for solid waste disposal.

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 and processing/disposal, the following study will be conducted to present appropriate overall measures for specific management approaches for solid waste while reviewing the necessary R&D tasks.

- The first step is to create processing/disposal options by examining pending issues related to processing technology, interim processing, and disposal options.
- Then, the options will be compared and evaluated using the property data that are becoming clear, and examinations will be conducted to establish a waste stream that is suitable for the characteristics of solid waste.

Institutions concerned, led by NDF, are conducting technical studies on integrated measures from characterization to processing/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.

3.2.3.1 Characterization

(1) 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[32] with statistical methods are underway and will continue.

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

(2) 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 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[33].

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

In March 2023, TEPCO developed an analysis plan for the characterization and optimization of storage/management to discuss solid waste processing/disposal methods. Based on the plan, the following will be addressed in cooperation with the JAEA:

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

Radioactive Material Analysis and Research Facility Laboratory-1 started analysis work using radioactive materials in October 2022. By the end of FY 2023, the simplified and speed-up analysis techniques that have been developed will be demonstrated as standard analysis methods.

Moreover, TEPCO's new facility for analysis is scheduled to be operational in the second half of the 2020s. The facility should be developed systematically with due consideration for the above analysis plan, emerging analysis needs in the decommissioning process, and the appropriate role allocation with the existing facilities.

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.

(1) 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 radioactive waste based on the concentration of radioactivity and examine the rational classification of waste and reuse on-site.

(2) 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 reuse and recycling, 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[34] 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, an examination will be carried out on storage/management methods which are safe, reasonable and feasible, such as classification according to the characteristics of the main nuclides with a view to long-term processing/disposal.

(3) 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.

(4) 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 the further expansion of fuel debris retrieval in 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 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. 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. 20) and examine further possibilities for volume reduction by referring to advanced cases overseas.

3.2.3.3 Processing/Disposal

To specify a suitable overall picture covering the entire waste stream, the trial examples of setting appropriate waste streams will be accumulated to acquire findings by waste stream widely. Therefore, the R&D of processing and disposal technologies required for the series of studies, as shown in Fig. 21, will be continued.

[34] The 107th meeting of the Study Group on Monitoring and Assessment of Specified Nuclear Facilities, Material 3-1, “Approach to Solid Radioactive Material Target in Medium-term Risk Reduction Target Map,” NRA

(1) Processing technology

Regarding the normal-temperature and thermal processing technology for which research and development have been promoted:

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

Activities to address the above pending issues will continue.

As for normal-temperature processing technology, consideration is given to the transformation of solidified waste as well as test methods to verify the possibility of solidification. In the case of thermal processing technology, the feasibility of the whole processing system, including supply and exhaust systems, is an issue in addition to the solidification process, and therefore it is necessary to carry out examination in a timely manner according to the start time of processing.

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.

(2) Disposal technology

Concerning disposal technology, to enhance the reliability of the disposal concept, feasibility of disposal concept will be evaluated based on a study of the long-term evolution behavior of the disposal facilities and incorporated the results into its discussion in light of the characteristics of solid waste. To appropriately allocate waste to a disposal concept that is shown to be feasible, knowledge on the sensitivity structure of scenarios and parameters to radiation should be expanded by adequately incorporating the characteristics of waste, changes in environmental conditions in and around disposal facilities into those scenarios and parameters of radiation dose assessment, and repeating tests. By using this knowledge, safe and reasonable disposal options are proposed.

Furthermore, after expanding the target of waste streams incorporating this disposal option, a group of disposal options will be examined with a bird-eye-view of all solid waste at the Fukushima Daiichi NPS. Then, contributions will be made to considering specific management approaches for solid waste in coordination with areas other than disposal, such as presenting targets for waste form performance and the accuracy required for characterization.

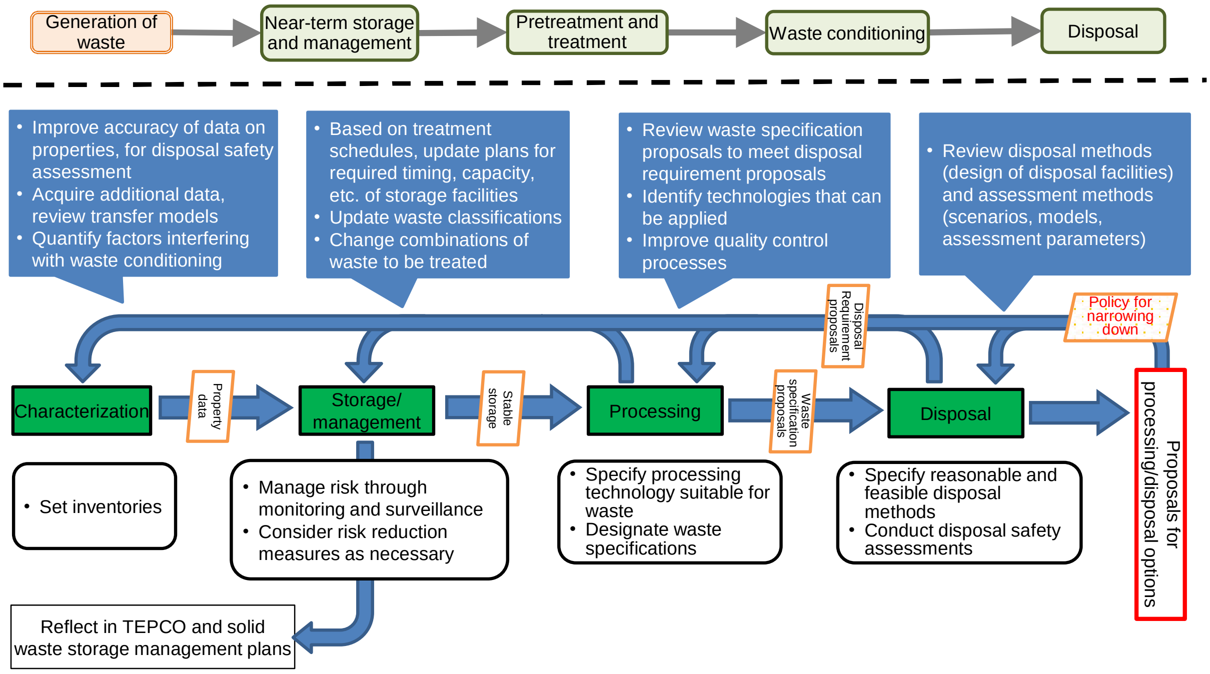


Fig. 21 Procedure to reasonably select safe processing/disposal methods of solid waste

3.2.4 Summary of key technical issues

The main technical issues and plans described in this section are summarized as shown in Fig. 22.

The Mid-and-Long-term Roadmap stated that the properties of solid waste would be analyzed, and the specifications of waste form and their production methods will be determined in Phase 3. Therefore, in Phase 3-[1], the study will be initiated to present appropriate overall measures for specific management approaches for solid waste. Specifically, based on the realistic inventory setting that incorporates property data evaluated by accumulating analysis data and applying statistical methods,

- Widely acquire findings by waste stream by accumulating trial examples of appropriate waste stream settings under the assumption of ensuring safety,
- Then, consideration will be given to specify appropriate overall picture covering the entire waste stream, 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.

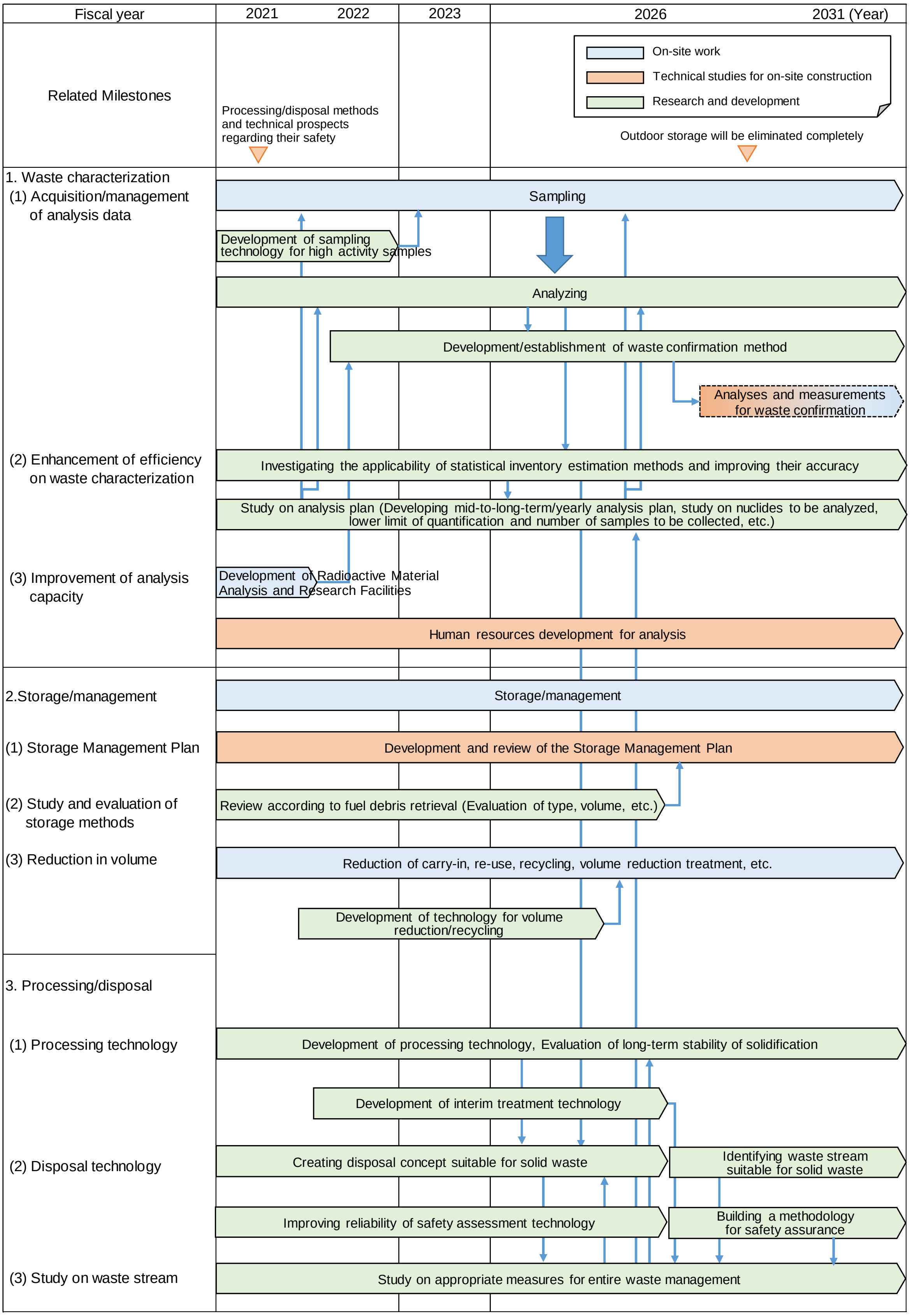


Fig. 22 Key technical issues and future plans on waste management (progress schedule)

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.

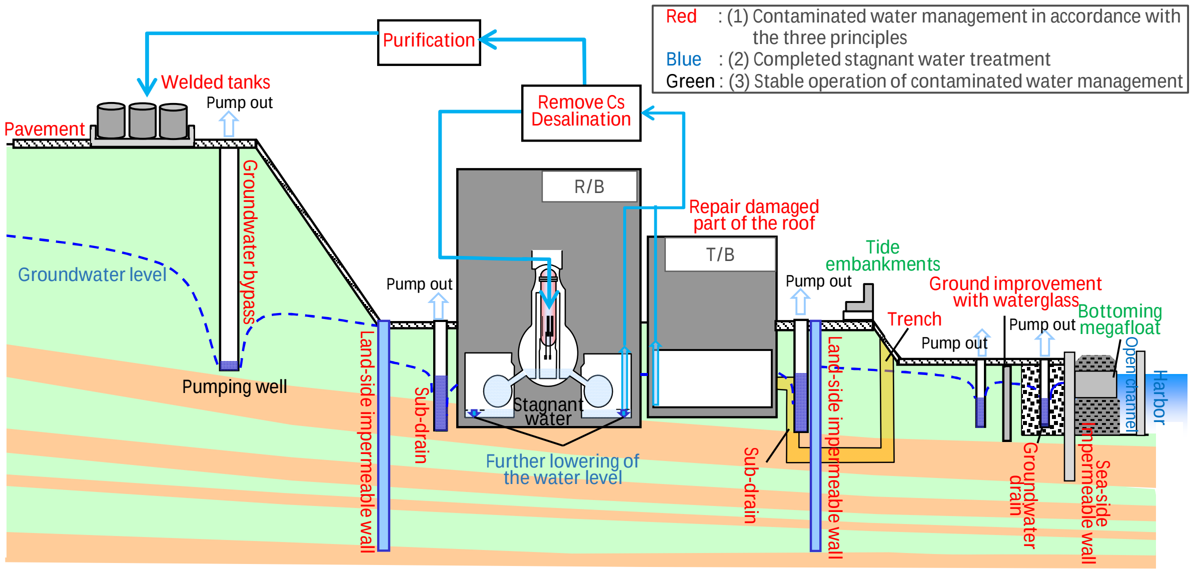
(2) To arrange the relationship with a decommissioning process including full-scale fuel debris retrieval beginning in the near future, and to promote examination of the measures of the contaminated water management for medium-and-long term prospects.

(3) To discharge ALPS-treated water[35] safely and reliably to secure the site and other resources and steadily advance the entire decommissioning process.

3.3.2 Progress

Fig. 23 shows the outline of contaminated water management. 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/rainwater that leaked into the buildings is liquid containing a considerable amount of the dissolved radioactive materials (inventory) from the perspective of measures to reduce the risk from radioactive materials. Therefore, its Hazard Potential is high and so is the Requiring Level for Safety Management, as the storage condition of such stagnant water deviates from what is originally intended. For this stagnant water in buildings, excluding the reactor buildings of Units 1 to 3, where circulating water injection is ongoing, and the process main building and high-temperature incinerator building storing contaminated water temporarily for purification treatment, the treatment of stagnant water in buildings was completed in 2020, and the inventory was significantly reduced. However, the Hazard Potential is still high.

[35] 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



(Source: TEPCO)

Fig. 23 Outline of contaminated water management [36]

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

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

To reduce the amount of contaminated water generated to less than 100 m^3/day by the end of 2025, 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. As a result, the increase in the amount of contaminated water generated during rainfall also tended to be controlled. The amount of contaminated water generated decreased from about 490 m^3/day (FY 2015) before management was in place to about 90 m^3/day (FY 2022). However, because the amount of rainfall in FY 2022 was lower than the average year, whether the goal of the Mid-and-Long-term Roadmap is achieved will be evaluated based on data from FY 2023 onward. With the aim to limit the amount of contaminated water generated to about 50 to 70 m^3/day by the end of 2028, local water sealing in the buildings[37] has been implemented as a countermeasure to control the inflow to the buildings. Fig. 24 shows the progress of contaminated water management and changes in the amount of contaminated water generated.[38]

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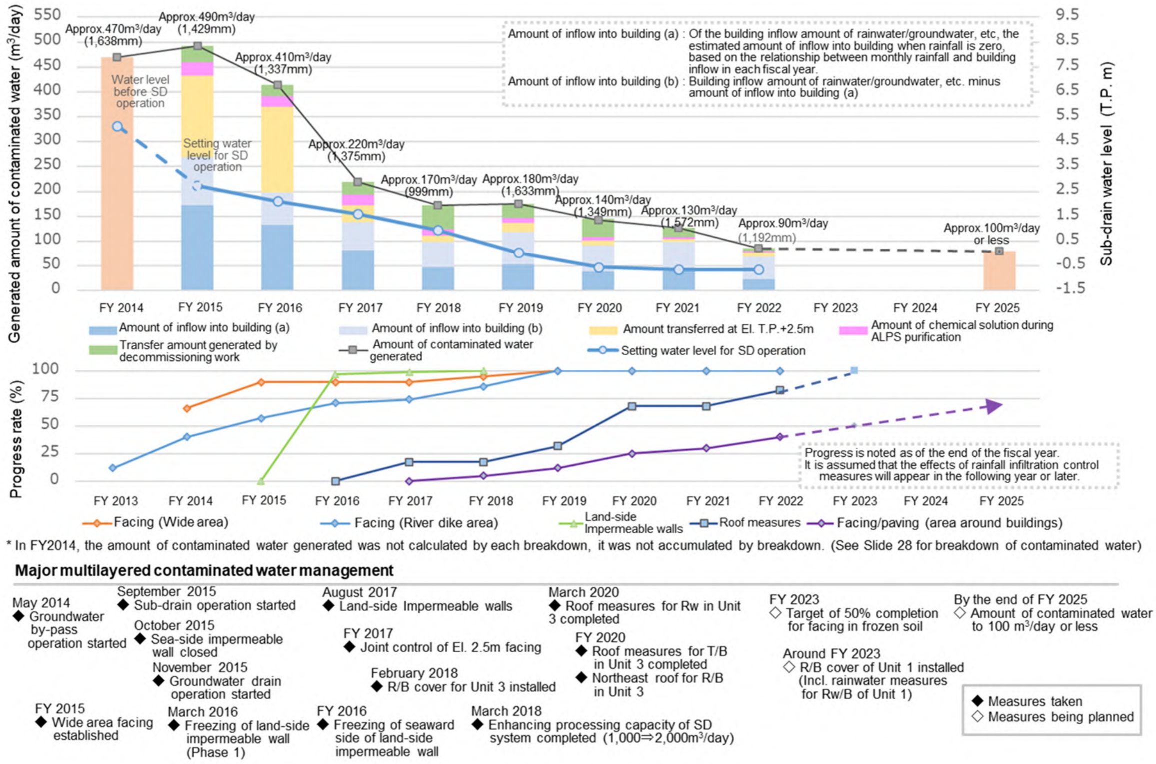
[36] Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water (112nd), Material 2-1, "Outline of decommissioning, contaminated water and treated water management," March 30, 2023

[37] 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 is present).

[38] Material 3-4, The 108th the Study group on Monitoring and Assessment of Specified Nuclear Facilities



(Source: TEPCO)

Fig. 24 Progress of contaminated water management and changes in the amount of contaminated water generated.[38]

(2) 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 process main building, and the high-temperature incinerator building, FY 2022 saw the achievement of a milestone in the Mid-and-Long-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 process main building and the high-temperature incinerator building.

(3) Efforts for stable operation of contaminated water management

As for tsunami countermeasures, the construction of the Kuril Trench tsunami tide walls was completed in September 2020, and the measures for closing building openings were taken in January 2022, followed by the installation of the Japan Trench tsunami tide walls, the reinforcement of the land-side impermeable walls, the relocation of the sub-drain and other water collection systems from the revetment side to higher ground, and the transfer of sludge generated by decontamination devices to higher ground. As a countermeasure for heavy rain, the new Drainage Channel D was installed to eliminate the risk of inundation in the vicinity of Units 1 to 4, which has been in service in low radiation-dose areas since August 2022. After a constant monitoring system for Drainage Channel D was completed in November 2022, and the widening and bypassing of the existing drainage was completed in February 2023, the full operation of Drainage Channel D began to enhance the drainage function of the existing drainage channels.

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

(4) Efforts toward discharging 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[39,40], 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[41] at the Inter-Ministerial Council for Countermeasures on 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 a Cabinet Meeting for the Steady Implementation of the Basic Policy on Disposal of ALPS-treated water to follow up on the implementation status of matters specified in the basic policy and implement additional measures flexibly. Table 3 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 Cabinet Meeting to compile immediate measures and a specific action plan and manage the progress. The government has held six meetings of related ministers to date to compile immediate measures and concrete action plans and manage 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.

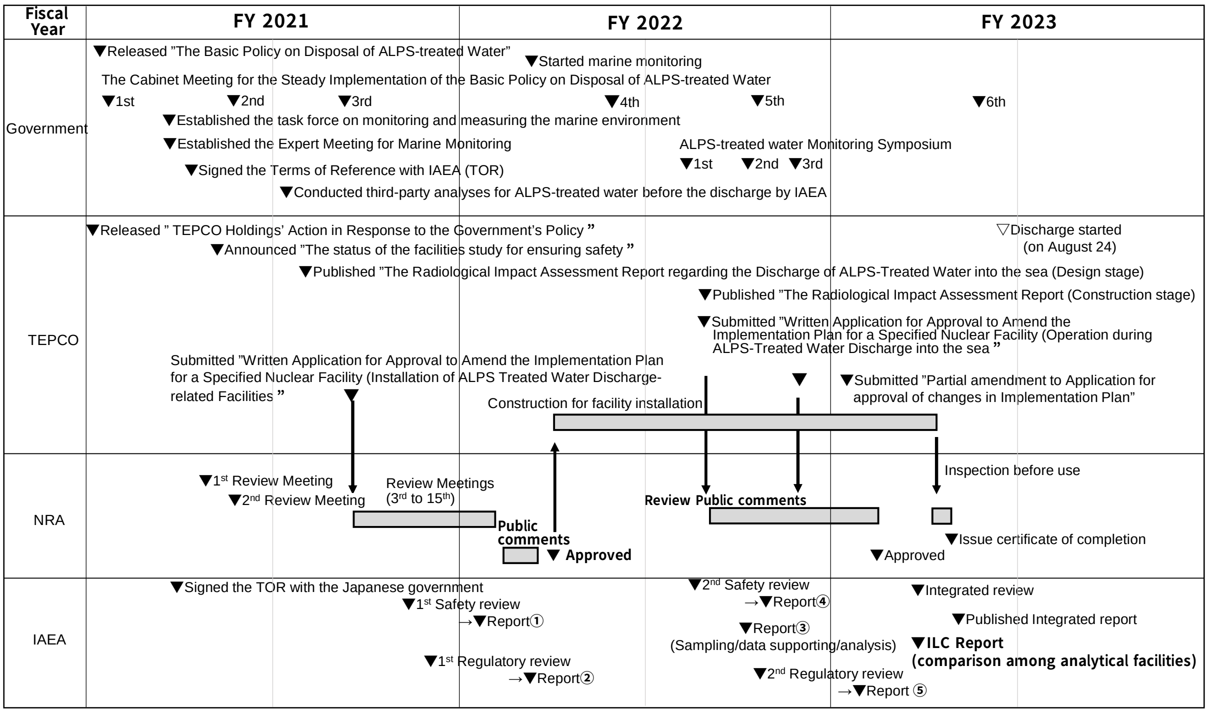
[39] Tritiated Water Taskforce Report, June 3, 2016

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

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

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 NRA in December 2021 and obtained approval in July 2022.

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



Subsequently, TEPCO specified the organizational structure for the operation, maintenance, management of ALPS-treated water dilution/discharge facilities, selected nuclides to be measured and assessed to verify whether the discharge standards are satisfied. 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 discharging ALPS-treated water into the sea) in November 2022. Reflecting the discussions at the subsequent technical meetings to review the implementation plan for the specified nuclear facility 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 discharging ALPS-treated water dilution/discharge facilities, full-scale construction, including an undersea tunnel, began in August 2022, and was completed in June 2023, after that, pre-service inspection by the NRA was completed.

A conceptual diagram and general view of the discharge facility published by TEPCO are shown in Fig. 25 and Fig. 26, respectively[42,43]. These discharge 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 measurement/verification 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[44] are not significantly present, and that (4) there are no water quality problems.

② Diluting facility

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.[45] 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 opening ditch of the intake channel 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 if the values that exceed the criterion level to suspend discharge are confirmed in the marine monitoring.

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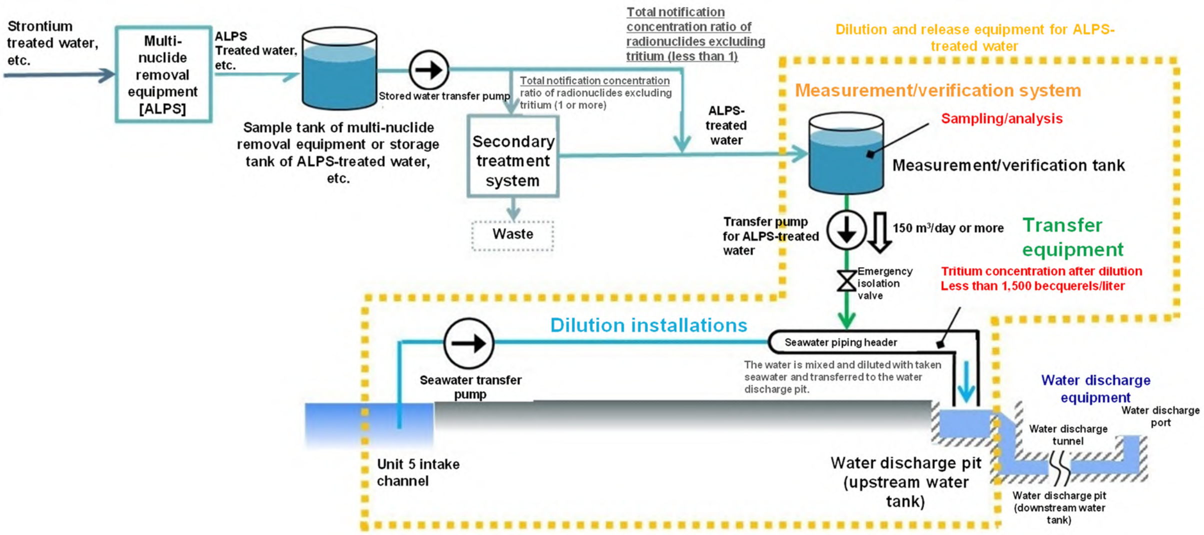
[42] 98th meeting of the study group on monitoring and assessment of specified nuclear facilities, Material 2-2, Installation of New ALPS Treated Water Dilution/ Discharge Facilities and the Related Facility, March 14, 2022

[43] TEPCO webpage, https://www.tepco.co.jp/press/release/2023/pdf3/230822j0101.pdf

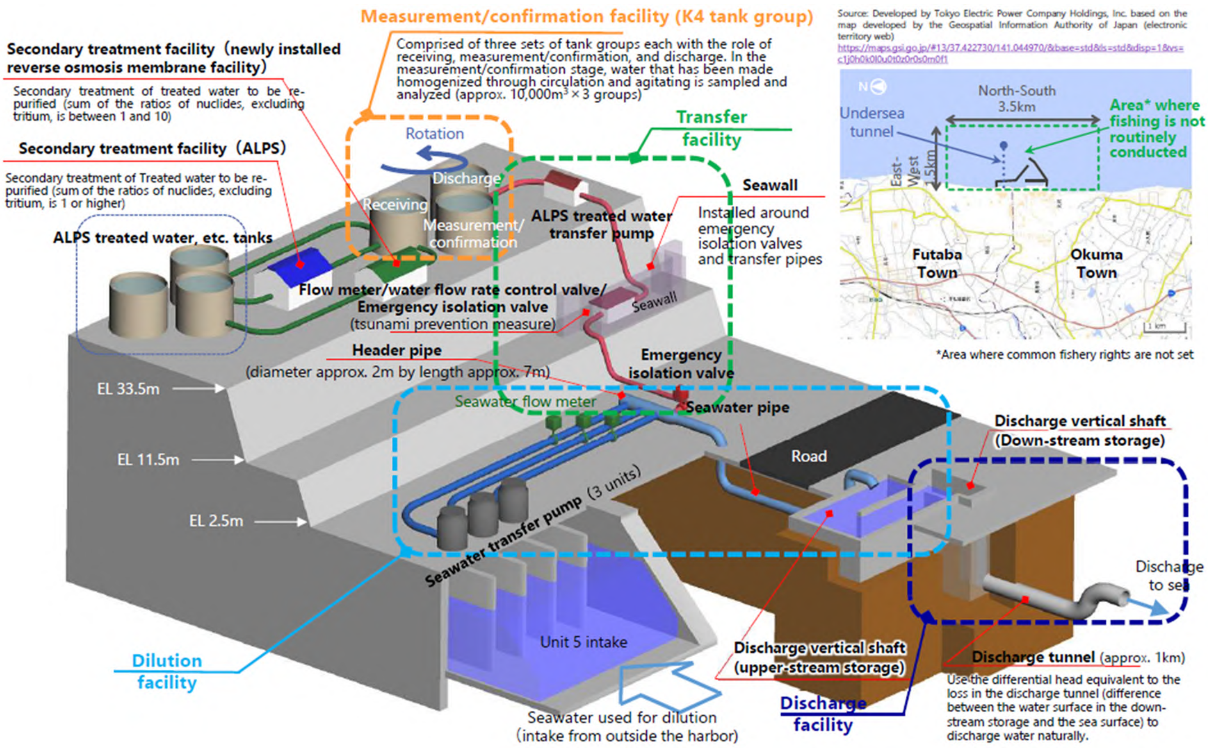
[44] Nuclides to be removed by ALPS (39 nuclides) other than those to be measured and assessed (29 nuclides)

[45] This is 1/40 of the regulatory concentration limit (60,000 Bq/L) and approximately 1/7 of the World Health Organization's (WHO) drinking water quality guidelines (10,000 Bq/L).



(Source: TEPCO)

Fig. 25 Conceptual drawing of discharge facilities



(TEPCO material edited by NDF)

Fig. 26 General view of discharge facilities [43]

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[46] 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.
- 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 sixth meeting of the Inter-Ministerial Council concerning Decommissioning, Contaminated Water, and Treated Water Management and the sixth meeting of the Inter-Ministerial Council concerning the Continuous Implementation of the Basic Policy on Handling of ALPS Treated Water 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[47], the ALPS treated water was discharged to the sea on 24 August, based on the proposed exact timing of the discharge of ALPS-treated water into the sea .

In order to ensure that the efforts related to the discharge of the ALPS-treated water proceed, TEPCO strengthened the systems, such as establishing of 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” which is responsible for centrally handling information dissemination, reputational measures and compensation, not only in Fukushima but also in various regions across the country. The system was strengthened by establishing the “ALPS-treated water Impact Response Team”[48].

Moreover, efforts are being made to disclose the on-site situation in a timely and easy-to-understand manner through communication on various occasions, such as visiting explanations and briefing sessions, and through information dissemination via various media, such as the website (Treated 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 [49], 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.

3.3.3 Key issues and technical strategies to realize them

3.3.3.1 Control of contaminated water generation amount

As for the control of the amount of contaminated water generated, efforts are being made to achieve the roadmap target of 100 m^3/day or less for average rainfall by 2025 through measures in progress to reduce inflow to buildings, such as lowering the sub-drain water level and facing. In

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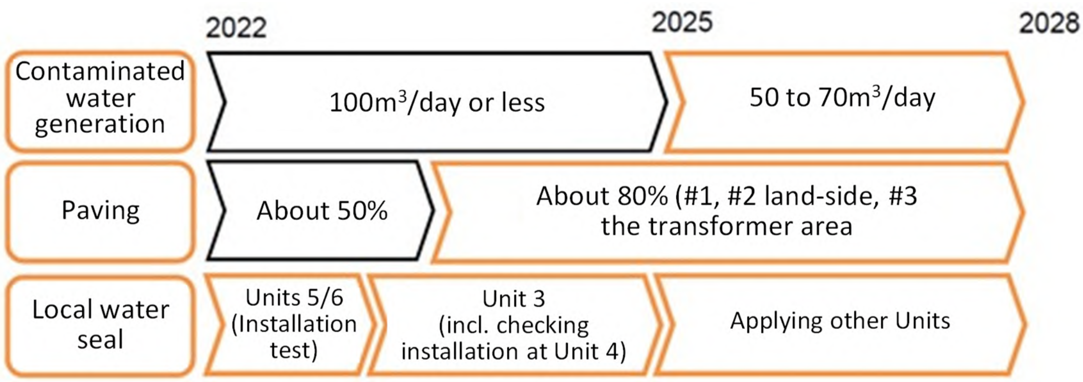
[46] https://www.iaea.org/sites/default/files/iaea_comprehensive_alps_report.pdf, on IAEA website
[47] https://www.kantei.go.jp/jp/singi/hairo_osensui/dai6/siryou2.pdf, on Prime Minister’s Office of Japan website
[48] https://www.tepco.co.jp/press/release/2023/1666016_8713.html, on TEPCO website
[49] https://www.tepco.co.jp/decommission/progress/watertreatment/dischargefacility/, on TEPCO website

addition, efforts to further reduce inflow to buildings are planned with local water sealing even after 2025 (Fig. 27).

The penetration in exterior walls and gaps between buildings, which are the main factors of groundwater inflow into buildings, has a depth distribution as shown in Fig. 28[50]. Especially in the gaps between buildings, there are nearly 200 sites of penetration at T.P. -0.65 m (Fig. 27), the current sub-drain water level (L value). If the water level is lowered to the assumed groundwater level in FY2025 (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.

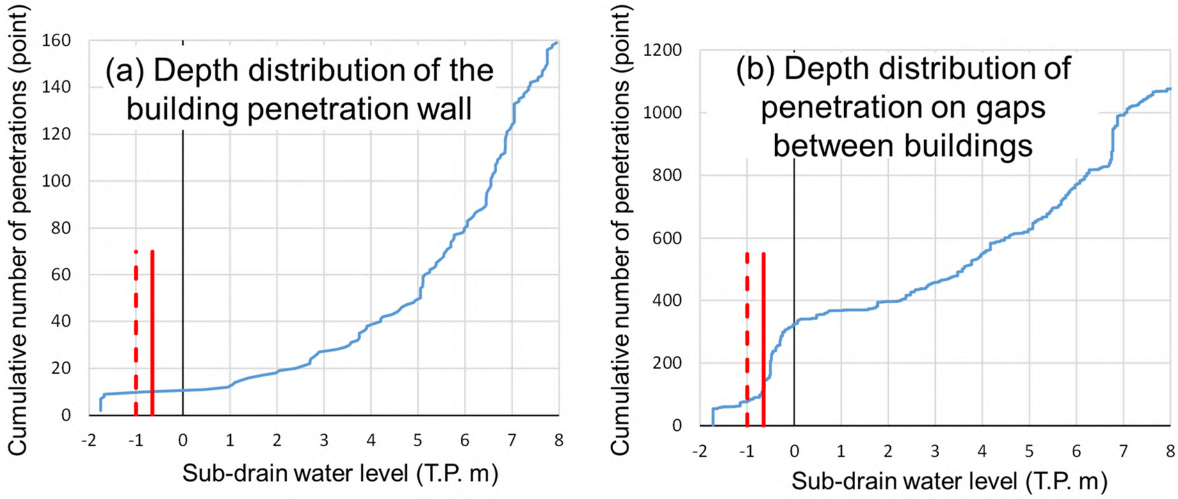
To suppress groundwater inflow from the penetration sites of these gaps, the plan is to establish a water seal part by boring holes at the ends of the gaps between buildings and filling them with mortar, etc. (Fig. 30). As for the water seal at the ends of the gaps, the construction method and materials were tested using test specimens off-site, and the results will be deployed in Unit 3. In addition, water sealing at penetration sites of the exterior walls of the buildings and facing of the areas around the buildings will be carried out in parallel while coordinating with other decommissioning work, targeting at the end of FY2028 (about 50–70 m^3/day).



(Source: TEPCO)

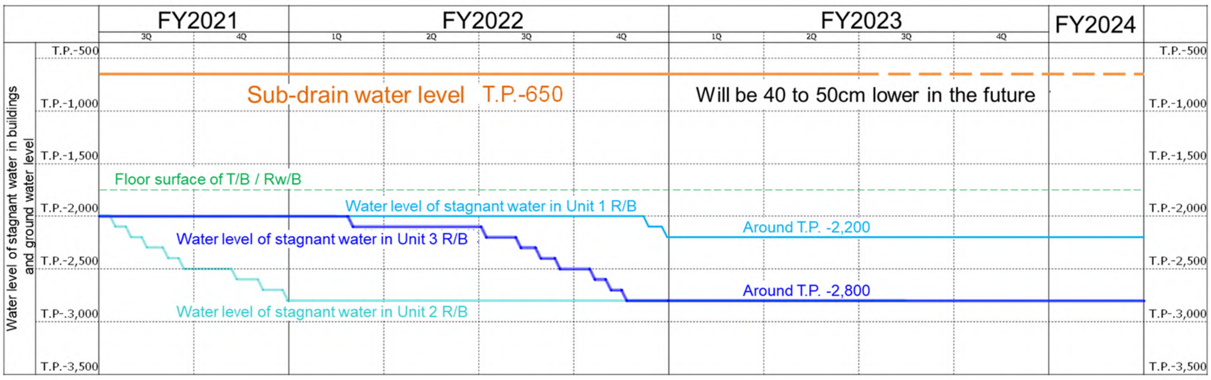
Fig. 27 Conceptual drawing of water sealing at the edge of the gaps between buildings

[50] Committee on Countermeasures for Contaminated Water Treatment (26th meeting), Material 1, “Status of contaminated water management at the Fukushima Daiichi NPS”, December 21, 2022



(TEPCO material edited by NDF)

Fig. 28 Depth distribution of the building penetrations[50]



(TEPCO material edited by NDF)

Fig. 29 Lowering of sub-drain and building water levels[50]

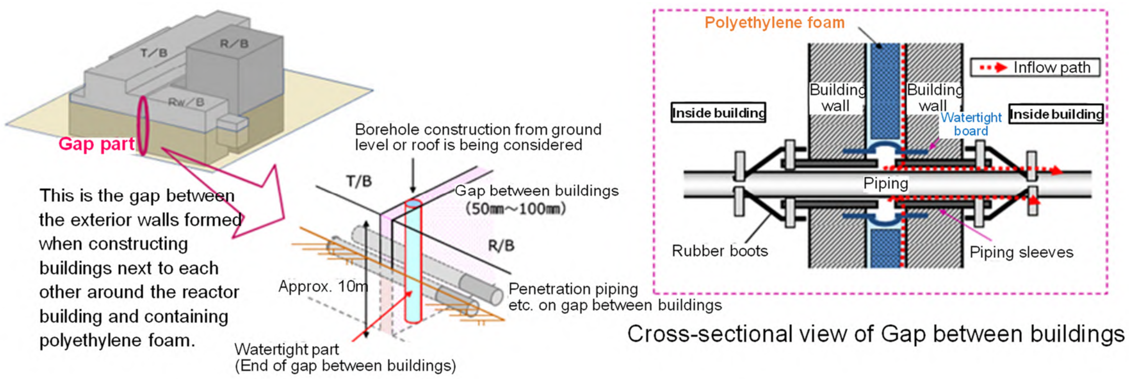


Fig. 30 Conceptual drawing of water sealing at the edge of the gap between buildings[50]

3.3.3.2 Treatment of stagnant water in buildings

(1) Further reduction of stagnant water

Due to the presence of high-radiation dose sludge containing 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.

Although reducing the amount of stagnant water in the reactor building to about half the level at the end of 2020 has been achieved, setting a new goal to reduce the stagnant water should be considered in integration with the fuel debris retrieval method, and shifted to the steps of stable stagnant water control through decommissioning work.

(2) 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 and high-temperature incinerator building. 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 process main building and high-temperature incinerator building[51].
- Install temporary storage facilities for stagnant water instead of storage on the basement floor[52].

The basement floors of both the process main building and the high-temperature incinerator building 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 work plan to recover zeolite sandbags under consideration is shown below. Fig. 30 shows the outline.

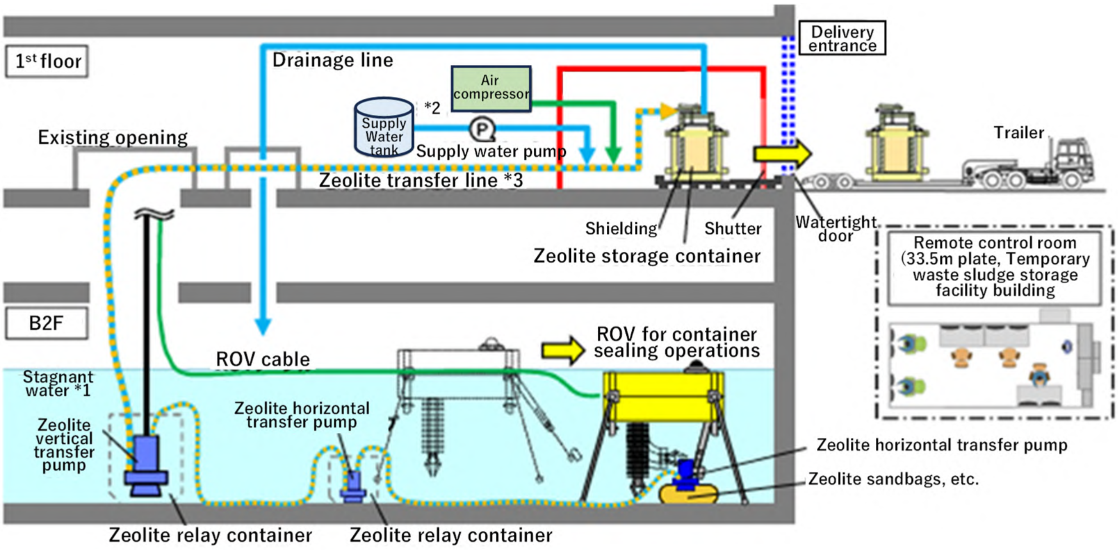
(1) Collect zeolite sandbags in a submerged state as much as possible to improve work efficiency.

[51] The 5th Engineering Meeting, Material 2-2 “Status of zeolite sandbags disposal study”, February 1, 2023
[52] NRA website; https://www.nra.go.jp/disclosure/law_new/FAM/140000310.html

(2) Transfer the collected zeolite and other materials to the ground floor by a robot for recovery (ROV (Remotely Operated Vehicle) + pump).

(3) Desalinate, dehydrate them in the building, seal them in metal storage containers, and transfer them to temporary storage facilities.

In this task, zeolite will be collected and recovered by suction as granular particles. This procedure may apply to 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.



(Source: TEPCO)

Fig. 31 Overview of the zeolite sandbag recovery task[51]

Because lowering the water level in the process main building and the high-temperature incinerator building to expose the floors will prevent the storage of stagnant water in these buildings, designing temporary storage facilities for stagnant water is in progress. This will take over the following functions that these buildings have performed.

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

These temporary storage facilities for stagnant water will be installed on the fourth floor of the process main building. The basement floor of the process main building after installation will be used only when the in-leak volume increases during heavy rain. The temporary storage facilities for stagnant water will combine the following two types of tanks to take over the above functions.

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

As the capacity of temporary storage tanks will become much smaller than that of the basement floor of the process main building (maximum capacity: approximately 16,000 m^3) and the basement floor of the high-temperature incinerator building (maximum capacity: approximately 5,000 m^3), design studies are underway to maintain their function even with a smaller capacity, and installation work followed by operational checks is scheduled from FY 2023 to FY 2024.

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

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

The relatively high total alpha concentrations have been detected in the stagnant water collected from the bottom of the torus room of the reactor building, and they have been confirmed to exist mainly in the form of granular particles (alpha sludge).[53] Since the effective dose factors of α-nuclides are remarkably high when inhaled or ingested, special management and countermeasures are required if α-nuclides spread to stagnant water in buildings or water treatment systems. The challenge is limiting the spread of α-nuclides as much as possible to avoid such a situation.

Currently, a total alpha concentration in the order of 10 Bq/L is maintained at the cesium sorption apparatus (SARRY/SARRY II) inlet, and the spread of contamination to the downstream side is suppressed. However, with the increase in the accumulated sludge at the bottom of the building in the future, more sludge may be mixed into the contaminated water, and the total alpha concentration at the water treatment system inlet may rise. To address such concerns, installing filter systems in the subsequent stage of the cesium sorption apparatus is under consideration[54].

With regard to water treatment systems for fuel debris retrieval, it is important to examine the timing and method of retrieval and the performance of the treatment facilities required at that time in a consistent manner.

When retrieving fuel debris, contaminated water containing a large amount of fine particles is generated by fabrication, including cutting and other processes, and α-nuclides in fuel debris may exist in various forms, such as fine particles, ions, and colloids. Because the water quality of such

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

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

contaminated water depends on the fabrication method, including cutting and other processes, it is difficult to assume the water quality when the fuel debris retrieval method has not been determined. Thus, the challenge is designing the water treatment system for fuel debris retrieval to cope with various water quality conditions and forms of α-nuclides.

However, analysis of the stagnant water in buildings has shown that the total alpha can be reduced by two to three orders of magnitude by filtration, indicating that most α-nuclides can be removed by filtration. Since mechanical fabrication without using chemicals leads to only small changes in chemical water quality, most α-nuclides are generated as fine particles, as in these analysis results, and the concentration of soluble α-nuclides may be maintained at a low level. Therefore, the form and particle size of α-nuclides at the sampling points should be verified to incorporate them into the system design for further expansion of fuel debris retrieval in scale. Specifically, to establish fabrication methods, including cutting and other processes, laboratory tests should be conducted to determine their impact on the chemical changes in water quality, which will enable the establishment of realistic water quality conditions for contaminated water and lead to rationalization and improved reliability of the water treatment systems.

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

The challenge is to ensure that periodic inspection and updating of equipment, including land-side impermeable walls, sub-drain systems, and existing water treatment systems (e.g., SARRY, ALPS), are implemented in order to maintain the effectiveness of contaminated water management over the medium-to-long term. 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/arrange backup and alternative items for the 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, the challenge is to take a bird's-eye view of contaminated water management in the medium to long term and to establish an approach to more stable contaminated water management and more appropriate maintenance/management for each system, in conjunction with the selection of methods for further expansion of fuel debris retrieval in scale that is currently underway. With this, studies on these issues should be carried out, and the interference with the fuel debris retrieval work should be considered. Specifically, if fuel debris retrieval is to be conducted under submersed conditions (the submersion method), the method will naturally have water seals, and therefore the current contaminated water management for the target units will no longer be necessary. On the other hand, if the method is not based on the submersion method (i.e., partial submersion method), it is desirable to employ the method that allows contaminated water management combined with in-leak control on the assumption of preventing out-leak of contaminated water. Thus, consideration should be given not to interfere with installing structures to retrieve fuel debris or demolishing surrounding facilities. In all methods, medium and long-term contaminated water management should be considered in anticipation of fuel debris retrieval methods, together with the verification of actual site applicability and technical feasibility.

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

The discharge of liquid waste generated in nuclear facilities into the sea, pursuant to the law, with a sufficiently small radiological impact on the human population and the natural environment is a globally method recognized and is adopted widely in Japan and abroad. The IAEA has published a review finding that activities related to the discharge of ALPS-treated water into the sea are consistent with relevant international safety standards and have a negligible radiological impact on humans and the environment. It is necessary to disseminate highly transparent information based on scientific evidence, including the above, to prevent the impact of reputational damage.

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

(1) ALPS-treated water analysis and evaluation structure

Fig. 32 shows the analysis and evaluation structure of ALPS-treated water collected at the measurement and confirmation facilities.

In addition to its own analysis before the discharge to the sea, TEPCO outsources to independent external organizations with ISO/IEC 17025[55] certifications and performs analysis to determine whether or not 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 engaged in ALPS-treated water analyses to support data submitted by TEPCO and verify analysis quality. The first inter-laboratory comparison (ILC) result report[56] published in May 2023 concluded that TEPCO has the ability to analyze ALPS-treated water accurately and precisely, and sampling procedures and nuclide analysis methods are appropriate.

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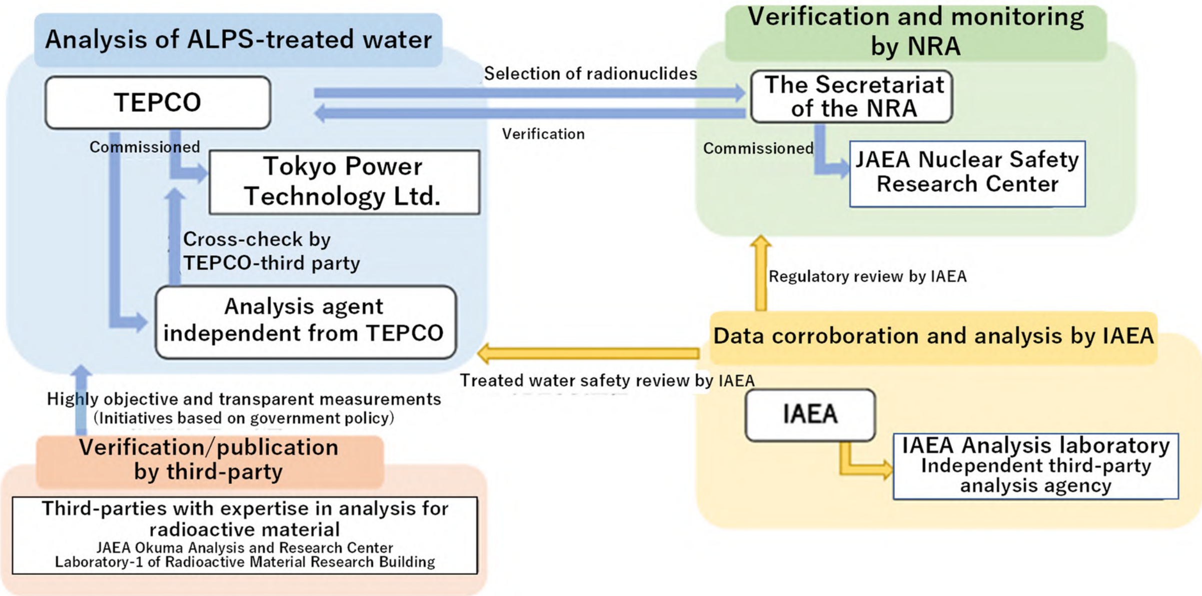
[55] International standards developed by the International Organization for Standardization for general requirements on the competence of testing and calibration laboratories.

[56] IAEA Website，https://www.iaea.org/sites/default/files/first_interlaboratory_comparison_on_the_determination_of_radionuclides_in_alps_treated_water.pdf



(Source: NRA)

Fig. 32 ALPS-treated water analysis and evaluation structure [57]

In this manner, several institutions are conducting various third-party analyses of pre-discharge ALPS-treated water for comparison with the analysis data disclosed by TEPCO. It is important that those data are made publicly available in a prompt and transparent manner. It is important to maintain such a system from the viewpoint of maintaining the quality of analysis and evaluation in light of the long-term nature of ocean discharges.

(2) Periodic verification of nuclides to be measured and evaluated

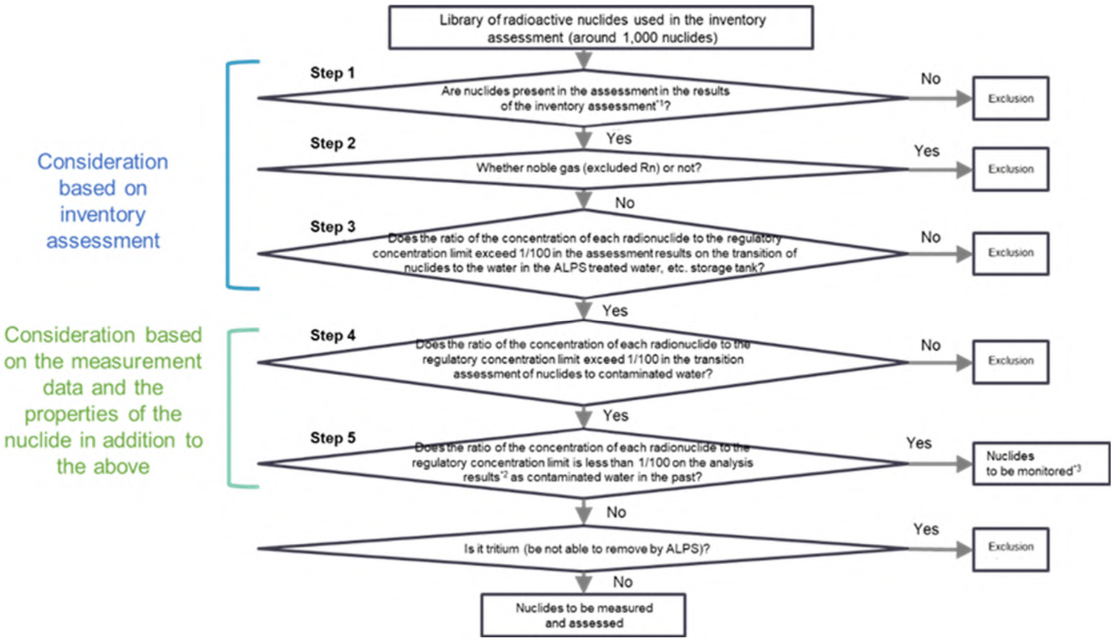
The target nuclides to be measured and evaluated before the discharge of the ALPS-treated water into the sea were selected after re-examining the nuclides that could be contained in the contaminated water before treated by cesium sorption equipment, ALPS and other systems in significant amounts, based on knowledge of decommissioning and buried facilities at nuclear power plants in Japan. A flow for selecting target nuclides (Fig. 33) was established, based on experts' opinions, by combining inventory assessment, measured data of nuclide concentrations in stagnant water in buildings, and study of the physical and chemical properties of nuclides. Consequently, 29 nuclides were selected as nuclides to be measured and evaluated based on this procedure [58] (Table 4). The approach to the selection of nuclides to be measured and evaluated is summarized in the Attachment 14.

When discharging ALPS-treated water into the sea, it is necessary to confirm that the sum of the ratios to the regulatory concentrations limits of the selected nuclides to be measured and evaluated is less than 1. On the other hand, although the target nuclides are selected after checking the results of the past analysis, it may change depending on the progress of decommissioning work in the future, for example due to factors such as changes in the transfer

[57] The 101st Study group on monitoring and assessment of specified nuclear facilities, Material 1-1, Attachment 2

[58] 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

coefficient from fuel debris to contaminated water. Therefore, it is necessary to confirm that the ALPS-treated water does not contain significant amounts of nuclides other than the selected ones to be measured and evaluated (hereafter referred to as “other nuclides”). If it is confirmed that significant amounts of other nuclides are contained (at 1/100 or more of the regulatory concentration limit), the target nuclides should be reevaluated based on the flow in Fig. 33. The decay of the radionuclides will also be reflected in the selection flow. If other nuclides are identified as a result of this reevaluation, an additional environmental impact assessment must be conducted. Of the 62 nuclides to be removed by ALPS, 39 nuclides[59] not to be subject to measurement and evaluation this time will be independently measured before the release to confirm that they are not contained in significant amounts to prevent reputational damage.



*1: The decay period of the inventory evaluation is appropriately set according to the time when the selection result is to be used. (First time set to 2023 (12 years after the accident))
*2: Nuclides that have been detected in the past are confirmed by the maximum value of the detection value, and nuclides that have never been detected are confirmed by the minimum value of the detection limit value
*3: Nuclides that shall be continuously confirmed if significantly exists in contaminated water.

(Source: TEPCO)

Fig. 33 Flow to select nuclides to be measured and evaluated[58]

[59] The 29 nuclides selected this time 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.

Table 4 Nuclides to be measured and evaluated and their quantification methods[58]

No.	Nuclides	Quantification method	*No.*	Nuclides	Quantification method
1	C-14	Beta-ray measurement after chemical separation	16	Ce-144	Gamma-ray nuclide analysis
2	Mn-54	Gamma-ray nuclide analysis	17	Pm-147	Evaluated from the radioactivity concentration of representative nuclides (Eu-154)
3	Fe-55	Beta-ray measurement after chemical separation	18	Sm-151	
4	Co-60	Gamma-ray nuclide analysis	19	Eu-154	Gamma-ray nuclide analysis
5	Ni-63	Beta-ray measurement after chemical separation	20	Eu-155	Gamma-ray nuclide analysis
6	Se-79	Beta-ray measurement after chemical separation	21	U-234	Evaluated as included in total alpha radioactivity
7	Sr-90	Beta-ray measurement after chemical separation	22	U-238	
8	Y-90	Radiative equilibrium with Sr-90	23	Np-237	
9	Tc-99	ICP-MS measurements	24	Pu-238	
10	Ru-106	Gamma-ray nuclide analysis	25	Pu-239	
11	Sb-125	Gamma-ray nuclide analysis	26	Pu-240	
12	Te-125m	Radiative equilibrium with Sb-125	27	Pu-241	Evaluated from the radioactivity concentration of representative nuclides (Pu-238)
13	I-129	ICP-MS measurements			
14	Cs-134	Gamma-ray nuclide analysis	28	Am-241	Evaluated as included in total alpha radioactivity
15	Cs-137	Gamma-ray nuclide analysis	29	Cm-244	

(Source: TEPCO)

(3) 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[60]. 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 efforts have been made to strengthen marine monitoring (Fig. 34). 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. Moreover, immediately after the start of the ocean discharge, swift analysis is performed, and the results are published in a preliminary report.

In addition, to maintain and improve the reliability and transparency of marine monitoring data, analysis of supporting data and inter-analytical laboratory comparison (ILC) were conducted by the IAEA. In the ILC result report on radionuclide analysis of seawater, seabed soil and fish,

[60] https://radioactivity.nra.go.jp/ja/contents/16000/15822/24/1001_0802r.pdf, on NRA website

published in June 2022[61], 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”.

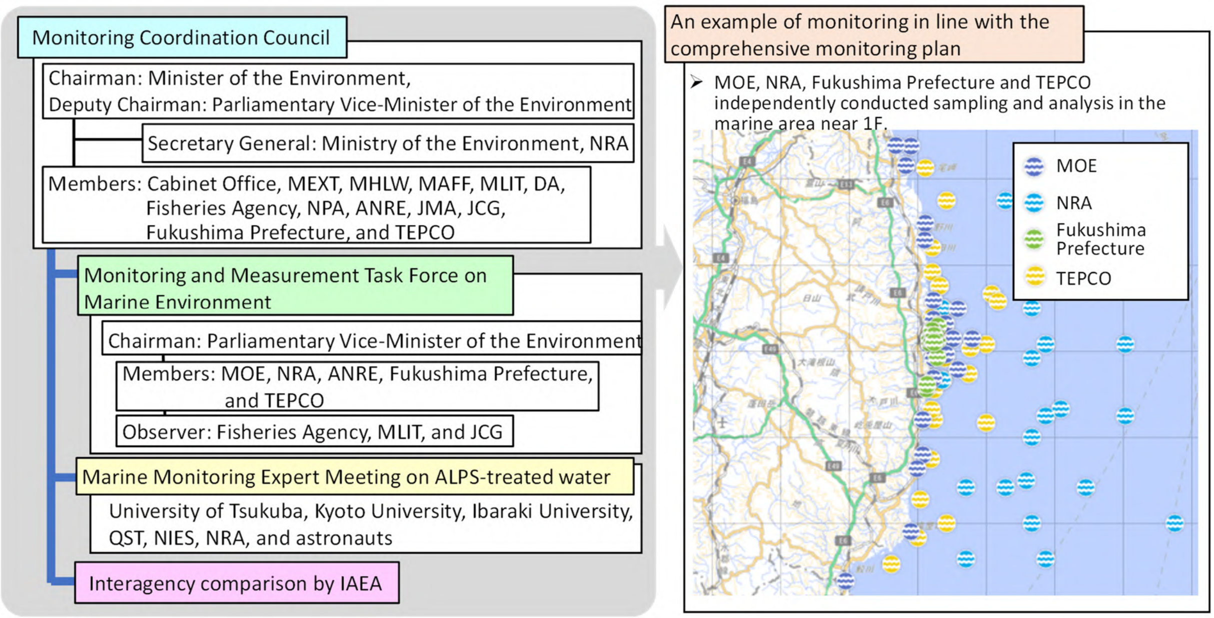


Fig. 34 Framework for discussion and implementation system for marine monitoring (Monitoring Coordination Council material[62], compiled by NDF with reference to TEPCO website[63] and other material etc.)

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 efforts are being made, 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[64].

61 IAEA Website，https://www.iaea.org/sites/default/files/22/06/2022-06-21_japan_ilc_2021_report_v4.2.pdf
62 The Ministry of the Environment Website, https://www.env.go.jp/content/000120258.pdf
63 TEPCO Website, https://www.tepco.co.jp/decommission/progress/watertreatment/monitoring/
64 Launch of the Overarching Radiation-monitoring data Browsing System in the coastal ocean of Japan (ORBS), March 13, 2023

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.

(4) Future operational plans, etc.

TEPCO should continue to conduct checks and reviews on the operational performance of the facilities for the discharge of ALPS-treated water into the sea and the results of marine environmental monitoring, and review and expand the plan flexibly as necessary. Then, the prompt and reliable implementation of site usage after the release of treated water is a challenge. With this, it is necessary to develop a discharge plan in accordance with the site use plan and revise it appropriately according to the situation while considering the concentration/decay of tritium contained in treated water in tanks and attenuation. Moreover, providing of education and training will be needed in a planned manner, including for contractors engaged in system operation and analysis, in order to proceed with prolonged decommissioning work safely and steadily.

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.

3.3.4 Key technical issues and future plans

The key technical issues and future plans described in this section are summarized as shown in Fig. 35.

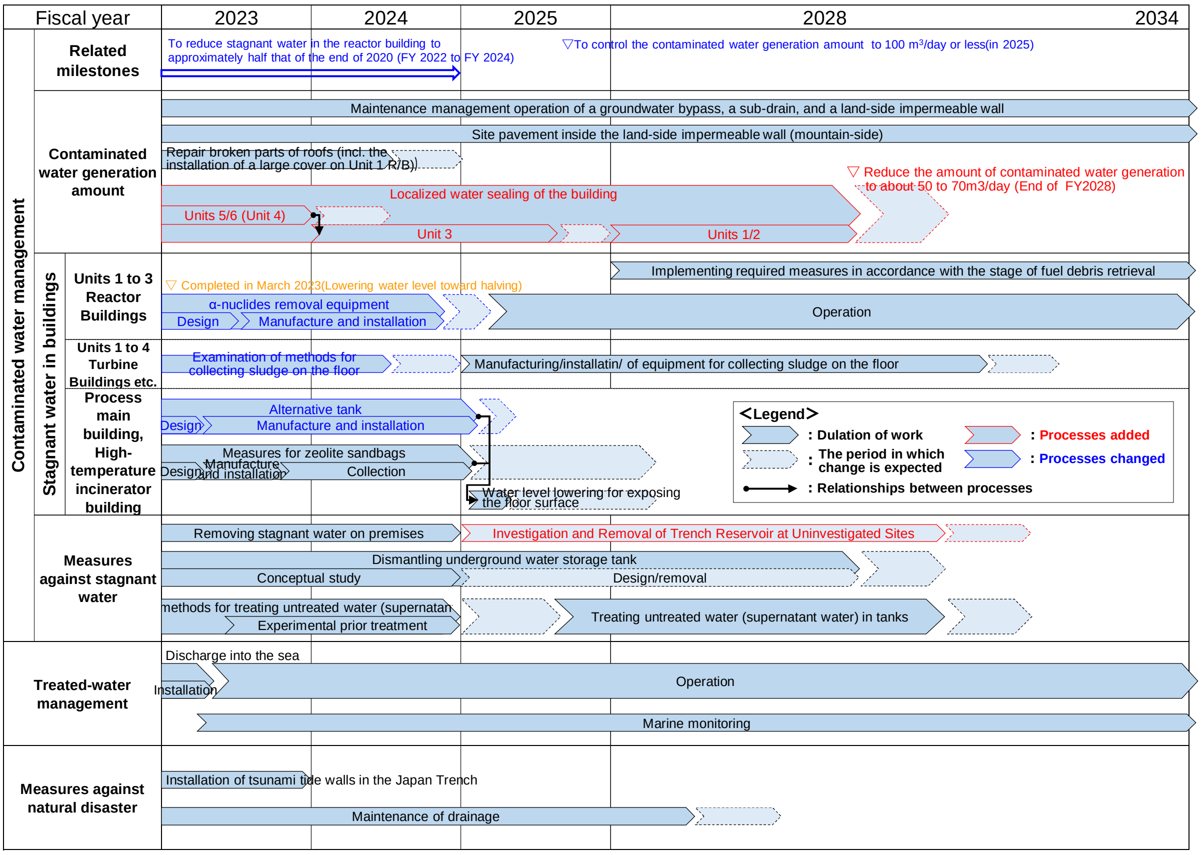


Fig. 35 Key technical issues and future plans on contaminated water/treated water management and natural disaster preparedness (progress schedule)

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. 36 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. 37 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, the plan is to start transferring new fuel from Unit 6 after FY 2023, and radiation dose measurement/cleaning of new fuel removed from Unit 4 was completed in March 2022.

Fig. 36 Layout drawing of the Common Spent Fuel Storage Pool and dry cask at the Temporary Cask Custody Area and the workflow

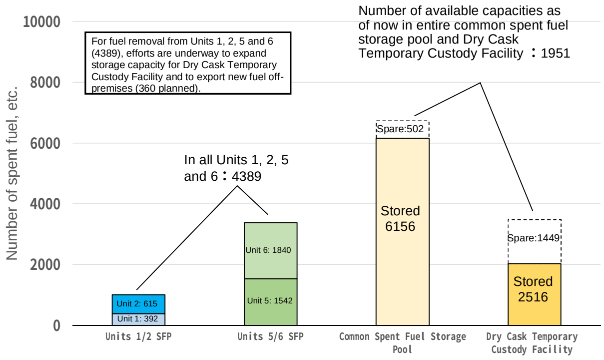


Fig. 37 Storage status of spent fuel (As of June 2023)

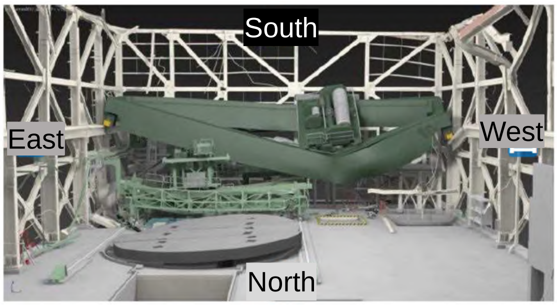
a. Unit 1

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. 38). 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. 39 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)

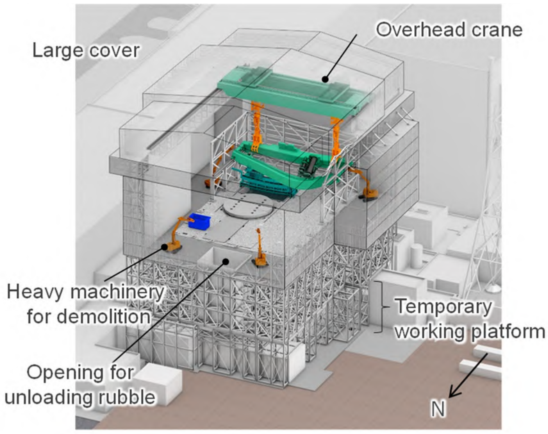
Subsequently, the area around the reactor building has been improved. Still, delays in removing Standby Gas Treatment System (hereinafter referred to as “SGTS”) piping (removal of high-dose pipes by remote control) caused delays in the preparatory work. The Mid-and-Long-term Decommissioning Action Plan 2023 states that, (as in the 2022 edition) due to delays in preparatory works, the installation of the large cover in Unit 1 is expected to be completed by the middle of FY 2024. Fuel removal in Unit 1, a milestone in the Mid-and-Long-term Roadmap, is expected to begin in FY 2027 to FY 2028 as planned. Work is underway to assemble a large cover frame in the off-site yard in parallel to installing a lower frame in the reactor building of Unit 1.



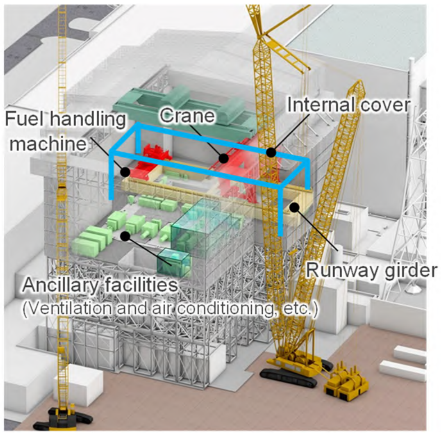
Condition of the existing installations under the collapsed roof (conceptual drawing)

Condition of the collapsed south-side roof

Fig. 38 State of the collapsed rubble on the Unit 1 operating floor



During rubble removal (Conceptual drawing)



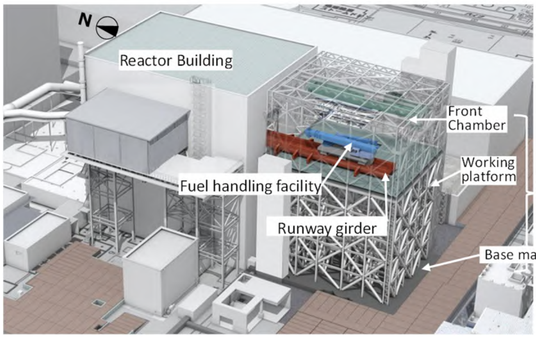
During fuel removal (Conceptual drawing)

Fig. 39 Fuel removal method from Unit 1 SFP

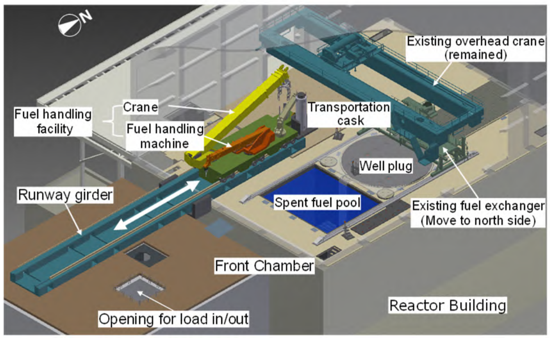
b. Unit 2

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. 40 shows a conceptual drawing of this method.

Ground improvement and the installation of the working platform base mat for fuel removal were completed in April 2022 and November 2022, respectively, and steel structure erection began in January 2023. Production of fuel handling equipment is also ongoing. Based on the results of dose surveillance in the operating floor conducted in 2021, the decontamination and installation of shielding on the upper part of the well-plug were carried out. The effectiveness of radiation dose reduction was rechecked in May 2022. In addition, the existing fuel handling equipment was relocated in June 2022, removing of obstacles from the spent fuel handling equipment operation room located on the south side of the spent fuel pool was completed of in March 2023, and decontamination is underway.



Fuel removal method (conceptual drawing)



Fuel handling facility (conceptual drawing)

Fig. 40 Fuel removal method from Unit 2 SFP

c. Units 5 and 6

For Units 5 and 6, the policy is to conduct fuel removal operation so as not to interfere with operations in Units 1 and 2, fuel transfer from the SFP to the Common Spent Fuel Storage Pool commenced in August 2022. The transfer of fuel from the Common Spent Fuel Storage Pool to dry casks at the Temporary Cask Custody Area was underway to secure the available capacity of the Common Spent Fuel Storage Pool. However, in May 2022, it became necessary to re-verify airtightness after loading fuel into dry casks. This led to a reconsideration of the fuel transfer process for Unit 6 from the Common Spent Fuel Storage Pool to the dry cask at the Temporary Cask Custody Area, causing a delay in the entire process of transferring spent fuel from Unit 6 to the Common Spent Fuel Storage Pool. Therefore, improvements have been made to ensure airtightness, including the cleaning of spent fuel with a newly introduced fuel cleaning system in the Common Spent Fuel Storage Pool and the addition of a process for water displacement in the dry cask. The presumed reason for the rework is that iron oxide (cladding) or calcium components (granular particles or ions) entered the flange surface when placing the primary lid of the dry cask in the Common Spent Fuel Storage Pool and formed foreign materials due to the effect of the transfer of fuel from the SFPs of Units 3 and 4 to the Common Spent Fuel Storage Pool.

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, in terms of risk reduction, the removal of such a high radiation dose equipment is needed following the fuel in SFP. With the removal 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.

3.4.3 Key issues and technical strategies to realize them

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.

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

(1) Unit 1

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:[65]

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

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

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

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.

(2) Unit 2

The key challenge is to remove fuel in the SFP from the opening on the south side of the operating floor using a fuel handling machine composed of a boom-type crane system, which has not yet been used for nuclear facilities in Japan. Since this fuel handling machine lacks precedent, the following measures should be implemented without fail.[67]

- Development of appropriate design and production schedules with a margin
- Conducting of mock-up tests that sufficiently simulate field conditions and operating methods, and feedback of these test results into design and production
- Sufficient mastery of system operation and functionality in advance due to the remote-controlled nature of the retrieval work

To install a fuel handling system, the issue is to steadily carry out preparatory work, including installing an anterior chamber on the working platform and an opening on the south side of the operating floor of the reactor building. The basic assumption in fuel removal from SFP is unattended operation by remote control. However, the challenge is to reduce the radiation dose on the operating floor as much as possible and improve the environment in light of the fact that attended operation is also assumed partially for system installation or troubleshooting, and the study group meeting mentioned above has pointed out that the well-plugs are highly contaminated[66].While decontamination and shield installation are underway for radiation dose reduction after relocating the existing fuel handling machine, installing an opening on the south side of the operating floor is scheduled after decontamination. Since the work area may be contaminated again, thorough measures to prevent dust dispersion should be taken when establishing the opening.

(3) 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.

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

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 the capacity of existing site bankers for storing high-radiation dose equipment of Unit 3, where removal has started, is limited, additional bunkers should be installed for other units where removal is also scheduled.

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. In addition to the existing metal casks, TEPCO has announced that it will study the application of concrete casks using canisters with proven track records overseas, as dry storage facilities.[68] Regardless of which dry storage facility is applied, the issue is the storage of damaged fuel existed in the pool.

Advantages of concrete casks include the following:

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

On the other hand, 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 should be established. If concrete casks are 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.

[68] Tokyo Electric Power Company Holdings Inc., Mid-and-Long-term Decommissioning Action Plan 2023 (March 30, 2023)

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.

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.

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. 41.

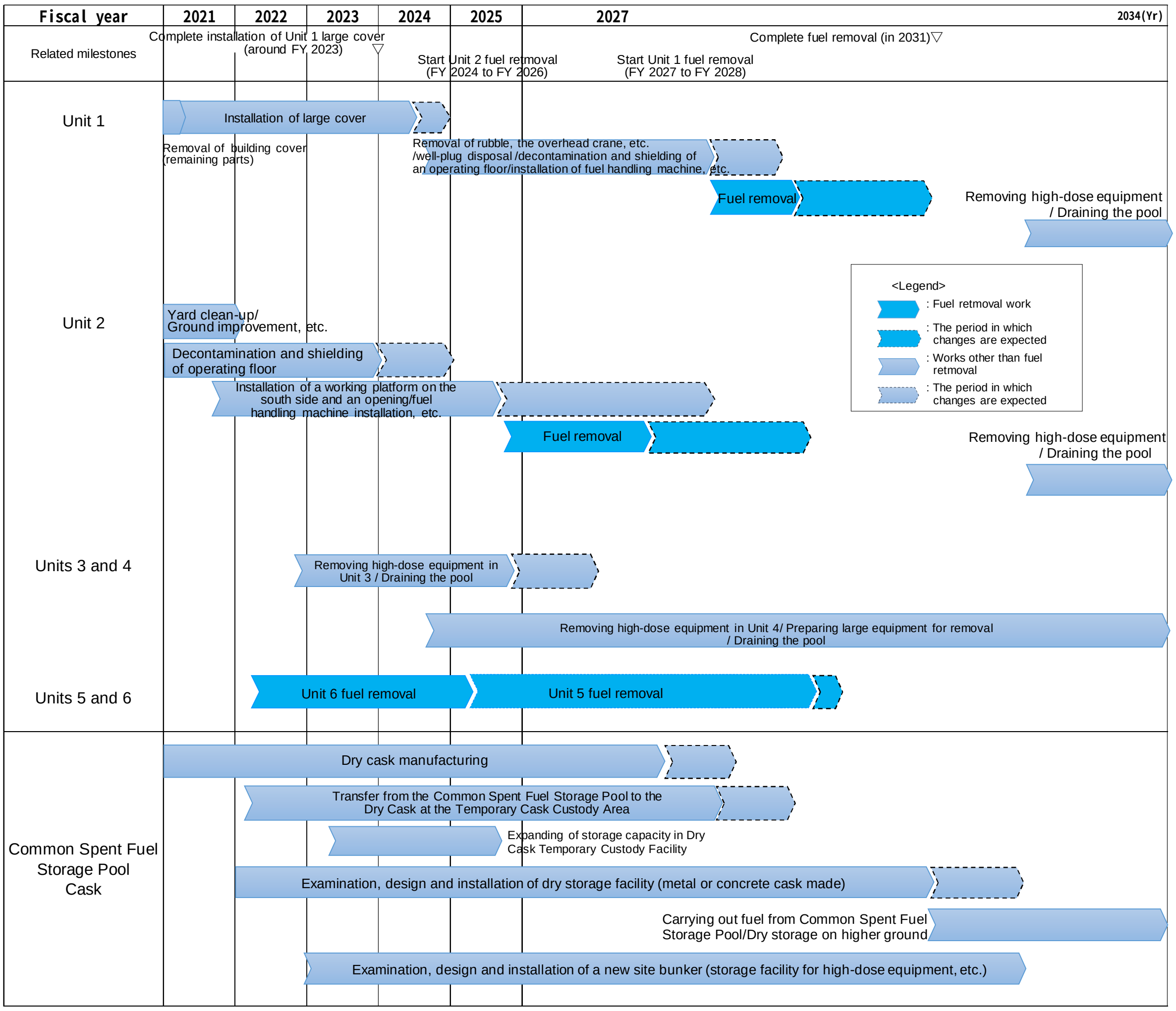


Fig. 41 Key technical issues and future plans for fuel removal from SFPs (Progress schedule)

4. Analysis strategy for promoting decommissioning

4.1 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.

In decommissioning the Fukushima Daiichi NPS, analysis with various analysis targets, purpose of analysis, and radiation dose rates must be performed, as shown in Fig. 42.

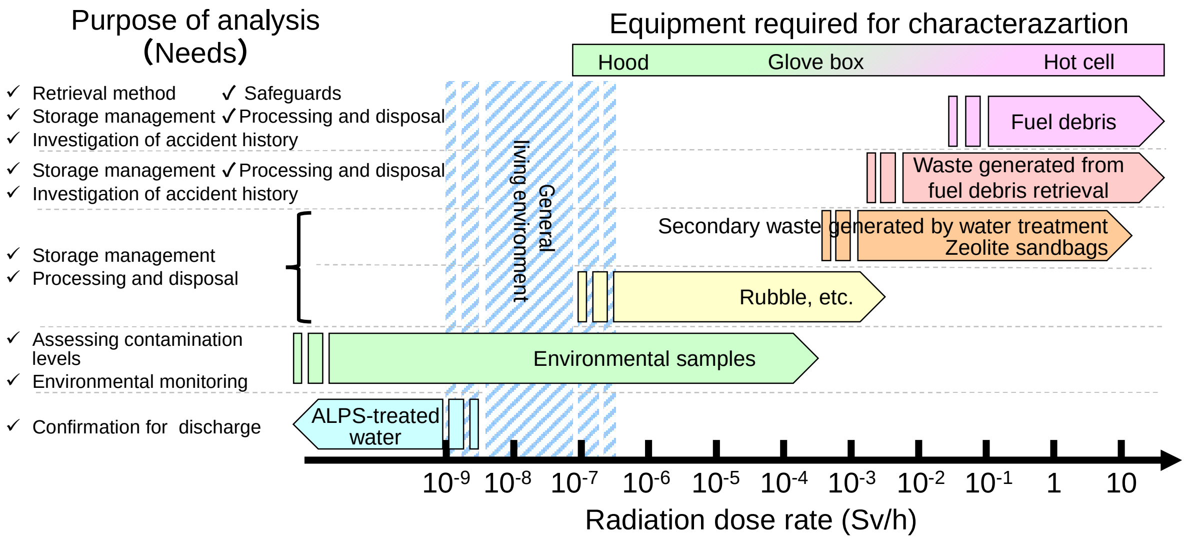


Fig. 42 Relationship between the purpose of the analysis, equipment required for characterization, and radiation dose rates of the analysis targets

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, and it is not under human control. Concerning the design of safety measures for decommissioning the Fukushima Daiichi NPS, it is assumed to use the 4 to 5 mass% U-235 content of the fuel before the accident to conservatively study safety assessment and safety measures for criticality control and transport. 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, there will be no need to include excessive 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 and 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 Phase 3 is approaching, 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 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 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.

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. To obtain good analysis results, 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. 43, and efforts are being made to achieve this.

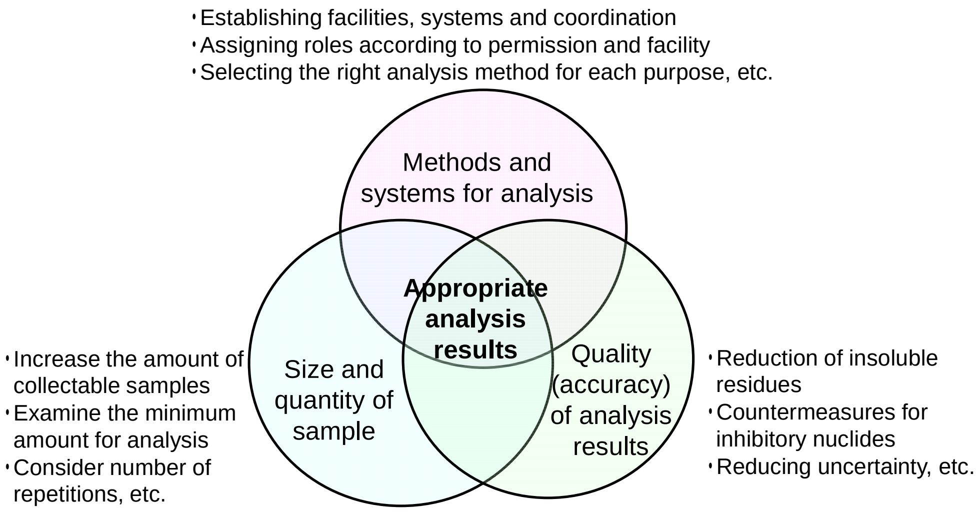


Fig. 43 Three elements of the fuel debris analysis strategy for the decommissioning of the Fukushima Daiichi NPS

4.2 Current status and strategies for analysis

4.2.1 Measures to strengthen analytical method and analysis structure

4.2.1.1 Measures to strengthen analysis structure

While the government has taken the lead in developing a Mid-and-Long-term Roadmap[69], 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 Phase 3 is around the corner after the fuel debris retrieval in the initial unit, an urgent task is to accelerate further the development of the analysis structure, which has been promoted so far.

The NRA has acknowledged that the amount of solid waste generated and the work of analyzing radioactive materials will certainly increase further in line with the progress of the decommissioning work[70], and revised the Measures for Risk Reduction Map and added Analysis Planning (including facilities and human resources) as one of its key targets.[71] Additionally, with a view to strengthening the analysis system necessary for the decommissioning of the Fukushima Daiichi NPS, the NRA has proposed to discuss measures to immediately resolve the issues (such as an all-Japan approach).[72]

The increased analytical work was a concern for TEPCO, the JAEA, NDF, and other related organizations. Therefore, to enhance the analysis structure, efforts have been steadily promoted by examining analytical plans, developing analytical and evaluation methods, securing facilities for analysis and analytical personnel, as well as strengthening cooperation among related 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 and Contaminated Water/Treated Water and the NRA meetings (refer to Attachment 15 for the action plan for each relevant organization) [73,74]. The immediate efforts will continue to be steadily implemented and necessary measures will be taken in the light of the situation.

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

[70] The 97th meeting of the Study Group on Monitoring and Assessment of Specified Nuclear Facilities, “Material 1-1: Revision of Measures for Mid-and-long-term Risk Reduction at TEPCO’s Fukushima Daiichi NPS (Risk Map) (1st)”

[71] The 98th meeting of the Study Group on Monitoring and Assessment of Specified Nuclear Facilities, “Material 1-1: Measures for Mid-and-long-term Risk Reduction at TEPCO’s Fukushima Daiichi NPS (Risk Map) (as of March 2022)”

[72] The 102nd meeting of the Study Group on Monitoring and Assessment of Specified Nuclear Facilities, “Material 1-2: Enhancement of the Analysis Structure Necessary for Decommissioning of TEPCO’s Fukushima Daiichi NPS”

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

[74] The 1st NRA committee FY2023” Material 1 : Policy initiatives to strengthen the analytical systems for Decommissioning of TEPCO’s Fukushima Daiichi NPS”

4.2.1.2 Discussion on 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.[75] As the demand expands for the analysis of lower concentration areas such as ALPS-treated water and environmental samples, it will become necessary to improve detection accuracy. 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 such as shielding and containment and to diversify analysis 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 an analysis plan that considers periodic maintenance, etc.

TEPCO extracted wastes with high priority for analysis based on the progress of analysis and risks associated with storage management, and reviewed the characterization policy and analysis plan according to the characteristics of each waste[76]. Table 5 provides the objective for analysis planning. In addition, after integrating and coordinating analysis plans for each type of waste, TEPCO designs the annual development of the necessary analysis capabilities and incorporates them into analysis personnel plans. This analysis plan is continuously updated to reflect changes in needs as decommissioning progresses. Moreover, TEPCO will implement the initiatives in the plan and, based on the progress made, will constantly review the necessary measures. Fig. 44 shows the analysis implementation flow for solid waste.

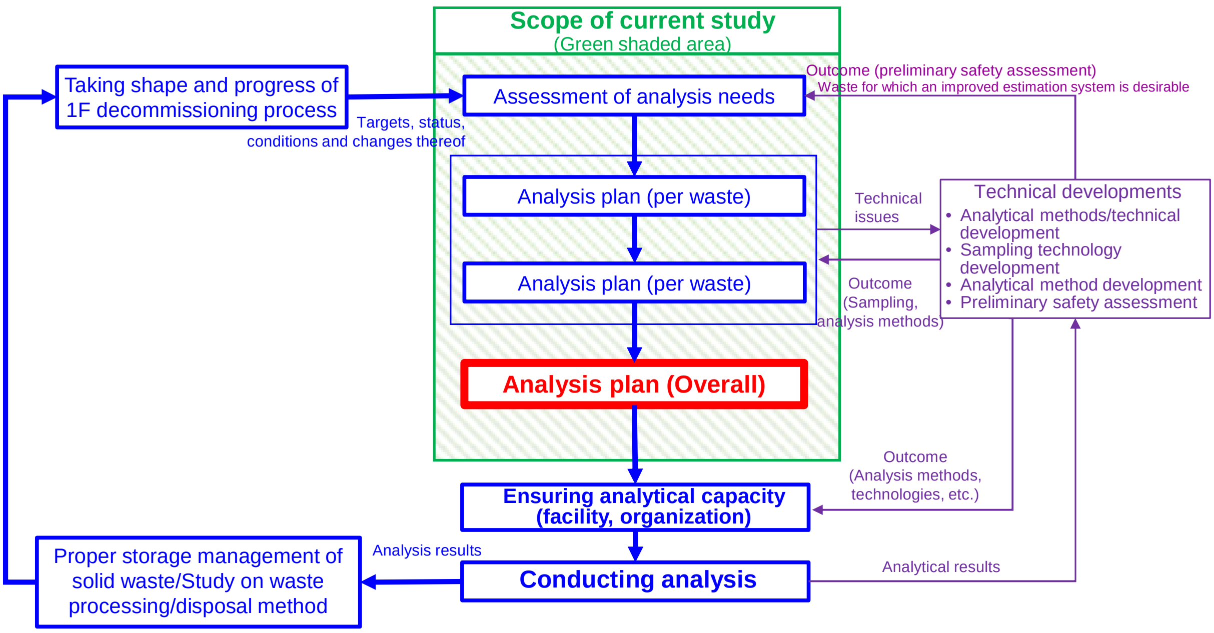
[75] The 104th meeting of the Study Group on Monitoring and Assessment of Specified Nuclear Facilities, “Material 1-3-2: Activity Status to Establish Analysis Structure”

[76] The 112nd Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water, “Material 3-4：The analysis plan of solid waste for Decommissioning of TEPCO’s Fukushima Daiichi NPS”

Table 5 Objective for analysis planning

Response to decommissioning progress	Details
Transition to waste management by 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 increasing 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)



(Source: TEPCO)

Fig. 44 Analysis implementation flow for solid waste at the Fukushima Daiichi NPS

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, solid waste and other samples from PCV internal investigations[77,78,79]. 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[80]. In addition to the JAEA review, it will be extended to fuel debris analysis plans with the assistance of the analysis support team described below.

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 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[81], 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 acquisition 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.[82] In addition, since molten fuel and structural materials will be mixed in the 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 is in progress as a technology development of simple (in-situ) analysis.

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

[78] The 108th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water, "Material 3-4 : Recent results on waste characterization – Characterization of major risk sources - "

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

[80] Working group on fuel debris and other research strategies, Japan Atomic Energy Agency, "Fuel debris analysis of TEPCO's Fukushima Daiichi NPS", JAEA-Review 2020-004, (2020)

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

[82] The 104th Meeting of the Study Group on Monitoring and Assessment of Specified Nuclear Facilities, "Material 1-3-3: Development flow of analysis and evaluation methods"

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).[83, 84] 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 them into safety assessment and work procedures. The objectives of Laboratory-1 are solid waste analysis and third-party analysis of ALPS-treated water,[85] and Laboratory-2 is intended to conduct fuel debris analysis. Laboratory-1 was completed in June 2022,[86,87] 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.[88] It also began third-party analyses of ALPS-treated water in March 2023.[89] 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.

As shown in Fig. 45, 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 waste analysis, such as metallographic observation, microstructural observation, and elemental mapping, there is a concern that the analytical capacity of Laboratory-2 will be exceeded 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)

83 The 24th Meeting of the Study Group on Monitoring and Assessment of Specified Nuclear Facilities, “Material 3-1: Development of R&D Hub Facilities for Decommissioning”

84 The 52nd Meeting of the Study Group on Monitoring and Assessment of Specified Nuclear Facilities, “Material 3-4: Opening of the Okuma Analysis and Research Center Facility Management Building”

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

86 Japan Atomic Energy Agency (JAEA), June 24, 2022 “Completion of Laboratory-1 of the Radioactive Materials Analysis and Research Facility (Okuma Analysis and Research Center) and Future Plans”

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

88 The 106th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water, “Material, Others: Commencement of Analysis Work at Laboratory-1 of the Radioactive Materials Analysis and Research Facility”

89 Sector of Fukushima Research and Department, Japan Atomic Energy Agency (JAEA), March 30, 2023, “Start of Third-party Analysis of ALPS-treated Water in Radioactive Material Analysis and Research Facility, Laboratory 1”

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 and prioritize analyses requiring promptness on-site and in adjacent areas of the Fukushima Daiichi NPS.

As for solid waste analysis, as the trial 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,[90] consideration should be given to facilities that will continue to be used going forward.

[90] Japan Atomic Energy Agency (JAEA), April 1, 2022, Medium-/Long-Term Management Plan for the JAEA Facilities

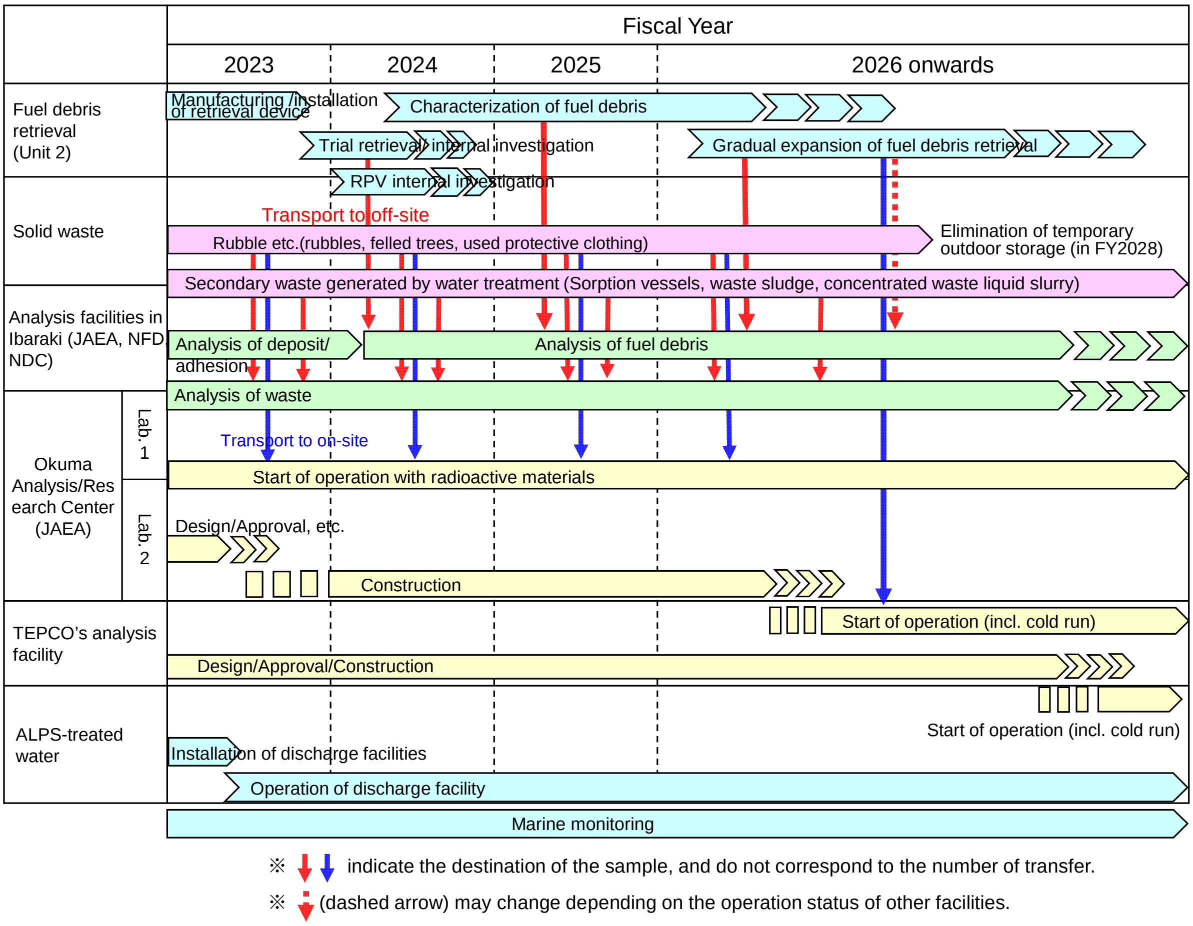

Fig. 45 Construction and operation schedule for fuel debris retrieval and new analytical laboratories

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 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[91]. 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. It is necessary for TEPCO and the JAEA

[91] The 112nd Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water, “Material 3-4：The analysis plan of solid waste for Decommissioning of TEPCO's Fukushima Daiichi NPS”

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 provide support for securing analytical personnel.

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 entails 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.[92, 93] Table 6 shows the records of personnel exchange between TEPCO and the JAEA and personnel acceptance from NFD to TEPCO.

Table 6 Personnel exchange between TEPCO and JAEA and accepting personnel from NFD to TEPCO

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

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 will be sent to the JAEA and private sectors to join R&D for development of analytical technicians[94].

In efforts to develop and secure analytical workers, the Fukushima Institute for Research, Education and Innovation (hereinafter referred to as “F-REI”) and the Agency for Natural Resources and Energy are collaborating to prepare a “human resource development training program” for radioactivity analysis, to expand the human resource base who will be analytical workers.

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

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

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

As the demand for analysis is expected to increase in the future, there will be a need for highly skilled personnel capable of analysis planning in anticipation of how the analysis results will be used. Analytical evaluators in charge of this task are required to have the ability to (i) appropriately incorporate the evaluation results into the areas required for the decommissioning process (retrieval method, safeguards, storage/management, and processing/disposal), (ii) provide appropriate instructions for the subsequent sampling, and (iii) logically and accurately understand accident events from analytical results. However, it is difficult for individuals to have all these abilities. Therefore, the Analysis Coordination Meeting and an Analysis Support Team were organized within NDF, as shown in Fig. 46. 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[95].

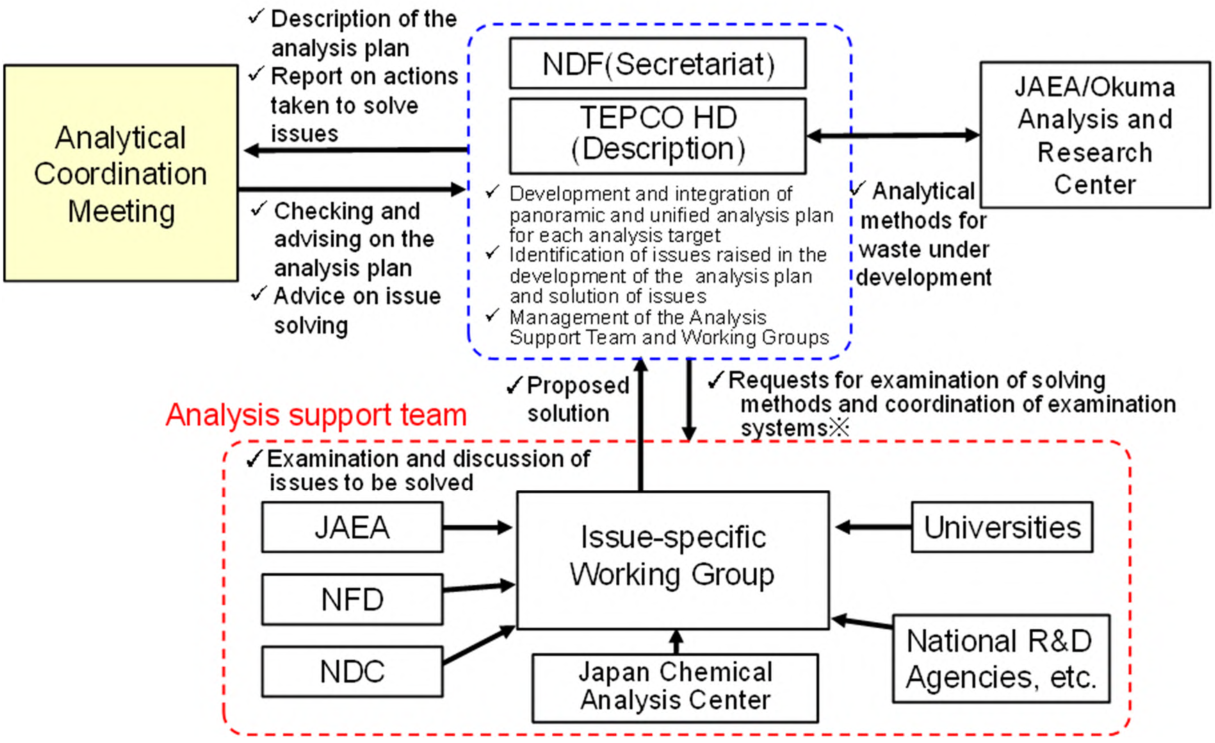

Fig. 46 Role of the Analysis Coordination Meeting and Analysis Support Team

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

[95] The 1st Analysis Coordination Meeting, https://www.dd.ndf.go.jp/tech-committee/

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.[96] [97]Currently, the Ibaraki area offices are preparing to analyze the Three Mile Island Unit 2 reactor (TMI-2) debris using the latest technologies to expand the fuel debris data. TEPCO and the JAEA are cooperating in implementing activities that estimate accident behavior.[98]

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. 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 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 the accuracy. However, if measurements take weeks or months, it is difficult to keep up with the increasing volume of analysis. Therefore, according to the analytical purpose, objects to be analyzed, and analytical method, it is also important to properly select the accuracy, measurement time, and measurement frequency based on the concerned analysis method.

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[96] Subsidized project related to “the Project of Decommissioning and Contaminated Water Management (Development of technologies for improving analytical accuracy and estimation of thermal behavior of fuel debris),” Final report of FY 2020, August 2021, Japan Atomic Energy Agency (JAEA) (2021)

[97] Ikeuchi, Koyama, Osaka et al., Japan Atomic Energy Agency ”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)

[98] Supplementary budget, “The Project of Decommissioning and Contaminated Water Management (Development of analytical and estimation techniques for characterization of fuel debris),” implementation results for FY 2021, International Research Institute for Nuclear Decommissioning (IRID), (2022)

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 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 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 sample 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 radioactivity in solid waste and the amount of nuclear fuel in fuel debris without destroying the sample using radiation, quantum, etc., emitted, scattered, or transmitted from the sample (hereinafter referred to as “non-destructive assay”). Table 7 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 stored in containers are measured with gamma 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 7 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.

On the other hand, since fuel debris has entrained the surrounding control rods (neutron absorbers) when the nuclear fuel melted, there are concerns about the accuracy of nondestructive measurement techniques using neutrons. Moreover, if the fuel assembly was intact, a method to evaluate burnup could be used by measuring gamma rays from Cs-137, a gamma-ray source with a strong penetration force. However, due to the volatilization of Cs-137 during the melting of nuclear fuel, the gamma-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.[99]

As an example of the application of non-destructive assay, Fig. 47 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 waste, the non-destructive assay ② to maintain subcriticality, and the non-destructive assay ③ to price waste for transportation and storage. Fig. 47shows 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 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

[99] Subsidy program for "the Project of Decommissioning and Contaminated Water Management (Development of Technologies for Scaling up Retrieval of Fuel Debris and Internal Structures (Development of Technologies for Sorting and Distinction between Fuel Debris and Radioactive Waste)" starting FY 2020, Final report, August 2022, International Research Institute for Nuclear Decommissioning (IRID), 2022

storage/management. In so doing, it is desirable to keep the range of uncertainty in the properties of fuel debris as small as possible while increasing information about the sample, including the number of sample analyses and the coordinate information at sample collection, to improve the reliability of the data.

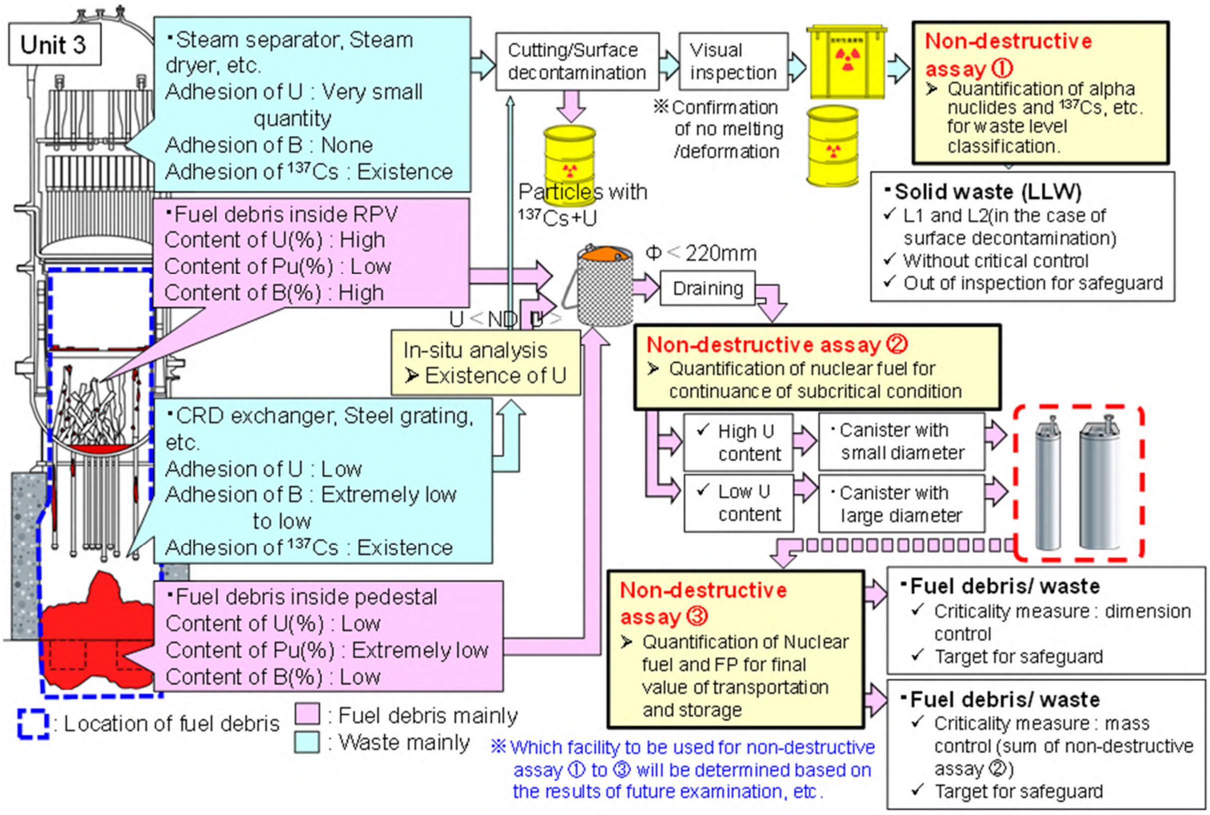

Fig. 47 An example flow of non-destructive assay in the handling process for retrieved fuel debris

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 waste contaminated with alpha-ray emitters, but unsuitable for waste not containing alpha-ray emitters. On the other hand, methods for measuring gamma-rays from fission and activation products and external measurement methods using X-ray CT can obtain information on the contents of containers even for waste that does not contain alpha-ray emitters, and are in practical use in industrial and medical applications.

4.2.3.3 Improvement in number of analyses

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.

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. At present, when trial retrieval of fuel debris is about to begin, it is necessary to accelerate research and development in consideration of the practical application for the gradual expansion of fuel debris retrieval and the further expansion of fuel debris retrieval in scale.

To solve these technical issues, various industrial-academic-governmental institutions, 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 practical application research and field demonstrations by manufacturers, and TEPCO (Fig. 48).

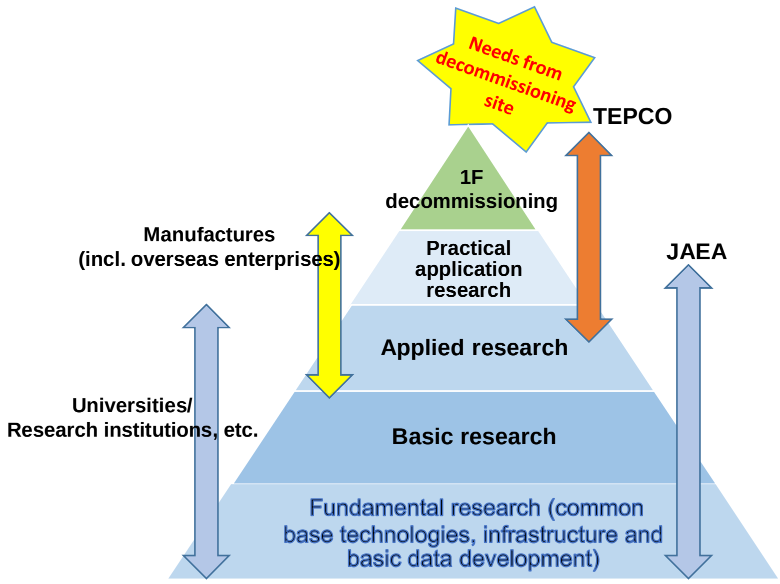

Fig. 48 Scope of studying decommissioning R&D and implementation entities

For application research and practical application research for decommissioning, the government provides support for the R&D carried out by each organization to solve highly difficult issues through the Project of Decommissioning, Contaminated Water and Treated Water Management 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 site application. 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, and it supports 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 the Project of Decommissioning, Contaminated Water and Treated Water Management and the World Intelligence Project has been promoted through the Decommissioning R&D Partnership Council.

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 Project of Decommissioning, Contaminated Water and Treated Water Management.

The R&D implementation structure is outlined in Fig. 49.

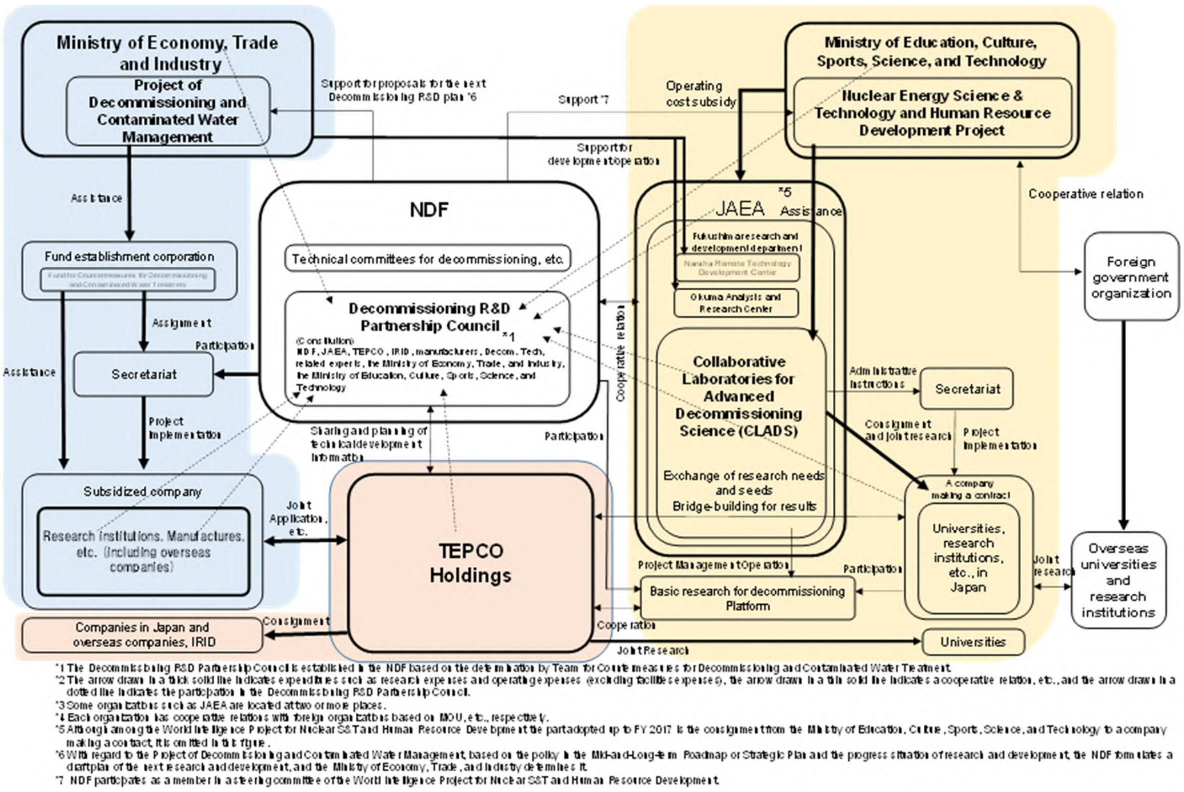

Fig. 49 Overview of the R&D structure of the decommissioning of Fukushima Daiichi NPS

Given that the progress of investigation inside the reactors has clarified on-site needs in decommissioning and TEPCO has begun full-scale engineering work for fuel debris retrieval, the leading players in the Project of Decommissioning, Contaminated Water and Treated Water Management have shifted from the current IRID-centered structure to researching institutions and manufacturers as key implementers based on TEPCO's needs, requiring smooth coordination between the R&D implementers and TEPCO. IRID deleted Articles 52 of its articles of incorporation (the term ending) in April 2023 and is engaged in research and development that should be addressed continuously, including a detailed investigation inside the Unit 2 PCV and trial retrieval of fuel debris.

In addition, F-REI was established by the government in April 2023 to contribute to the reconstruction and revitalization of Fukushima. F-REI plans R&D in five fields ([1] robots, [2] agriculture, forestry and fisheries, [3] energy, [4] radiation science, drug discovery, and medical care, and [5] collection and dissemination of data and knowledge on nuclear disasters). Among the R&D that will contribute to decommissioning, the plan in the field of [1] robots includes the development of remote-operated elemental technologies (e.g., tactile feedback) assuming decommissioning, the development of analytical methods and human resources, and the development of international researchers in cooperation with the IAEA[100].

F-REI integrates technologies and methods multidisciplinary and academically to advance initiatives in new areas. As these efforts will lead to participation in decommissioning R&D from a wide range of fields other than nuclear power. NDF will continue to collect information on the status of F-REI's R&D and human resource development, and will also collaborate with the F-REI based on its implementation.

5.2 Key issues and strategies

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

NDF and TEPCO have been preparing the R&D Medium-to-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 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 the engineering schedule of TEPCO, the R&D Medium-to-Long-term Plan is developed to identify the required R&D and appropriately incorporate R&D results when needed. The plan has also included basic/fundamental research since FY 2022. In FY 2023, the R&D Medium-to-Long-term Plan was revised based on the revision of TEPCO's Mid-and-Long-term Decommissioning Action Plan, study on retrieval method for further expansion of fuel debris retrieval in scale, progress of ongoing R&D activities, and making requests for information (RFI), as well as the medium-to long-term issues that are being discussed by four parties, including TEPCO, Decom.Tech, Collaborative Laboratories for Advanced

[100] The 11th Decommissioning R&D Partnership Council, Material 1-1-3, "F-REI research and development contributing to decommissioning"

Decommissioning Science of the JAEA, Sector of Fukushima Research and Development, Fukushima Research Institute (hereafter referred to as “JAEA/CLADS”), and NDF (Attachment 16).

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

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

The Ministry of Economy, Trade and Industry has been providing support of research and development through the Project of Decommissioning, Contaminated Water and Treated Water Management to solve technically challenging issues for decommissioning since FY2013. In the Project of Decommissioning, Contaminated water and Treated water Management to date, a number of decommissioning R&Ds have been performed the main achievements and challenges of which are listed below.

- The investigation equipment was inserted into the PCV, where the situation had been unknown due to the high radiation doses and high contamination, and revealed the situation inside and outside the Unit 1 pedestal, the deposits of possible fuel debris in Unit 2, and the failure situation of in-core structures in Unit 3. However, there are still issues, such as observing the damage on the RPV bottom.
- Muon surveys inside the RPVs have estimated the remaining fuel state, but the challenge is an internal investigation by actually entering inside.
- Concerning the unprecedented analysis of fuel debris in BWRs, analytical methods for prompt and accurate analysis have been established and standardized, and the characterization of fuel debris based on the analysis of deposits and adhered materials sampled inside the buildings and in investigation inside the reactors has also been advanced. However, the challenges are to continue these efforts and address the increase in the size and quantity of fuel debris, and establish data evaluation methods due to the heterogeneous composition.
- Fuel debris retrieval will be extremely difficult because the operation needs to be carried out remotely to avoid working in an environment with high-radiation doses and high contamination. Several solutions for safety measures, such as retrieval methods, criticality control, and containment of radioactive materials, have been proposed. Moreover, it is necessary to solve emerging issues that will arise from examining the fuel debris retrieval method in the future.
- Efforts were made to establish a flexible and reasonable waste stream for a large amount of solid waste with diverse properties (the flow of the integrated measures from characterization to processing/disposal). As a result, the Technical Prospects were provided in FY 2021. From now on, to present appropriate overall measures for specific storage/management approaches for solid waste storage, the challenge is examining

options for processing/disposal management, comparing and evaluating them, while promoting characterization.

- Future challenges, such as developing supporting technologies for integrated decommissioning management[101], which need to be solved after further expansion of fuel debris retrieval in scale

Given the above, the Project of Decommissioning, Contaminated Water and Treated Water Management should be promoted continuously as part of important research and development tasks to complete decommissioning. Attachment 17 shows the R & D efforts to date.

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

In order to support the Project of Decommissioning, Contaminated Water and Treated Water Management, NDF is formulating the next fiscal year's decommissioning R&D plan for the next two years. After adjustment and discussion with parties concerned at R&D planning meetings attended by TEPCO, the Ministry of Education, Sports, Culture, Science and Technology (MEXT), the Ministry of Economy, Trade and Industry (METI), and NDF, the next fiscal year's decommissioning R&D plan is first deliberated on by the Fuel Debris Retrieval Expert Committee and Waste Management Expert Committee, which are the committees at NDF, and then by the Decommissioning Strategy Committee. After this, it is summarized as an NDF proposal. This 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 and Contaminated Water/Treated Water, and the Project of Decommissioning, Contaminated Water and Treated Water Management has been implemented accordingly. The list of FY2023 decommissioning R&D plans as the next fiscal year's decommissioning R&D plan reported at the 111st Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water[102] held in February 2023 is shown in Fig. 50.

[101] Development of an information management system to integrate and share monitoring and operational data acquired during the long decommissioning period using digital technology, and to maintain safe operations by implementing accurate on-site operations.

[102] The 111st Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water. "FY2023 decommissioning R&D plans"

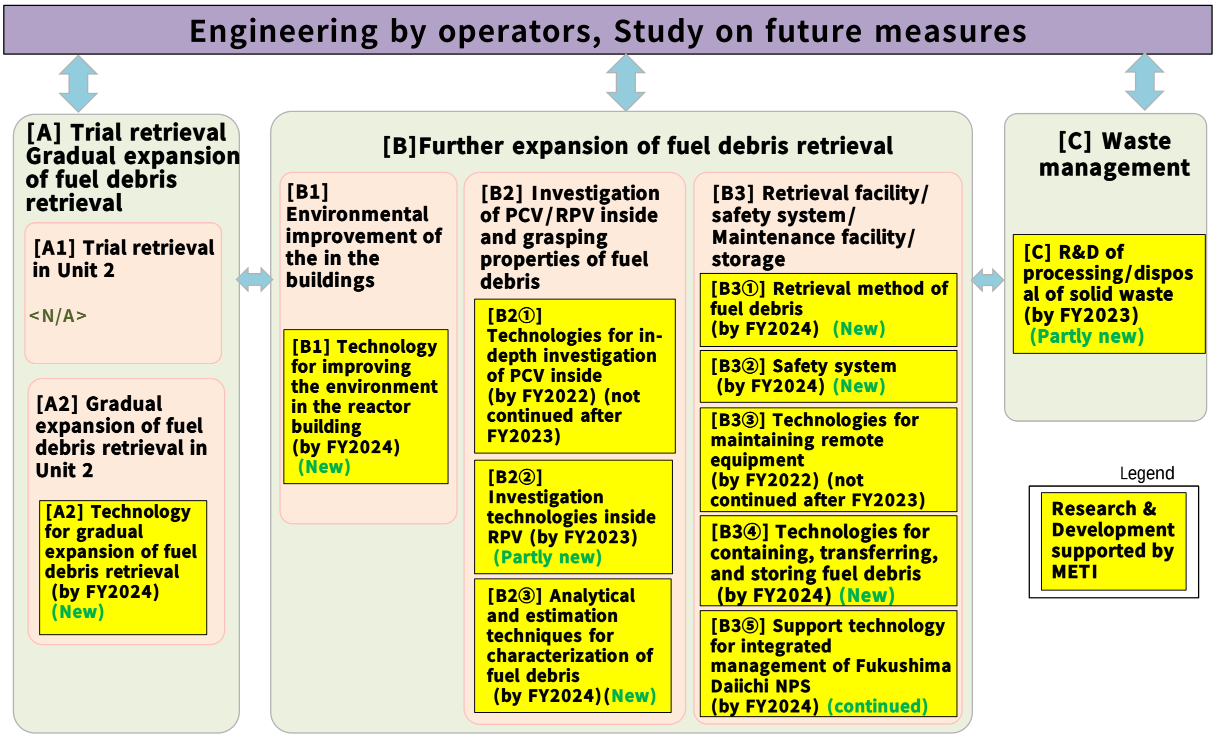

Fig. 50 List of FY 2023 decommissioning R&D plans

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

Since FY 2022, to contribute to discussions on the next fiscal year's decommissioning R&D plan, requests for information (RFI) have been made as R&D proposals and planning to widely solicit information on the R&D details to be addressed toward the decommissioning of the Fukushima Daiichi NPS.

(3) Further research and development implementation structure for the Project of Decommissioning, Contaminated Water and Treated Water Management

Given that the progress of investigation inside the reactors has clarified on-site needs in decommissioning and TEPCO has begun full-scale engineering for fuel debris retrieval, decommissioning research and development is changing from a joint effort by IRID to a stage where TEPCO's engineering-based development is being advanced. In light of these environmental changes, the implementation structure of the Project of Decommissioning, Contaminated Water and Treated Water Management shifted from an IRID-led subsidized project structure to a new R&D structure led by researching institutions and manufacturers based on TEPCO's needs. In addition, as a structure, TEPCO applies for issuance jointly with research leadership to facilitate cooperation with them and is responsible for the project management in this Project.

As a result of the transition to such a new implementation structure, the issues below remain. Therefore, NDF is undertaking requests for information (RFI) and project reviews to ensure cooperation between research leadership and TEPCO and further strengthen functions related to planning proposals for R&D and securing the actual site applicability of research results (Fig. 51).

- Discuss R&D details from broad perspectives in the Project of Decommissioning, Contaminated Water and Treated Water Management.
- Perform project assessment in terms of practical engineering and actual site applicability and incorporate the results into R&D tasks.

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. For RFIs made in FY 2022, dozens of proposals were made, some of which were incorporated into the FY 2023 decommissioning R&D plan. In FY 2023, based on the experience of FY2022, public participation through RFI has been solicited after improving the application process, including extending the application period and changing the entry procedure. The system will be improved continuously, including how to scrutinize proposals. 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 broad base of operators who join the Project of Decommissioning, Contaminated Water and Treated Water Management, and to widely collect R&D seeds through public solicitation, which will lead to accelerating the resolution of issues in decommissioning.

b. Project review

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

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

The project review started in FY 2023. Since this is the first trial, results will be reviewed to improve the system continuously.

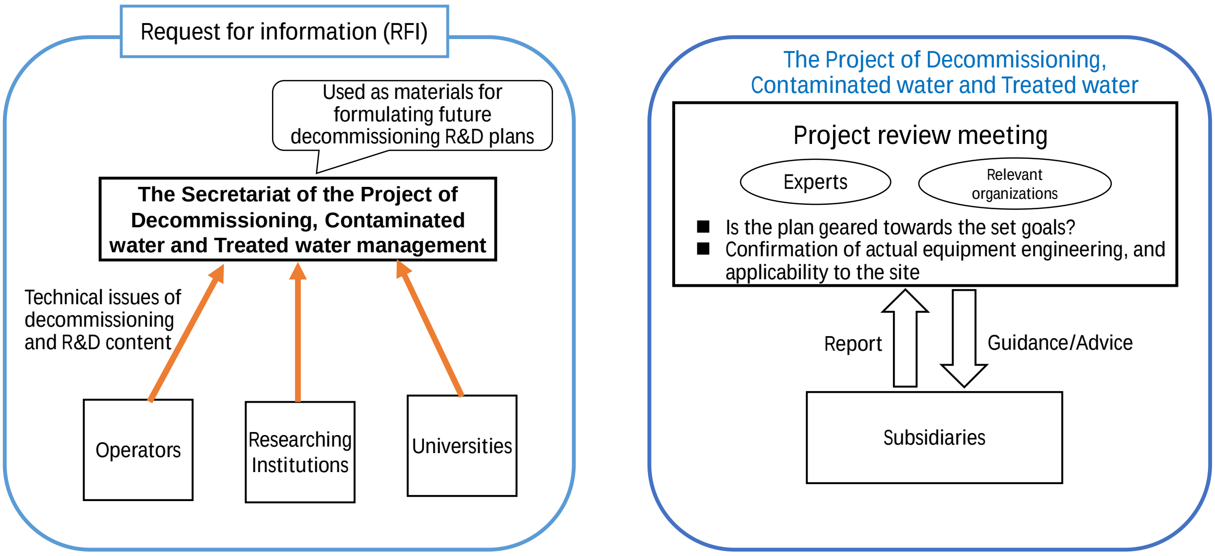

Fig. 51 RFI and project review

Regarding the outcome of the development that has been conducted through the Project of Decommissioning, Contaminated Water and Treated Water Management, since the decommissioning of the Fukushima Daiichi NPS is a national/social issue, 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 terms of disclosure of results and sharing knowledge, and TEPCO currently leads this initiative. The results that can be made public are disclosed on the Secretariat's website[103] immediately after the completion of the project.

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.

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

[103] Management Office for the Project of Decommissioning, Contaminated Water and Treated Water Management Website (https://dccc-program.jp/category/result)

of the nuclear field, and through close coordination and alignment including international joint research. JAEA/CLADS is responsible for the implementation of this World Intelligence Project to strengthen cooperation between universities and researching institutions, and establish a system to implement medium-and-long term R&D and human resource development, contributing to decommissioning more stably and continuously. In the World Intelligence Project public call, the “overall map of the basic/fundamental research” is used in soliciting applications, which provides an overview of the entire decommissioning process from contaminated water management to waste processing/disposal and identifies the R&D needs and seeds required[104].

The following three programs are in progress in the World Intelligence Project FY 2023. Moreover, although the project will start in FY 2024, public applications for joint research between Japan and the United States have been launched this autumn in addition to Japan and the United Kingdom. Attachment 18 shows the selected issues of the World Intelligence Project adopted in the past.

- The Issue-solving Decommissioning Research Program: To solve issues by promoting needs-based research and development for steady progress in decommissioning the Fukushima Daiichi NPS.
- The International Collaborative Decommissioning Research Program (Japan-UK Joint Research): To promote R&D by integrating and collaborating research in various fields in Japan and the UK to gather broad knowledge and contribute to accelerating the decommissioning of the Fukushima Daiichi NPS.
- Decommissioning research program based on development of research human resources: Toward the decommissioning of the Fukushima Daiichi NPS, the JAEA and universities have established a collaboration laboratory to promote human resource development that supports decommissioning research over the mid to long term[105].

Further, since FY 2021, efforts have been made to match decommissioning needs with research seeds, such as holding workshops with the participation of TEPCO and companies involved in decommissioning. In FY 2022, Research Supporters (RS)[106] were introduced to maximize the use and outcomes of the results at the decommissioning sites.

The challenge is adequately applying basic/fundamental research results contributing to issue-solving to decommissioning sites. It is important 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.

[104] 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).

[105] “Industry-academia collaboration laboratory,” where the JAEA, as leadership, works closely with universities and private companies.

[106] Research Supporters are JAEA personnel who support research as the JAEA/CLADS to individual World Intelligence Project-adopting institutions.

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

To deepen the matching between needs and seeds and implement R&D for decommissioning consistently from basic/fundamental research to applied practical application research, to date, there has been a collaboration between the Project of Decommissioning, Contaminated Water and Treated Water management and the World Intelligence Project, with some of the World Intelligence Project being deployed in the Project of Decommissioning, Contaminated water and Treated water Management. In order to develop future research and development further than before, NDF and organizations concerned should actively exchange and share information on the results of each project and work together on the use of the Decommissioning R&D Partnership Council and initiatives to share future directions and issues shared at such Meeting. Further collaboration with TEPCO is required for the field application of the research results.

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 Collaborative Laboratories for Advanced Decommissioning Science (Tomioka-machi, Fukushima Prefecture) of the JAEA, with JAEA/CLADS as its core, is working on research and development based further on decommissioning needs, to enhance the base functions by establishing a network of universities, researching institutions, and industry in Japan and overseas to promote the R&D and human resource development in an integrated manner, establishing the “Decommissioning research program based on development of research human resources” in the World Intelligence Project, and the research, development, and human resource development projects that connect organizations through a cross-appointment system[107] after the establishment of a research/human resource development base (collaborative lab).

It is also important to build research and development infrastructures as hardware. The Naraha Center for Remote Control Technology Development of JAEA, which began full-scale operation in Naraha Town, Fukushima Prefecture, in April 2016, is a facility where mock-up testing can be performed for the development and demonstration of remote-control devices and equipment. In particular, prior to the introduction of equipment into a severe environment that cannot be accessed by humans, it is essential to conduct full-scale mock-up tests for verifying the performance and for remote operation training and establishment of operating procedures, etc. In 2023, a mock-up test of the robot-arm was conducted for the trial retrieval of fuel debris 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. The Laboratory-1 of Radioactive Material Analysis and Research Facility, where low-dose and medium-dose solid waste analysis as well as third-party analysis of ALPS-treated water are to be conducted, was completed in June 2022, and its controlled area was set in October of the same year, and its operation was started after hot testing with radioactive materials._The preparatory construction work for Laboratory-2, which analyzes high-activity samples such as fuel debris, started in the autumn of 2022, and the preparation is being advanced with the aim of completion in FY 2026. The data from the analysis and research will be utilized to establish a technical basis and clarify fuel debris properties for the reliable processing/disposal management of radioactive waste and its safety for 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 center for R&D for decommissioning has been established, and R&D infrastructures for medium-and-long-term prospects have been built. (Fig. 52)

[107] Cross-appointment system is a system that allows researchers to engage in research, development, and education according to their roles in universities and public research institutions, while being employed by two or more institutions, under certain engagement rate (effort) control.

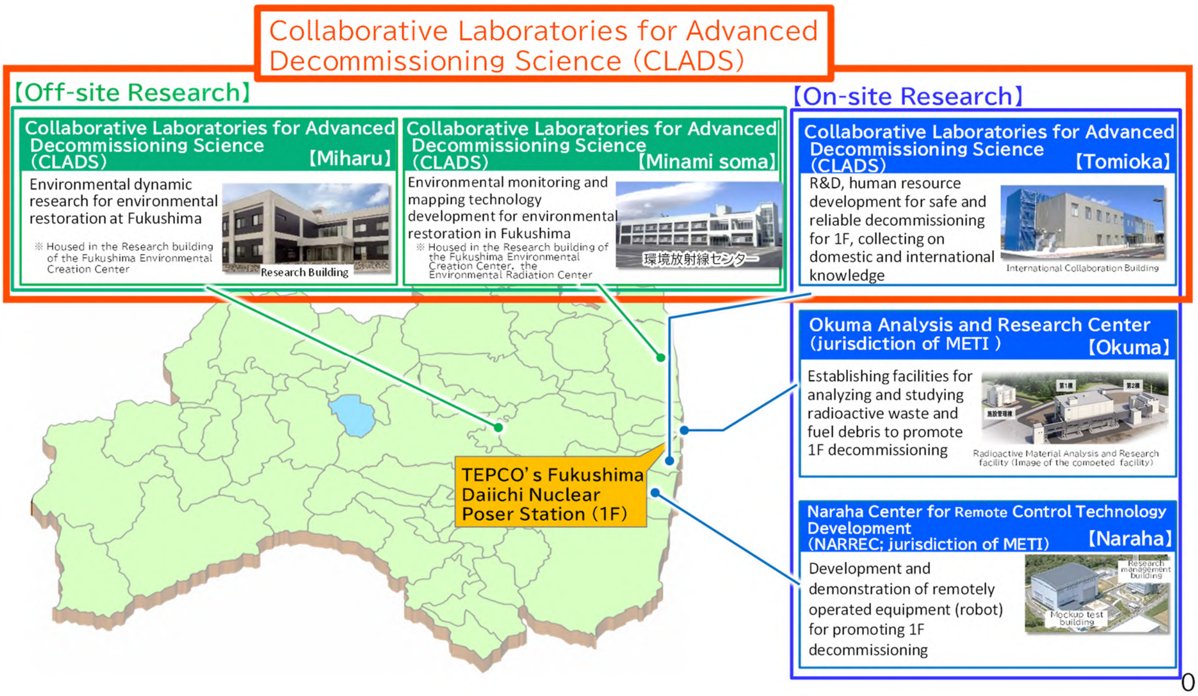

Fig. 52 Research centers for Decommissioning in Fukushima[108]

[108] Source: The 11th Decommissioning R&D Partnership Council, Material 2-1, “Status and direction of research and development”

6. Activities to support our technical strategy

6.1 Capabilities, organization, and personnel to proceed with decommissioning

6.1.1 Ensuring the capability, organization and personnel 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, organization, and human resources 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 the 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 three 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 fiscal 2022 include enhancing the authority of project managers through reorganization, building and operating a risk monitoring system, improving safety and quality levels, and preparing a forward-looking plan (Mid-and-Long-term Decommissioning Action Plan). The major initiatives are listed below.

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

In April 2020, the Fukushima Daiichi Decontamination and Decommissioning Engineering Company was reorganized to establish a program[109]/project structure and the Decommissioning Safety & Quality Office was set up directly under the Chief Decommissioning Officer (CDO). As

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

a result, the authority of project managers has been strengthened by assigning full-time project managers and granting budget implementation authority. In terms of operation, while process management is being promoted using process management software, efforts were made to improve the operational propelling force of the decommissioning project by establishing a system in which management and other related parties share information on the progress, issues and risks of each program and project every month. Moreover, the Decommissioning Safety and Quality Office was set up to ensure the safety of decommissioning work and to maintain and improve the level of work quality in the face of the extremely uncertain and technically challenging tasks such as fuel debris retrieval.

TEPCO established Decom.Tech in 2022 to undertake engineering and other activities related to large-scale debris retrieval. In addition, TEPCO's employees are seconded here to address themselves on the management of costs and processes required for completion of work, risk management for uncertain factors, and acquisition of design expertise, which have been dependent on manufacturers. By improving the capabilities through OJT, TEPCO has been trying to enhance its independence in engineering and EPC[110] management activities associated with the increasingly difficult decommissioning work, it is important to strengthen project management capabilities.

② Strengthening of risk management

Risk management is an activity to identify uncertain events before they materialize and to "take preventative measures" so as not to let events that negatively affect the project happen, or to "minimize the effects" even if they occur.

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.53. 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.[111] 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].

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

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

[111] 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.

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.

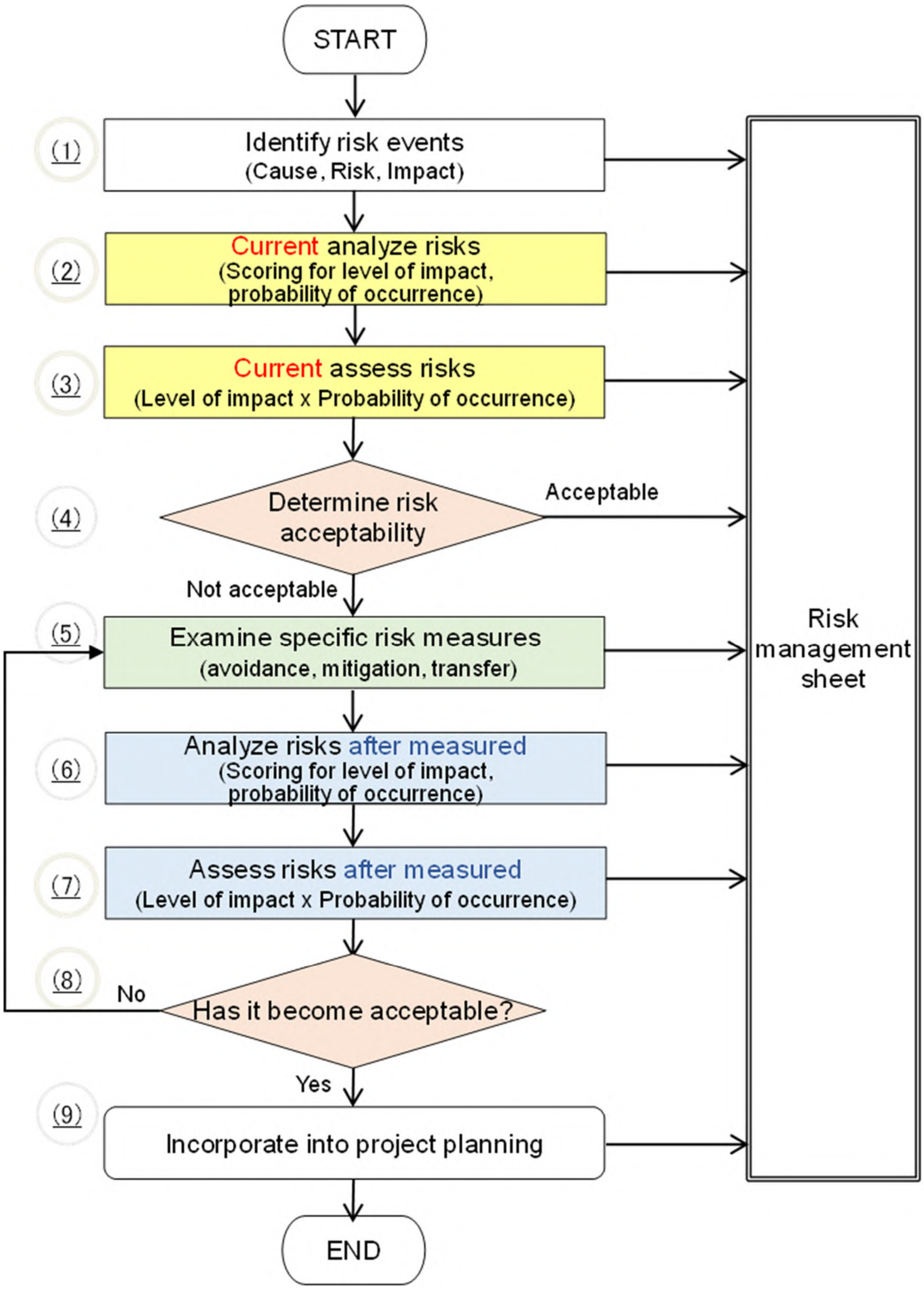

Fig. 53 Standard workflow of risk management

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

Since the accident at the Fukushima Daiichi NPS, TEPCO has been implementing the decommissioning project, referring to the requirement based on the Act on Special Measures

Concerning Nuclear Emergency Preparedness and the Nuclear Reactor Regulation Law[112], 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 with the aim of presenting a concrete work plan to achieve the milestones of the Mid-and-Long-term Roadmap and the Target Map for Reducing Medium-term Risk. After this, in March 2023, TEPCO published the Mid-to-Long-Term Decommissioning Action Plan 2023, which was updated every year based on the progress of the work.

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.

④ Formulation of R&D medium-to-long-term plan[113]

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.

⑤ Enhanced budget planning

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

[112] Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors
[113] For detail, refer to Chapter 5.

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 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.

⑥ 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 CDO, and other management and awareness of moving toward solutions is becoming established.

⑦ 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 has begun effectiveness evaluations for most items. Through additional inspections, TEPCO has been improving measures as needed with advice from the NRA. Based on the policy for confirmation announced by the NRA in September 2022, TEPCO is promoting “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 will not hesitate to invest resources to strengthen on-site capabilities, particularly for nuclear security.

In the future, TEPCO plans to compile measures to strengthen the nuclear material protection function and evaluation of each measure in the Improvement Action Results Report.

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. Additionally, in view of the peculiarities of the Fukushima Daiichi NPS, there are required abilities for upgrading the overall decommissioning strategy to advance a coexistence of reconstruction and decommissioning. 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[114] and engineering based on safety and operator's perspectives[114]

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 exist in unconventional and unsealed conditions without complete barriers to contain the radioactive materials, such as reactor buildings and PCVs. Furthermore, the environment is subject to constant changes due to natural events such as weather and earthquakes, as well as aging degradation of equipment and buildings, and has uncertainties in the conditions of radioactive materials and containment barriers. In addition, the accessibility of personnel and systems is limited due to high radiation doses and damage to equipment and buildings, making it difficult to obtain complete on-site information. Moreover, unlike other plants, it is not always clear what safety requirements should be met to achieve the objectives of individual operations.

[114] Refer to Chapter 2 for details.

On the other hand, each plant contains significantly less energy with less active equipment to be managed and fewer constraints on plant configuration management than that of a conventional reactor.[115]

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[116]. 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.[117]

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 various stakeholders on the matters it has established, and proceed with the decommissioning work in cooperation with other parties based on the agreements.

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[115] 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.

[116] 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.

[117] 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.

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[118], 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[119], 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[120] is an important measure to strengthen these capabilities and should continue to be pursued vigorously.

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 [121]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), specify 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, 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

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[118] When any work is to be carried out at 1F, 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 and ALARP approach, given uncertainties in on-site information peculiar to 1F, 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.

[119] 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.

[120] Insourcing" means acquiring an ability to implement planning, design, maintenance, and operation independently, aiming at improving employees' technical capability, productivity, and operation quality. This initiative will ultimately contribute to the improvement of safety. In addition, appropriate management of knowledge acquired by insourcing can have various effects, such as improvement of engineering judgment for inexperienced work, improvement of operation and maintenance quality, and enhancement of on-site capability.

[121] 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.

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 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 8).

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”.

NDF and TEPCO are benchmarking the acquisition management[122,123], one of the precedent cases leveraging such a project management structure, as adopted by the U.S. federal government, and are actively learning the methodology with the cooperation of external experts starting from FY 2017. Taking examples from actual projects, they are implementing a part of the work required when employing this management structure on a trial basis and verifying procedures.

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 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

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

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

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.

Table 8 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
Cost estimation methods	Data-based cost estimation (analogy: analogy, integration, parametric: sensitivity, analysis, etc.)	Quotation/price list, etc.

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.

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 & Plant Siting Division 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 confirm the activities so that TEPCO will step up progress to achieve coexistence of reconstruction and decommissioning as the integration and reorganization advance.

6.1.1.4 Initiatives to recruit and develop personnel

In Fukushima Daiichi NPS, it is necessary to systematically secure and develop human resources in anticipation of the expansion of operations in line with the progress of the fuel debris retrieval plan. Specifically, 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.

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.

6.1.1.4.1 Short-term efforts

The decommissioning work at the Fukushima Daiichi NPS is at the phase of starting 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.

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[124] 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 conducting 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[125], conduct digital transformation (DX) [126], and obtain the necessary outputs with limited resources through efforts.

6.1.1.4.2 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

[124] 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.

[125] 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.

[126] 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.

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[127], reskilling employees with a view to the medium- to long-term[128], personnel management including attractive career path design for young employees, enhancing the understanding of the community[129], and making up for personnel shortages through collaboration with external organizations[130].

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.

6.1.2 Fostering the next generation responsible for the decommissioning of Fukushima Daiichi NPS and promoting public understanding

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

In order to continue decommissioning of the Fukushima Daiichi NPS over a long period and to continue the R&D activities necessary to that end, it is essential to train and secure future researchers and engineers and to ensure the inheritance of technological skills. It is necessary for

[127] 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.

[128] 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.

[129] 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.

[130] 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.

industrial-academic-governmental institutions overall to move steadily ahead with efforts according to each level of the secondary and higher education stages.

As described in the section 6.1.1, it goes without saying that securing human resources by TEPCO is critical. At the same time, in decommissioning the Fukushima Daiichi NPS, it is necessary to recruit and develop personnel specialized in nuclear energy as well as those with different backgrounds who have expertise in science and technology in other fields.

Therefore, 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.

Under these circumstances, the World Intelligence Project by MEXT and JAEA/CLADS has introduced a system in which students and young researchers are engaged in decommissioning research. From the perspective of human resource development, it provides support for young researchers and teachers in preparing and implementing lecture curriculums related to decommissioning. In the Creative Robot Contest for Decommissioning for technical college students as part of the World Intelligence Project, on an ongoing basis, students present their research results, exchange views with researchers and engineers involved in the decommissioning of the Fukushima Daiichi NPS, and are given awards for excellent performance.

As eight 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 who are 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 seven times, gives students an opportunity to interact directly with researchers and engineers involved in decommissioning. The conference was held in person for the first time in 4 years in 2023, when the impact of coronavirus infection had eased. Under this system, the project should be implemented continuously so that the perspectives of decommissioning sites in TEPCO and those of the activities in higher education institutions can be more aligned.

For junior and high school students in the earlier stage of secondary 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. In addition, Student Sessions for high school students, etc., have been held to give thought to the reconstruction of Fukushima, along with the International Forum on the Decommissioning of the Fukushima Daiichi NPS (hereinafter referred to as the “International Forum”). In the Student Session 2022, a tour to observe the situation in the Futaba area was conducted for the first time, and the knowledge gained from the tour was utilized in the next day’s Future Workshop. The Future Workshop is designed to discuss what to do now to develop a desirable future for the Futaba area based on future prospects, decommissioning status, and other information derived from statistical data in the Futaba area. These opportunities have been provided to approximately 60 high school students and others who are in the period of considering the specifics of their career options 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.

The institutions concerned should continuously promote and strengthen their efforts to secure and develop human resources for the next generation according to their respective roles and levels.

6.1.2.2 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 for promoting public understanding. In particular, from the perspective of enhancing resilience to various disasters in the future, the challenge is to acquire knowledge and experience of nuclear energy and decommissioning and to ensure that children have opportunities to learn depending on their 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 on December 28, 2021, and revised on August 30, 2022), the government is promoting the continuation and expansion of on-site classes and the use of radiological supplementary readers. NDF also holds workshops for local students to discuss decommissioning and reconstruction, as described above.

6.2 Strengthening international cooperation

6.2.1 Significance and the current status of international cooperation

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. While Japan does not have sufficient experience in investigations and analyses to estimate conditions inside reactor buildings, PCVs, and RPVs, research and development to execute such activities, and mockup tests, including training of workers, there are challenging engineering issues. Although there has not been sufficient experience or research accumulated in Japan to address these issues in the period of accumulating efforts after the accident, it is believed that learning and incorporating experience and lessons learned from decommissioning activities at sites in other countries, in which the knowledge described above is already accumulated, will make the difference in the success or failure of the decommissioning of the Fukushima Daiichi NPS, and is important as a risk reduction strategy. To this end, as specific efforts, it has been recognized that it is necessary to promote bilateral cooperation in line with the circumstances of partner countries and utilize the framework of multilateral cooperation through international organizations such as the IAEA and the OECD/NEA to incorporate and implement useful global experience in decommissioning.

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 decomissioning of Fukushima Diichi NPS. To this end, in addition to gathering of wisdom and sharing of experience, it is necessary to disseminate transparent information to the international community and to engage in continuous dialogue.

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 formed and maintained cooperative relationships with professional organizations with a proven track record in decommissioning activities in the US, the UK, and France. In this way, institutions concerned in Japan are strengthening international cooperation by concluding cooperation agreements with overseas institutions concerned and other initiatives.

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 19).

The Japanese government, TEPCO, and NDF are each working with their counterparts to share technical cooperation, 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.

As international travel was restricted from 2020 amid the global COVID-19 pandemic, conferences were mostly held online, but they are now held in person again, with more opportunities to speak on-site. NDF is considering and holding in-person, online, and hybrid meetings, taking into account the movements of overseas organizations and what is convenient for participants (Fig. 54) The widespread use of online systems to hold meetings has made it easier to secure opportunities for communication with overseas institutions than before the pandemic, thereby improving operational efficiency and contributing to the maintenance and development of relationships.

Fig. 54 The 7th International Forum on the Decommissioning of the Fukushima Daiichi Nuclear Power Station

6.2.2 Key issues and strategies

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

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.

Public decommissioning implementation entities are leading in promoting decommissioning of legacy sites in each country, offering many points of reference regarding technology and management as a leading model. 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 gain practical experience and conducts visits and periodic information exchanges with decommissioning-related organizations and companies. NDF needs to collect wisdom and knowledge, including lessons learned from decommissioning of overseas legacy sites and facilities engaged in highly difficult decommissioning work around the world through long-term partnerships with the public decommissioning implementation entities with a central role in each country, including NDA in the UK, CEA (French

Alternative Energies and Atomic Energy Commission) in France, and Department of Energy, Office of Environmental Management (DOE) in the US.

Therefore, it is expected that the decommissioning will be undertaken with the following three strategies into consideration.

As a first strategy, 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 strengthen cooperation with its counterparts. To realize the decommissioning of the Fukushima Daiichi NPS, it is expected to integrate global technical and operational wisdom and knowledge and fully incorporate 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.

As a second strategy, in addition to the countries mentioned above, it is desirable to explore the possibility of applying general-purpose technologies from more countries to decommissioning and collect technical information to obtain cooperation from more experts, including countries that do not use nuclear technology. Decommissioning of the Fukushima Daiichi NPS is a process of solving unexplored engineering problems by combining knowledge from various fields, including remote technology, and 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.

Thirdly, twelve 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 can 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, for example, 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. The global energy landscape is also changing, 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. In response to this, many countries have been reviewing their energy policies. 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 ➊ an approach for experts and ➋ an approach for 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 12 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, the world's experts must first be correctly understood. 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 desirable 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.

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.

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 Local community engagement

6.3.1 Significance and the current status of local community engagement

6.3.1.1 Basic concept

The fundamental principle for 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 hinder reconstruction efforts due to anxiety and distrust of decommissioning.

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 very long period of time, the continuous cooperation of companies, especially local companies, is essential. At the same time, the participation of local companies in the decommissioning project is an important pillar of 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. 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.

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, and 14,728 in FY 2022). 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 about 100,000 visitors as of the end of March 2023. 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 (hereinafter referred to as "Commitment"), 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, steadily promotion of 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

In addition, a survey of the needs of both prime contractors and local companies for human resource development and joint research with several universities have started. The contents of the "Medium-to-Long-Term Outlook" 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. In particular, since FY2022, the “Medium-to-Long-Term Outlook” has been provided to indicate specific tasks in which local companies may be able to participate and share information contributing to the consideration of participation by local companies.

These initiatives have led to steady results, with a total of 706 decommissioning-related matches as of the end of March 2023 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 establish a plant 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 large-scale fuel debris retrieval.

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 promptly disseminate information on the current decommissioning status in an easy-to-understand manner by taking every possible measure. Therefore, in addition to continuously providing opportunities for direct participation, including face-to-face meetings and site visits, 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, based on the "Action Plan for Steady Implementation of the Basic Policy on the Disposal of ALPS-Treated Water" (formulated on December 28, 2021, and revised on August 30, 2022), the government is implementing measures to overcome rumors by communicating safety based on scientific evidence, providing support for capital investment and expansion of sales channels for fishermen, and enhancing safety nets such as funds and compensation.

TEPCO has been working to suppress reputational damage through information dissemination via its "Treated-water portal site" and safety confirmation by related organizations, etc., based on the TEPCO Holdings' Action in Response to the Government's Policy on the Handling of ALPS Treated Water from the Fukushima Daiichi Nuclear Power Station (released on April 16, 2021). TEPCO should continue the utmost efforts to foster 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.

With the understanding of prime contractors, it is also necessary to consider specific methods of ordering and contracting that will make it easier for local companies to receive orders and to implement these methods on a trial basis. As a result of interviews conducted with local companies in FY 2020, it became clear that local companies do not necessarily want to be the main contractors, but tend to want to enter the market as a subcontractor to gain technology and experience. After properly understanding the intentions and needs of these local companies, a scheme can be established to benefit both parties by not only approaching local companies but also encouraging existing prime contractors to place orders with local companies, including technical guidance. In addition, this scheme will grant contract incentives, such as multi-year contracts and priority order placement, if certain results are achieved in placing orders to local companies or personnel development. Adopting such beneficial methods for both parties can promote awarding contracts to local companies. In particular, since the last fiscal year, the “Medium-to-Long-Term Outlook” has been provided to indicate specific tasks in which local companies may be able to participate. It is important to continuously implement initiatives to expand the participation of local companies. While continuously considering initiatives that facilitate the participation of local companies and that will enable them to receive constant and a certain scale of orders, a stance that proceeds with long-term decommissioning with the local community, Fukushima Prefecture, should be expressed.

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.

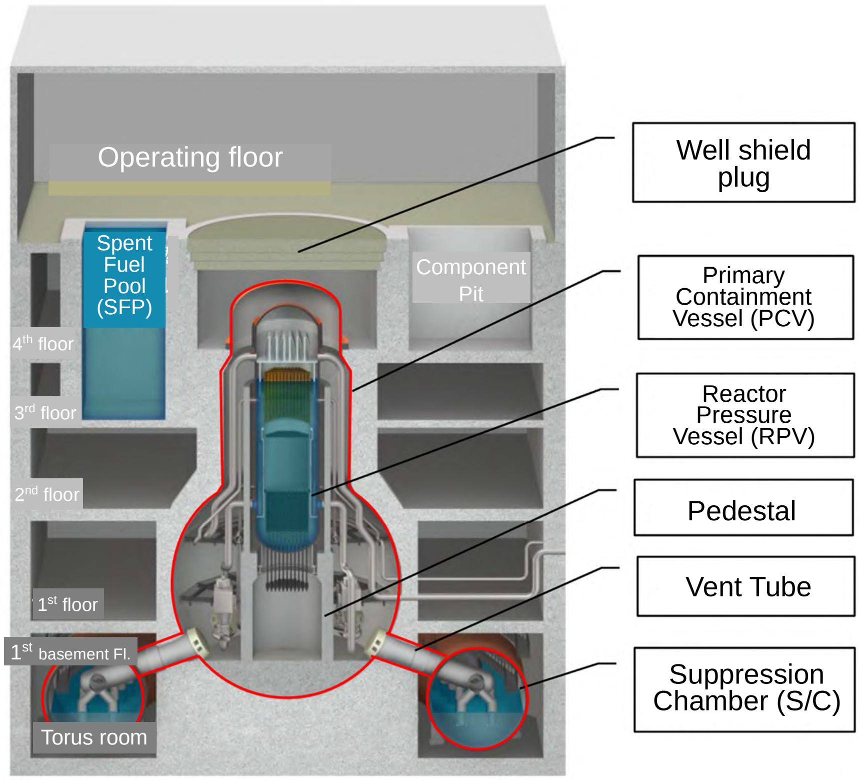
Moreover, it is necessary to further strengthen cooperation and collaboration with local governments, including Fukushima Prefecture, and local related organizations, including the Fukushima Innovation Coast Framework Promotion Organization and the Fukushima Soso Recovery Promotion Organization, which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

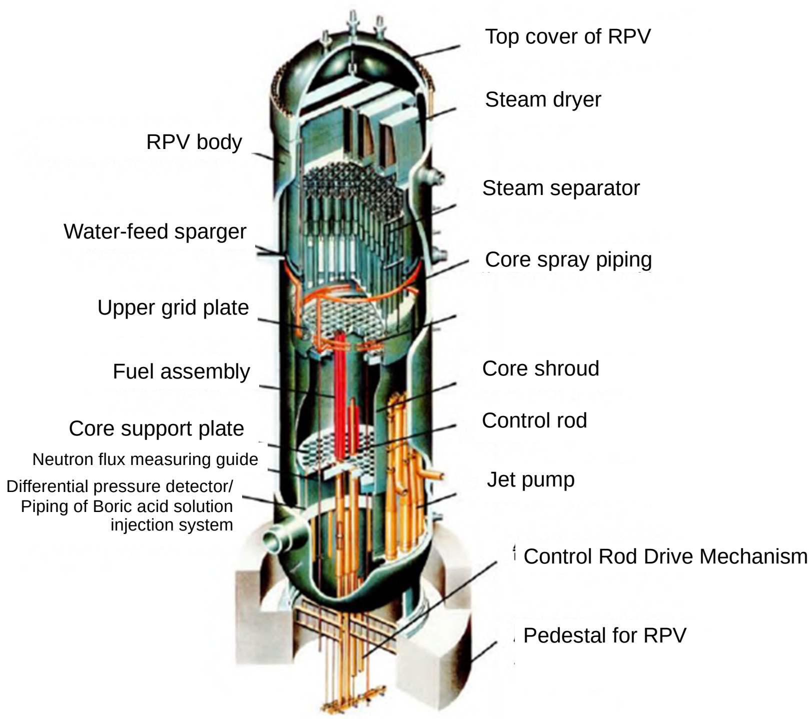
SED	Safety and Environmental Detriment
SGTS	Standby Gas Treatment System
TMI-2	Three Mile Island Nuclear Power Plant Unit 2
Penetration X-2	PCV penetrating part X-2
Penetration X-6	PCV penetrating part X-6
Center of the World Intelligence project	The project that promotes nuclear science and technology 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)

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



(Courtesy of IRID)

Fig. 55 Structural drawing inside Reactor building



(Courtesy of IRID)

Fig. 56 Structural drawing inside Reactor Pressure Vessel (RPV)

List of Attachment

Contents

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

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

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

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

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

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

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

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

- The first 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 fuel debris retrieval in 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 fuel debris retrieval in scale, the status of efforts to discharge ALPS-treated water into the sea and the analytical strategy for promoting decommissioning.

Attachment 2 Major accomplishments to date relating to the decommissioning of the Fukushima Daiichi NPS[131]

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131 The 117th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water. "Material 2: Progress towards decommissioning, etc."

2 Handling of ALPS treated water

Reference 2／6
August 31, 2023
Secretariat of the Team for Countermeasures for Decommissioning, Contaminated Water and 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.

Information provision and communication to foster understanding

■ Measures for decommissioning, contaminated water and treated water of the Fukushima Daiichi Nuclear Power Station need efforts to reduce risks over a long term. Regarding handling of ALPS treated water as a part of decommissioning, to local residents, those who in the fishery industry and related parties, we will thoroughly explain about the policies and responses concerning the facility design, operation and management to ensure safety, monitoring of radioactive materials and others, and proceed with **efforts to sincerely face their concerns and interests and respond to each of them**.

■ Moreover, to **further deepen the understanding** of everyone in Japan and overseas, efforts to **coherently disseminate** measurement results of ALPS treated water and information concerning facility operation, radiation impact assessment and others will continue and be enhanced.

● **Visits and Discussion Meetings of Fukushima Daiichi Nuclear Power Station**
To solve people's questions, TEPCO invites their visits to the power station and answer their questions on site. From people who participated in the visit gave feedbacks such as "by directly seeing the decommission site and having dialogues, they could obtain deeper understanding about the present situation, issues and status of safety measures." TEPCO will continue these efforts to invite more people including online visits.
<Visits in FY2022: 15 times, 142 participants in total>

● For overseas, the was renewed. **"Treated Water portal site in English, Chinese and Korean"**
- "Sea Area Monitoring" page in English, Chinese and Korean was published
- "The 1st IAEA Review" explanation booklet was published in English, Chinese and Korean

● When inaccurate or misleading overseas information was detected, for maximum suppression of reputation, return call or other actions will be taken.

● A condition to deliver science-based information to overseas media and embassies in Japan will be created.
- Approach to major media and embassies is being enhanced.
- For accurate media coverage, regular press conferences will continue to be held.

● **Safety review of International Atomic Energy IAgency (IAEA)**
In November 2022, IAEA review team visited Japan to conduct the second review concerning safety of ALPS treated water (the first review was conducted in February 2022 and the report was published in April)
- The article of the IAEA Review concerning handling of ALPS treated water and overview of the report are published timely on the TEPCO website.
- Instructions from IAEA were reflected in the revision of the implementation plan and the radiation assessment report.
- The report of the second review will be published around early 2023.


IAEA review team arrived at the Fukushima Daiichi Nuclear Power Station

● 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. The progress will be shown coherently and clearly.
- Regarding behaviors of tritium and others, a lot of research has been conducted in Japan and overseas. Based on the experimental results, firstly experimental data for a half year will be collected and subsequently, the same as past experimental results, the theory "tritium in vivo is not concentrated and the concentration of tritium in vivo will not exceed the level in the growing environment" will also be reaffirmed.

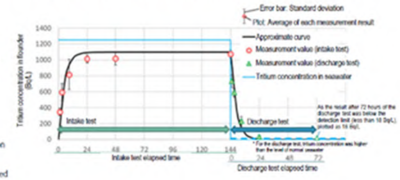

Flounder in rearing preparation tank


Overall view of mockup tanks

● **Measurement of tritium concentration of flounder (tritium concentration less than 1,500 Bq/L) and analysis of results**
Based on the measurement results of tritium concentration, the following was confirmed as in the past insight:

[Intake test]
- The tritium concentration did not exceed the level in the growing environment (in this test, the concentration exceeding the level in ALPS treated water diluted with seawater)
- The tritium concentration reached equilibrium in a certain period

[Discharge test]
- When flounder having reached equilibrium in the tritium concentration higher than the level of normal seawater is returned to normal seawater, the concentration decreased over time



- 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 Twitter: https://twitter.com/TEPCOfishkeeper

Examination concerning handling of ALPS treated water

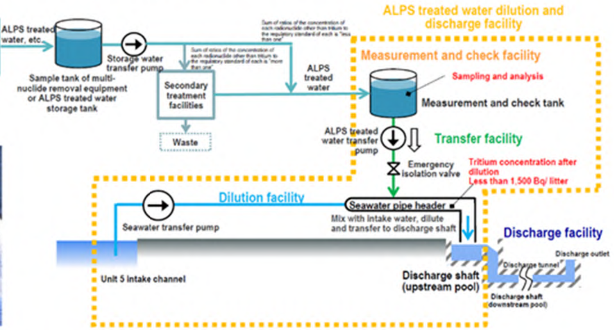
Tritiated Water Taskforce (2013.12 – 2016.5, 15 meetings)
2016.6 Report of Tritiated Water Taskforce

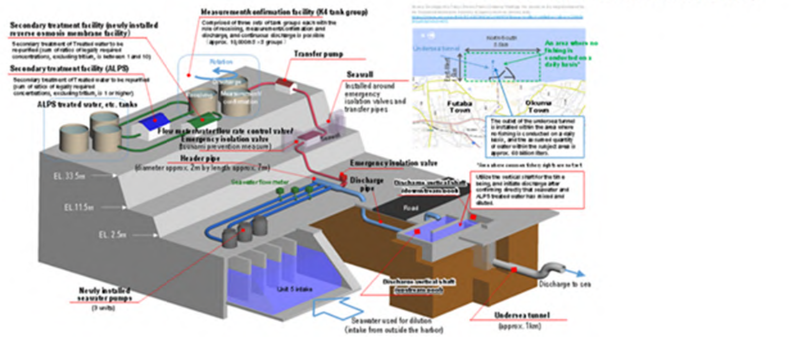

Tank area viewed from the Large Rest House (2015.10.29)

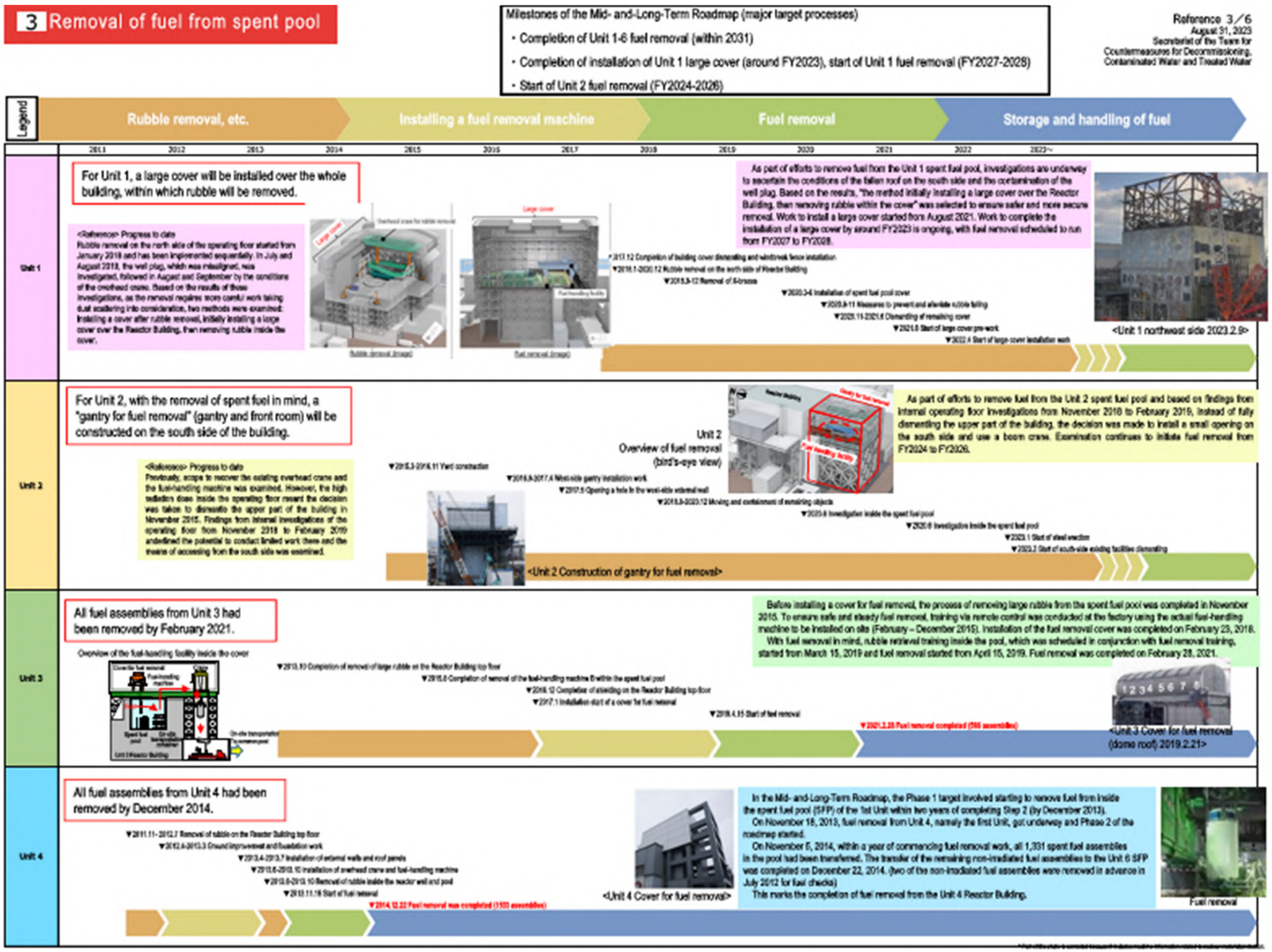
Subcommittee on Handling of ALPS treated water (2016.11 – 2020.1, 17 meetings)
2018.8 Explanatory and hearing meeting, receiving opinions
2020.2 Report of Subcommittee on Handling of ALPS treated water
Opportunity for receiving opinions from parties concerned concerning handling of ALPS treated water (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

2014 2015 2016 2017 2018 2019 2020 2021 2022 2023

【Overview of ALPS treated water dilution and discharge facility】






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)
Reference 3／6
August 31, 2023
Secretariat of the Team for
Countermeasures for Decommissioning,
Contaminated Water and Treated Water
Legend
Rubble removal, etc.
Installing a fuel removal machine
Fuel removal
Storage and handling of fuel
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023~
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 those 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.
Large cover
Large cover
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
▼2019.9-12 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
▼2021.6 Start of large cover pre-work
▼2022.4 Start of large cover installation work
<Unit 1 northwest side 2023.2.9>
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.
<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.
▼2015.3-2016.11 Yard construction
▼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
▼2020.6 Investigation inside the spent fuel pool
▼2023.1 Start of steel erection
▼2023.2 Start of south-side existing facilities dismantling
Unit 2
Overview of fuel removal
(bird's-eye view)
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.
<Unit 2 Construction of gantry for fuel removal>
Unit 3
All fuel assemblies from Unit 3 had been removed by February 2021.
Overview of the fuel-handling facility inside the cover
Cover for fuel removal
Fuel-handling machine
Crane
Spent fuel pool
Unit 3 Reactor Building
▼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
▼2012.6-2013.3 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
▼2013.6-2013.10 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

4 Work toward fuel debris retrieval

Milestones of the Mid-and-Long-Term Roadmap (major target processes)

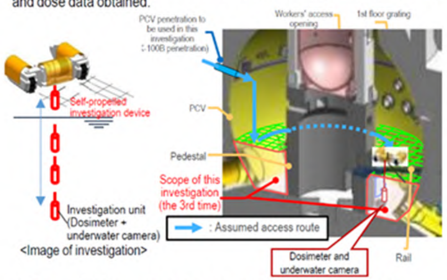
Start of fuel debris retrieval from the first unit (Unit 2). Expanding the scale in stages (within 2021 ※The schedule will be extended for about 1 year due to the spread of COVID-19 infections)

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

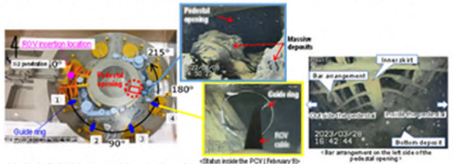
・In April 2015, a device having entered the inside of the PCV via a narrow opening (bore:φ100 mm) collected information such as images and airborne dose inside the PCV 1st floor.

・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.



<Status inside the PCV (February 9)> <Bar arrangement on the left side of the pedestal opening>

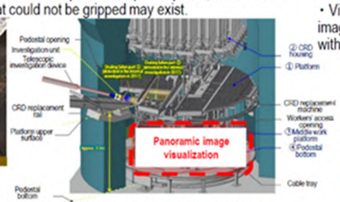
Unit 2 Investigation overview

・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.

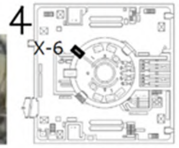

Bottom of the pedestal (after being processed in panoramic image visualization)



・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

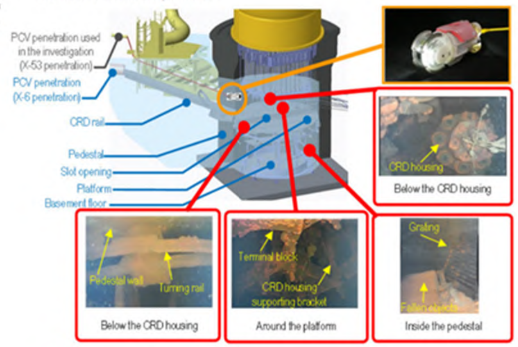
・In October 2014, the conditions of X-53 penetration, which may be under water and which is scheduled for use to investigate the inside of the PCV, was investigated via remote-controlled ultrasonic test equipment. The results showed that the penetration was not under water.

・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

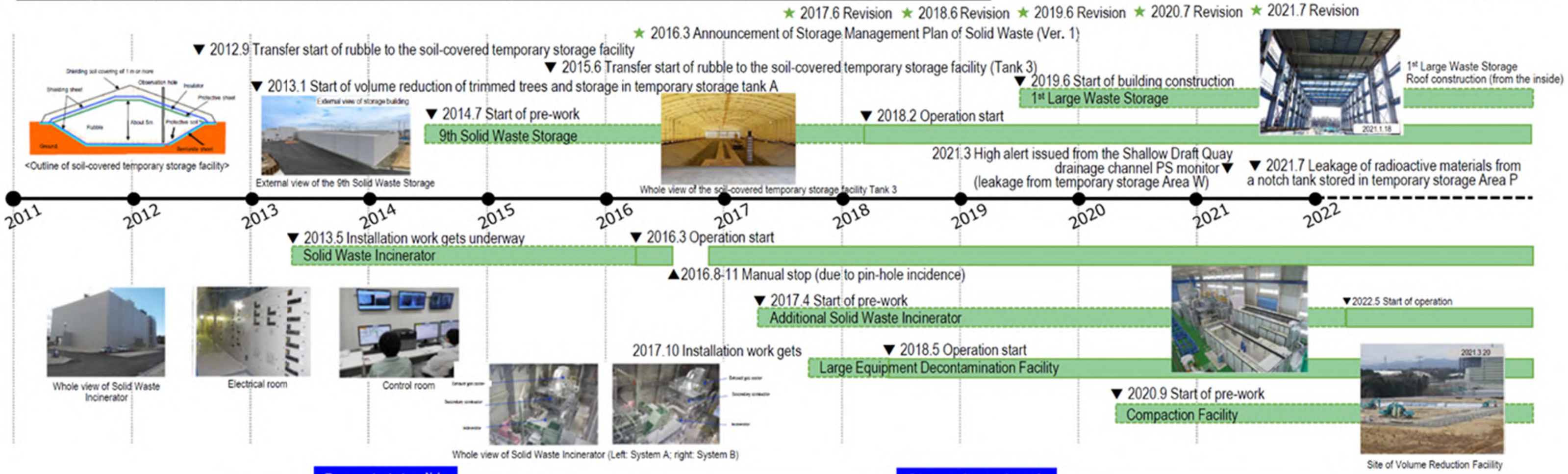
Investigations inside the PCV	1st (2015.10-12)	- Acquiring images - Measuring the air temperature and dose rate - Measuring the water level and temperature - Sampling stagnant water - Installing permanent monitoring instrumentation (2015.12)
	2nd (2017.7)	- Acquiring images - Installing permanent monitoring instrumentation (2017.8)
Leakage points from PCV	- Main steam pipe bellows (identified in 2014.5)	

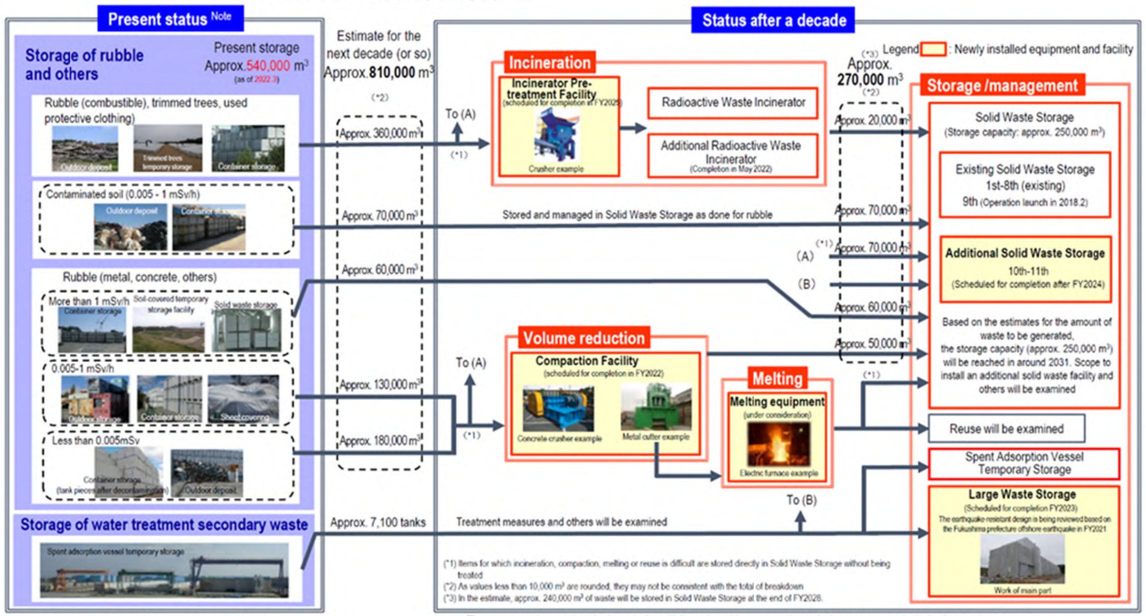
Evaluation of the location of fuel debris inside the reactor by measurement using muons
The evaluation confirmed that no large lump existed in the core area where fuel had been placed and that a portion of the fuel debris potentially existed at the bottom of the RPV. (2017.5-9)

Images are provided by the International Research Institute for Nuclear Decommissioning (IRID)

5 Management of solid radioactive waste

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 Daiichi 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 Daiichi 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.

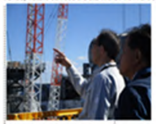
Large rest house under construction
(2014.9.30)

Access Control Facility
(2014.11.7)

- ▼ To help workers in the Fukushima Daiichi 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 Daiichi 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.

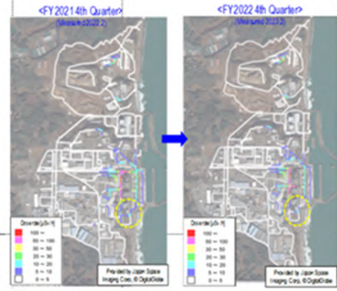


Visit by Governor of Fukushima Prefecture to the Fukushima Daiichi NPS (2018.11.1)

Visit by Prime Minister Kishida to the Fukushima Daiichi NPS (2021.10.17)

Visit by Prime Minister Kishida to the Fukushima Daiichi NPS (2023.8.21)
Observation of ALPS Treated Water Dilution/Discharge Facilities from high ground on Units 5 and 6 side

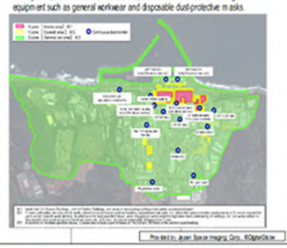
<Travel survey results of major roads within the site>
It was confirmed that compared with the last fiscal year, the dose rate has been declining on roads near the southeast side of the Unit 4 Turbine Building and the west side of the Process Main Building (area circled by yellow dot line).



- ▼ 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
(2016.1.7)

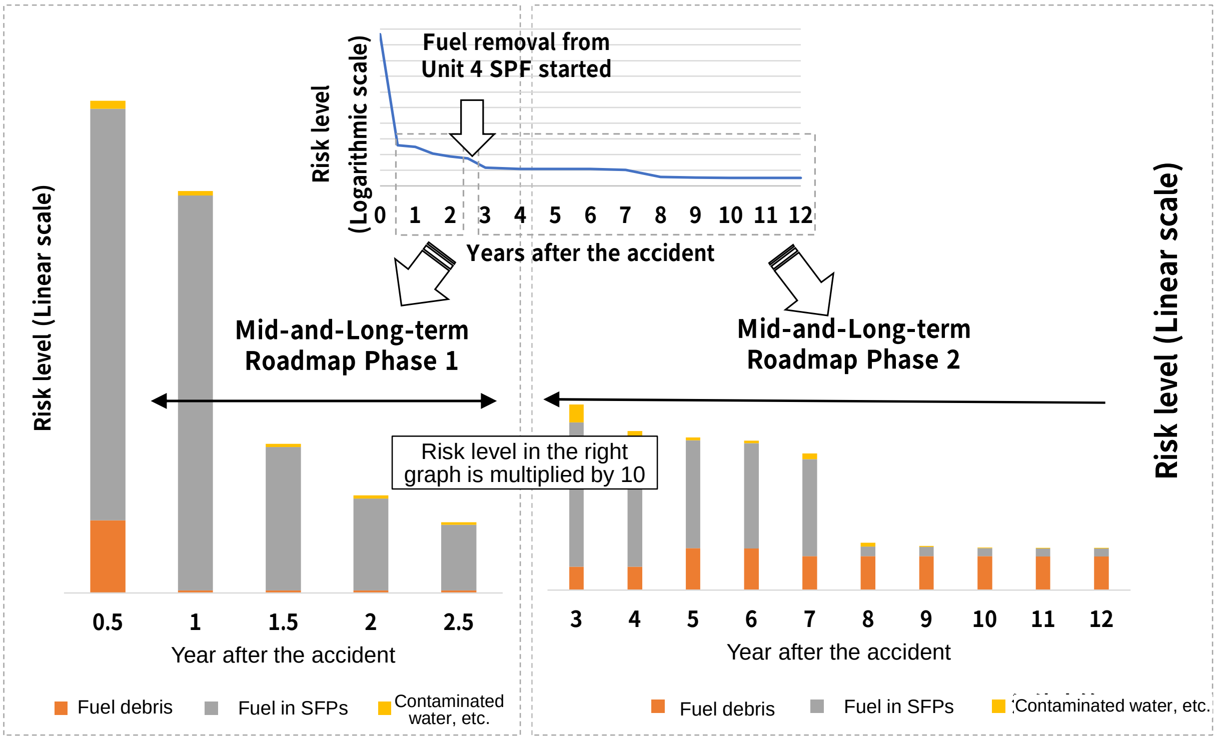
Facing
(2017.4.13)

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 presented in the Technical Strategic Plan 2022 (11 years after the accident), because some ALPS slurry stored in HICs affected by beta irradiation need to be transferred. However, it is tending down in the Technical Strategic Plan 2023 (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 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.

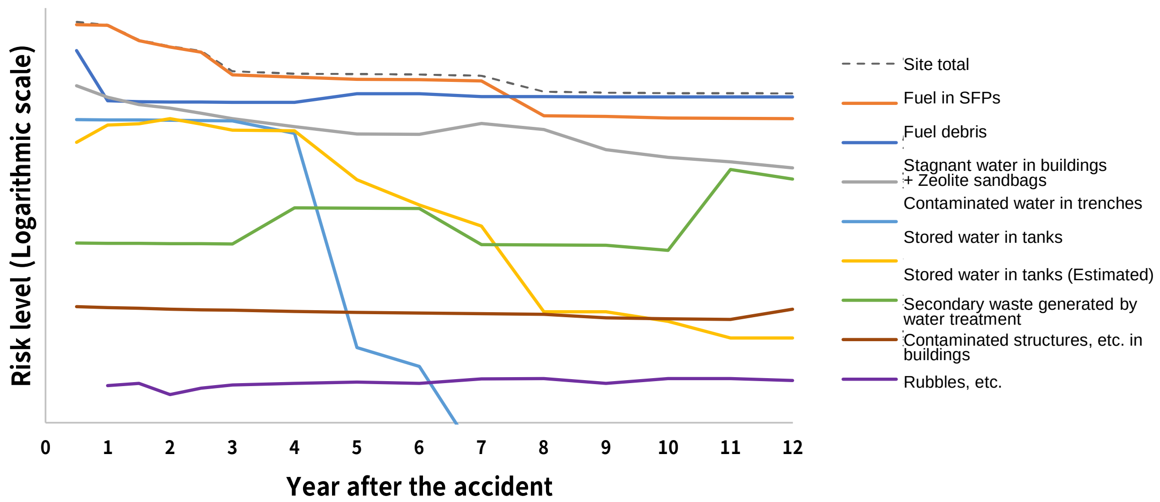


Fig. A3-2 Change in the risk level for each major risk source

(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)[132].

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[133]. 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[134].

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[121].

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[135].

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.

(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

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

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

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

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

effect of subdrains and land-side impermeable walls, water drainage in condensers, and the start of the operation of Third cesium sorption apparatus (SARRY-II). This stagnant water treatment in the buildings so far significantly contributes to risk level reduction of the total site following contribution by fuel removal in SFP.

(4) Contaminated water in trenches

Although the contaminated water of high concentration has been stagnated in the seawater pipe trenches in Units 2 to 4 since immediately after the accident, the trenches were blocked and the treatment of the stagnant water has been completed (in 2015)[136]. 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 [137].

(5) Stored water in tanks

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

The treatment of the concentrated salt water generated from the treatment with KURION before ALPS came into operation was completed in 2015 through the operation of ALPS and the advanced multi-nuclide removal equipment (Advanced ALPS)[138].

Risk level of these stored water in the tanks are also lowered by raising and duplexing the weir (for the existing tanks completed in 2014), transferring from flanged tanks to welded tanks, and treating the Sr-treated water remaining at the bottom of the flanged tanks (in 2019), and treating ALPS-treated water (in 2020). The remaining concentrated saltwater at the bottom of flanged tanks is being collected for dismantling the tanks as at the end of March 2023, then the remaining water, after sludge removal by filtering, is planned to be transferred to the process main building.

(6) Secondary waste generated by water treatment

Many radioactive materials have moved from contaminated water to secondary waste through water treatment. What has been generated includes the sludge from decontamination device, the waste sorption vessels by operation of KURION and SARRY (in 2011) and by the SARRY-II (in

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

[137] Inspection of stagnant water contains radioactive materials observed in trenches of Fukushima Daiichi NPS, (FY2021)”, Tokyo Electric Power Company Holdings, Inc.

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

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 eleven years 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 during FY2023, the risk level is on a downward trend based on the progress of the transfer work during FY2022. Although the number of HICs whose cumulative absorbed dose approached the standard value will gradually increase over time, ensuring that the cumulative absorbed dose can be managed so as not to exceed the standard value will reduce the risk level by systematically implementing the transfer operation. For other risk sources, the sludge from decontamination device greatly contributes to the risk level though, sludge is not newly generated at present, and thus, the risk level of the total secondary waste generated by water treatment is not on an increasing trend. As a tsunami countermeasure, the sludge from decontamination equipment stored in the main process building (T.P. 8.5m) will be extracted (planned for FY2025), placed in a storage container, and transferred to the elevated area (T.P. 33.5m) [139].

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. As a result of the integrity assessment assuming hydrogen explosions, plans for purging operations, etc. are being considered for Unit 3 S/C and HPCI turbine exhaust lines that exceed the elastic deformation range[140].

(8) Rubble, etc.

Rubbles, etc. as solid waste are stored under a variety of conditions such as in solid waste storage, in temporary waste storage and by outdoor accumulation. Each has different Requiring Level for Safety Management, and the rubbles stored in outdoor sheet covered storage and

[139] Reference 1-1-7, “Changes to the process for extracting sludge from decontamination equipment (Supplementary explanation material)”, The 104th Study group on monitoring and assessment of specified nuclear facilities, Tokyo Electric Power Company Holdings, Inc.

[140] Reference 2-1, “Response to Unit 1 RCW in light of hydrogen accumulation event (Impact assessment of hydrogen accumulation event)”, The 10th Technical meeting on the examination of the action plan for specific nuclear facilities, Tokyo Electric Power Company Holdings, Inc.

outdoor accumulation are of the highest risk level. In the past, the facilities with better management condition have been enhanced by soil covered temporary storage facilities (in 2012), fallen tree temporary storage pool (in 2013), expansion of solid waste storage facilities (in 2018), etc. In addition, the rubble from temporary storage facilities was transferred to the better-controlled solid waste storage facility (in 2020). With the start of operation of the additional solid waste incineration facility (May 2022), combustible rubbles and other materials stored outdoors can be transferred to the solid waste storage facility after incineration to reduce their volume. Furthermore, outdoor temporary storage is planned to be discontinued by the end of FY 2028 by further increasing volume reduction installations and solid waste storages, etc., in accordance with the Solid Waste Storage Management Plan[141].

[141] The Solid Waste Storage Management Plan at the Fukushima Daiichi NPS (February 2023 Edition), Tokyo Electric Power Company Holdings, Inc.

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) feed back 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.[142, 143] 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. In view of the fact that the past assessment of these effects was limited, it is necessary to make maximum use of existing techniques and evaluation results for planning and implementing an investigation plan, in which remote control under a high-radiation dose environment is a challenging issue, and to develop underlying technologies to understand the situation. In so doing, while giving priority to safety, it is useful to actively introduce the latest knowledge and achievements not only in the nuclear field but also in other fields. Specifically, for RPV pedestal in Unit 1, PCV internal investigations revealed the loss of concrete in the lower part of the pedestal near the worker access entrance and almost the entire inner wall of the pedestal, so TEPCO is conducting assessments based on these findings. However, the information obtained is still limited, and many of the conditions for examination will be based on assumptions. Therefore, regardless of the evaluation results, it is important to assess the impact of anticipated events such as loss of support function, and to consider the necessary measures. In addition, the information obtained will provide useful leads to clarify the accident progression, which should be used with other information for future evaluation.

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.

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142 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.

143 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.

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

In addition, one method for seismic risk preparedness is reducing the stress generated during an earthquake. For example, drainage is planned for the S/C in Units 1 and 3 with a water level higher than during normal operation caused by the accident. In all cases, measures are being taken to first install new water level gauges with a wide measurement range to ensure that all possible measures are implemented to reduce water levels.

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 define seismic classes and perform seismic evaluation accordingly. However, it is still challenging to repair and reinforce buildings and main equipment damaged by the accident in a high radiation dose environment. Because of this, the earthquake ground motion and the design criteria used in the design will be defined appropriately in accordance with the new seismic design policy determined by the NRA[144, 145] 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.

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

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

① New seismic design policy determined by the NRA (Reference)

The NRA stated, “Given that the earthquake ground motion of the Great East Japan Earthquake in 2011 exceeded Ss 600, and that the ground motion of the earthquake on February 13, 2021, exceeded Sd 300, the earthquake ground motion to be used in the future seismic design of 1F should take into account these seismic motions observed,”[3] and”. For the time being, it is appropriate to reorganize ‘the concept of earthquake ground motion and its application to the seismic design of 1F’ based on the earthquake ground motion for review (Ss 900).”[3] The NRA approved the application of the system based on the existing earthquake ground motion[146] for review (the Ss 900 system). In addition to the conventional seismic classes (Classes S, B, and C), B+ was newly adopted as a seismic class higher than Class B.[3]

Based on the above, the following seismic policy[3] applies to newly installed systems.

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

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

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

Regarding the concept of classification of seismic classes and the application of earthquake ground motion in the seismic design of the Fukushima Daiichi NPS, “In the seismic evaluation of facilities and systems at 1F, the earthquake ground motion to be applied shall be established taking into consideration (1) seismic classes (S, B+, B, C), and (2) impacts on decommissioning activities, consequent impacts on upper classes, service life, design progress, amount of radioactivity of contained liquid, etc., and measures shall be determined as needed.”[4] The procedures for establishing earthquake ground motion and determining the necessary measures according to the seismic classes and characteristics of facilities are provided in Attachment.[4] However, the procedures have been changed to make a decision after examining the exposure assessment period and realistic mitigation measures, including radiation protection measures and building seismic design.[147] In addition, for facilities and systems in the B+ class whose functions shall be maintained against 1/2 Ss, there must be an evaluation of the impact on them from the earthquake off the coast of Fukushima Prefecture on March 16, 2022.

146 Tokyo Electric Power Company Holdings Inc., “Examination of protection against external events at the Fukushima Daiichi Nuclear Power Station,” Study group on monitoring and assessment of specified nuclear facilities meeting (27th), Material 2, October 3, 2014.

147 NRA, “The concept of classification of seismic classes and the application of earthquake ground motion in Tokyo Electric Power Company Holdings Inc. Fukushima Daiichi Nuclear Power Station,” Nuclear Regulation Authority (51st meeting), Material 3, November 16, 2022

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[148] 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. 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

[148] NDA Prioritization – Calculation of Safety and Environmental Detriment score, EPGR02 Rev.6, April 2011.

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[149].

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[150]. The STP is defined as the volume of water required to dilute 1TBq of radioactive materials and corresponds to the radiation dose coefficient. Ingestion of a certain amount of such diluted water throughout the year will result in a radiation exposure dose of 1mSv. The SED indicator conservatively uses the larger radiation dose coefficient between ingestion and inhalation.

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

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 when containment function is totally lost and that 10% of radioactive material is released in the case of powder based on the measurement data. Because of no clear basis, the indicator in case of solid is set to a sufficiently small value assuming that the solid materials are less easily released.

[149] The NDA Prioritization Process - Development Process Route Map Report, EGR014 Rev.0, July 2006.
[150] Instruction for the calculation of the Radiological Hazard Potential, EGPR02-WI01 Rev.3, March 2010.

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 be applied 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.	15

	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.	
7	“Safety assessment criteria” are satisfied until “the time of work (such as transfer, treatment, recovery, etc.)” for the risk source. Facilities dissatisfying “safety assessment criteria” exist in the surrounding area, and the potentiality is high to make (receive) the diffusion impact*5 of the risk source to (from) these adjacent facilities. The component for diffusion control function is single.	8
8	“Safety assessment criteria” are satisfied until “the time of work (such as transfer, treatment, recovery, etc.)” for the risk source. The potentiality is high to make (receive) the diffusion impact of the risk source to (from) these adjacent facilities. The component for diffusion control function is multiple.	5
9	“Safety assessment criteria” are satisfied until “the time of work (such as transfer, treatment, recovery, etc.)” for the risk source. The potentiality is low to make (receive) the diffusion impact of the risk source to (from) these adjacent facilities. The component for diffusion control function is single.	3
10	“Safety assessment criteria” are satisfied until “the time of work (such as transfer, treatment, collection, etc.)” for the risk source. The potentiality is low to make (receive) the diffusion impact of the risk source to (from) these adjacent facilities. The component for diffusion control function is multiple.	2
*1. This refers to “at the time” of study on SED score, i.e., “at the present time” of assessment. *2. “Safety assessment criteria” described in this sentence refer to “the matters for which measures should be taken” or “securing of diffusion control function within the scope of design basis event”. *3. This refers to the time of “recovery” of the risk source for disposition and carrying out for which SED score shall be studied. *4. External events (natural disasters, etc.) are postulated as contingencies. *5. The potentiality of diffusion of the risk source exists to (from) adjacent facilities when facilities receive external impact caused by contingencies or impact caused by any events (fire, etc.), etc.		

Table 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 the Table 1 in Chapter 2 of the body part. Looking ahead to the decommissioning of the entire Fukushima Daiichi NPS, it is necessary to focus on risk sources that are not explicitly addressed in the major risk sources. Table 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.[151].

Table A6- 1　Risk sources that are not explicitly addressed in the major risk sources (1/3)

Issue	Risk source	Descriptions
Liquid radioactive materials	Sludge on the floor in the buildings	The floor surface of turbine buildings and radioactive waste disposal buildings of Units 1 to 4, waste process building and Unit 4 reactor building remain exposed, and radioactivity of sludge after the exposure was 1.9×10^{13}Bq[152]. For reactor buildings of Units 1 to 3, process main building and high temperature incinerator building, stagnant water processing is underway.
	Underground water tank	The residual water in all the underground water tanks were completely recovered [153]. Dismantling and removal policies are under consideration.
	Accumulated water on site	Extracted by the comprehensive risk inspection performed in 2015[154]. Since then, the concentration of radioactive materials and volume of water are being checked accordingly [155].
Spent fuel	Fuel in Units 5/6 SFP	Unit 5 : 1,374, Unit 6 : 1,456[156]
	Spent control rods, etc.	Spent control rods, etc.: 23,547. Shroud fragments, etc.: 193 m^3 [157]. The major nuclide is Co-60.
	In-pool water	Salt removal in Units 2 to 4 was completed in 2013.

[151] NRA, "Measures for Mid-term Risk Reduction at TEPCO's Fukushima Daiichi NPS (Risk Map)", (March 2023 Edition)

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

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

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

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

[156] The 100th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water "Reference 3-2 : Storage status of spent fuel, etc."

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

Table A6- 1 Risk sources that are not explicitly addressed in the major risk sources (2/3)

Issue	Risk source	Descriptions
Solid radioactive materials	Rubbles around buildings	Dismantling of rubbles scattered on the roof floor of the buildings due to hydrogen explosions is now in operation and planned. The amount of rubbles has not been confirmed.
	Waste before the earthquake	185,816 drums are stored[158]. The major nuclide is Co-60.
Counter-measures to external events, etc.	Rainwater inleak into buildings	Rubble on the roof was removed and waterproofing was newly provided. Purification materials were installed in the gutters. Check valves were installed in the drainpipes. The roof drain was repaired and closed[159]. Facing of the Elevation T.P.2m, T.P.6m and T.P.8.5m was completed[160].
	Megafloat	The work of bottoming and internal filling was completed[161]. Revetment maintenance and embankment work are underway.
Important issues to progress decommissioning	Dust in operating floor	Below the target value of release control (1×10^7 Bq/h). Gradually declining[162].
	Radiation source on the 3rd and 4th floors of Unit 3 R/B	On the 3rd floor, beams at several locations were damaged. A maximum of 45 mSv/h was measured. On the 4th floor, 104 mSv/h was observed[163].
	Drainage	In drainage A, Cs-137: lowered to ND ~ 23 Bq/L [164]. 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[165], and measures such as operation of discriminating-type PSF monitors were taken[166].

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

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

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

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

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

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

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

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

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

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

Issue	Risk source	Descriptions
Important issues to progress decommissioning	Exhaust stack	Exhaust stack of Units 1/2 : dismantlement work was carried out since August 2019, and the upper part of 61 m out of the total height of 120 m was divided into 23 blocks in total for dismantling. On May 1, 2020, a lid was installed on a barrel 59 meters above the ground to prevent rainwater inleak, and dismantling was completed[167]. Exhaust stack of Units 3/4 : Measured 3mSv/h at the base[168].
	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[169]

[167] "Completion of Dismantling of Exhaust Stack of Units 1/2 at Fukushima Daiichi NPS" (May 1, 2020), Tokyo Electric Power Company Holdings, Inc.

[168] The 19th Committee on Accident Analysis of the Fukushima Daiichi NPS "Reference 4 : Interim report on the investigation and analysis of the accident at TEPCO's Fukushima Daiichi NPS (proposal)"」

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

Attachment 7　Change in risk over time

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

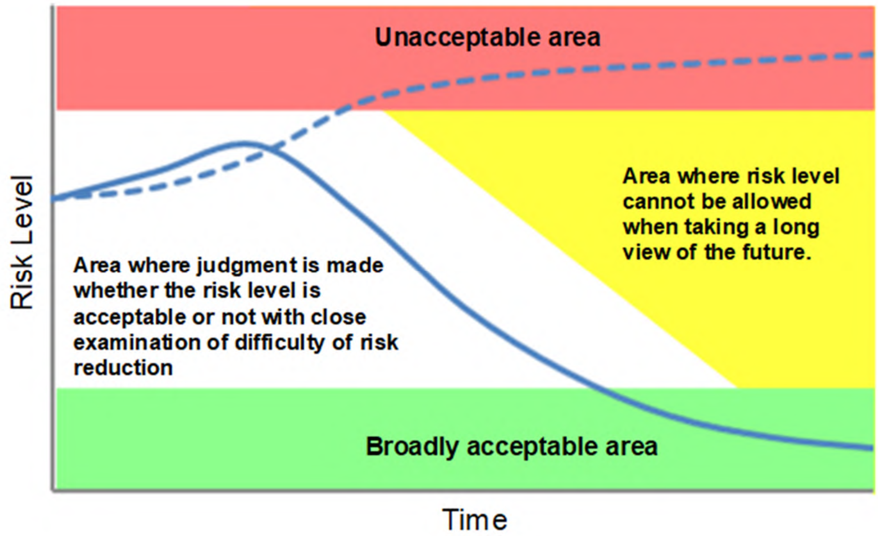


Fig. A7-1 Change in risk over time[170]

[170] 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[171],[172].

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 of specific unit. For more detail, as shown in the Fig A8-1, fuel debris can be classified by form such as damaged pellets, debris, crust, etc.

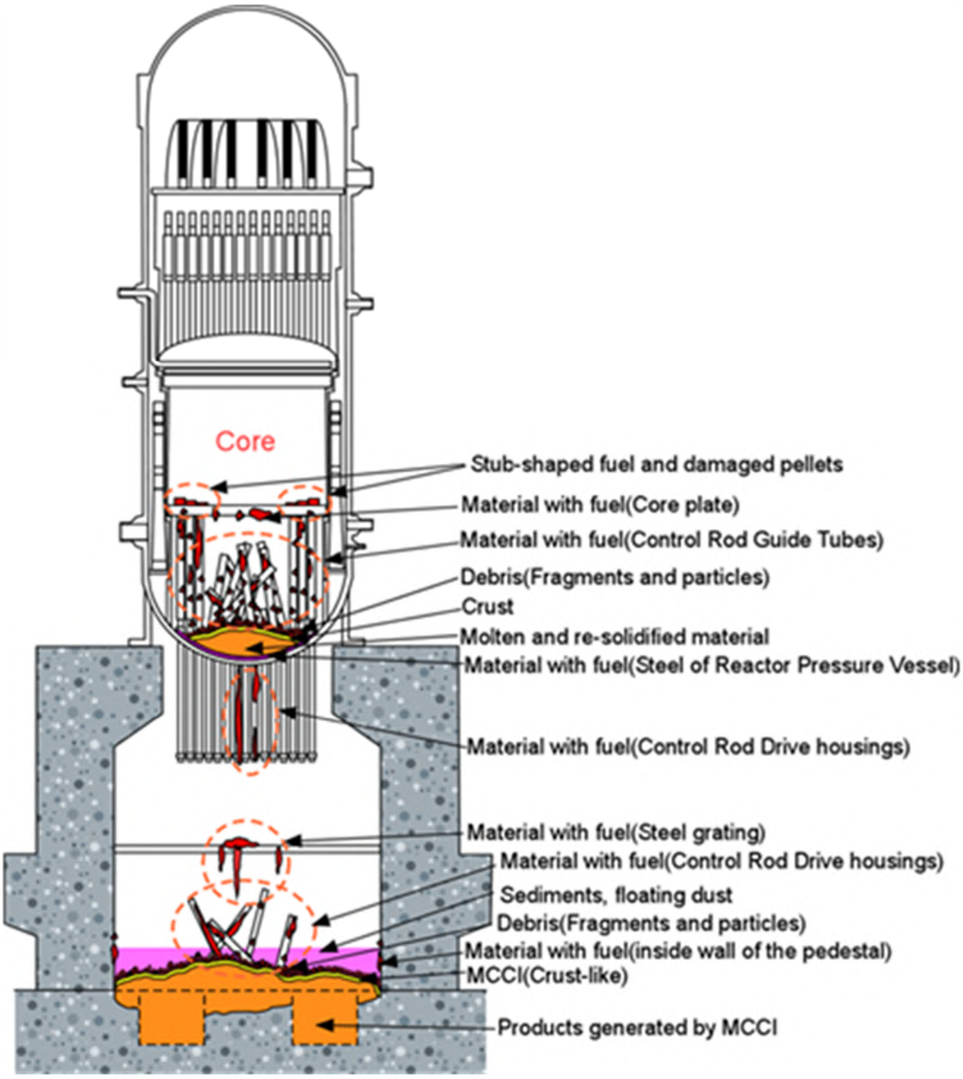


Fig. A6-1 Estimated inside of the PCV of the Fukushima Daiichi NPS

171 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)

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

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

Based on this, an example of fuel debris concept as a retrieval target of fuel debris is as shown in Fig. 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.

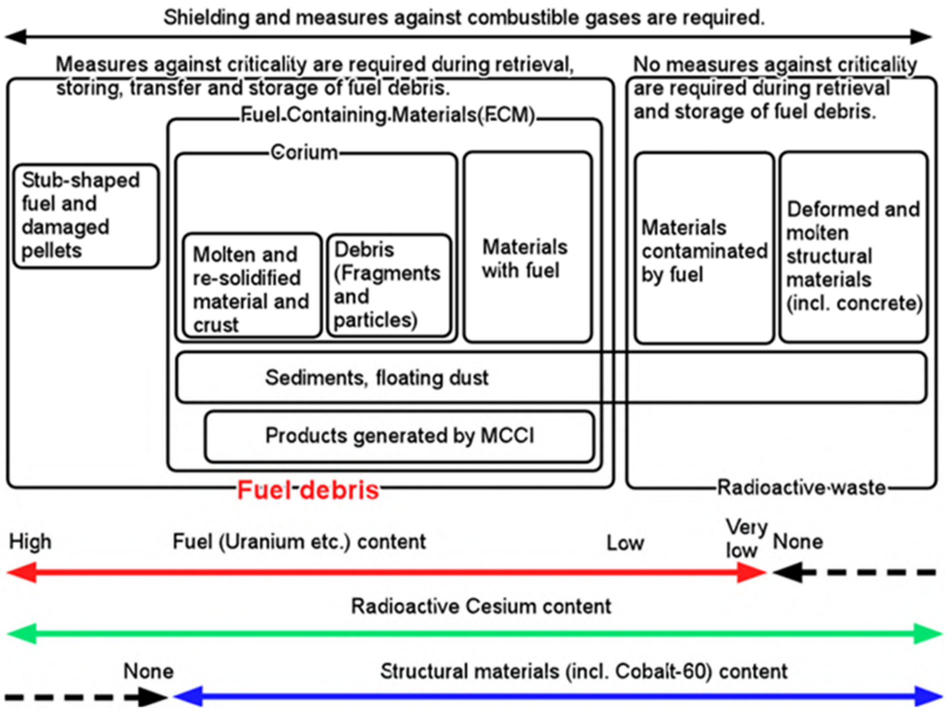


Fig. A6-2 An example of organized concept of fuel debris as fuel debris retrieval target at the Fukushima Daiichi NPS

【Glossaries and Terms】

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

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

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

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

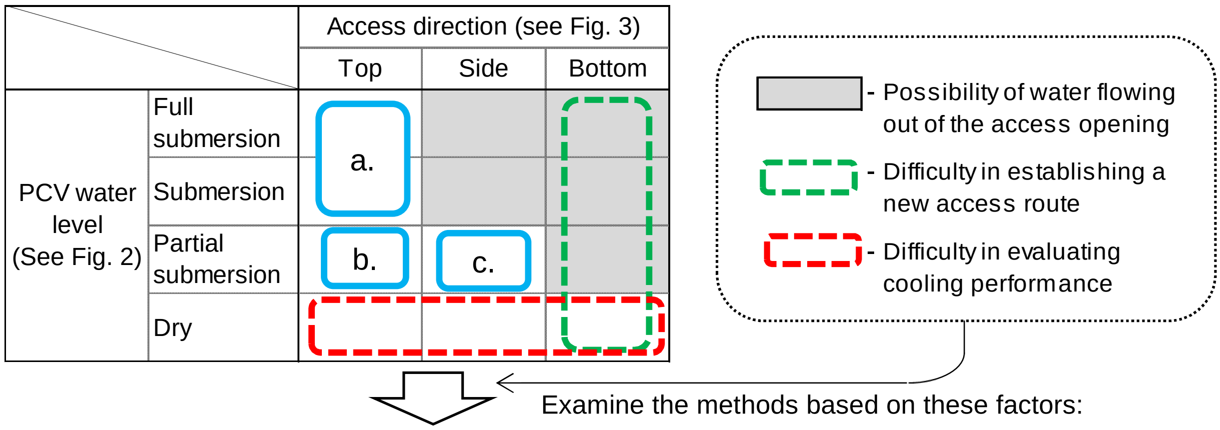
Fuel deposits : Molten fuel that has adhered to and solidified on components that do not originally contain fuel components, like CRD housing and grating, where fuel adhesions can be observed by sight.

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

Attachment 9 Changes in considerations on retrieval methods in the previous Technical Strategic Plans

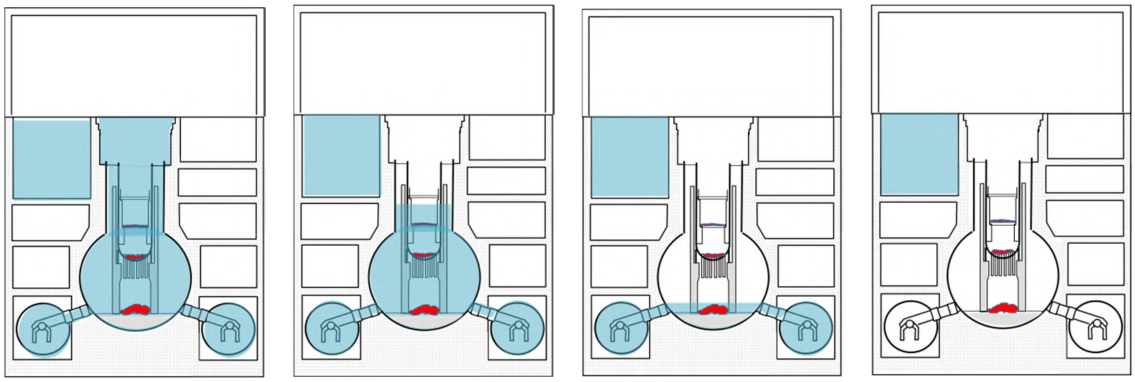
In the Technical Strategic Plans 2015 and 2016, options for fuel debris retrieval methods were explored based on a combination of the PCV water level (full submersion, submersion, partial submersion, and dry methods) and access directions (top, side, and bottom-access) to fuel debris. As a result, three 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. A9-1 to A9-3)

Combination of PCV water level and access direction



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

Fig. A9-1 Examination of the methods by a combination of the PCV water level and access directions to fuel debris



Full submersion method | Submersion method | Partial submersion method | Dry method

- 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

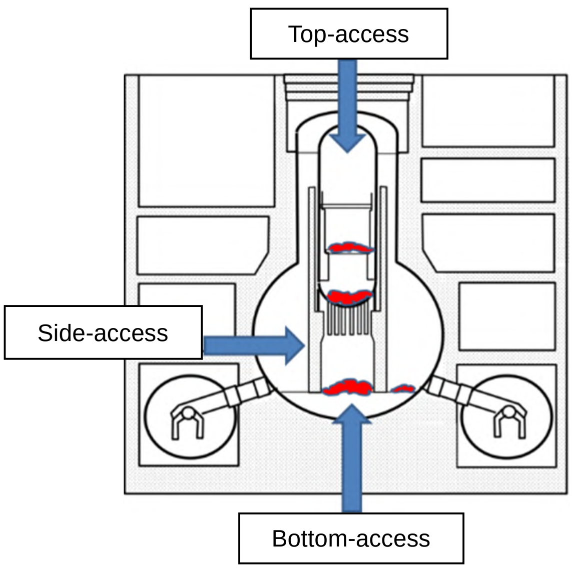


Fig. A9-3 Access direction to fuel debris

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 expanded by step up, while reviewing operations flexibly based on new findings obtained from the property of fuel debris and working experiences.

② Optimization of entire decommissioning work

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

③ Combination of multiple methods

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

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

④ Approach focused on partial submersion method

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

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

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

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

○ The bottom of PCV is most accessible and a certain amount of knowledge about it has already been accumulated through the investigation inside PCV.

- ○ There is a possibility that fuel debris retrieval could be started earlier.
- ○ Fuel debris retrieval could be performed at the same time as spent fuel removal

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

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Study on concept of fuel debris retrieval

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

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

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

↓

Comprehensive assessment

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

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

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

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

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

↓

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 tightened enclosure that contains the arm-type access equipment combined with existing safety system without significant modification.

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

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

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

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

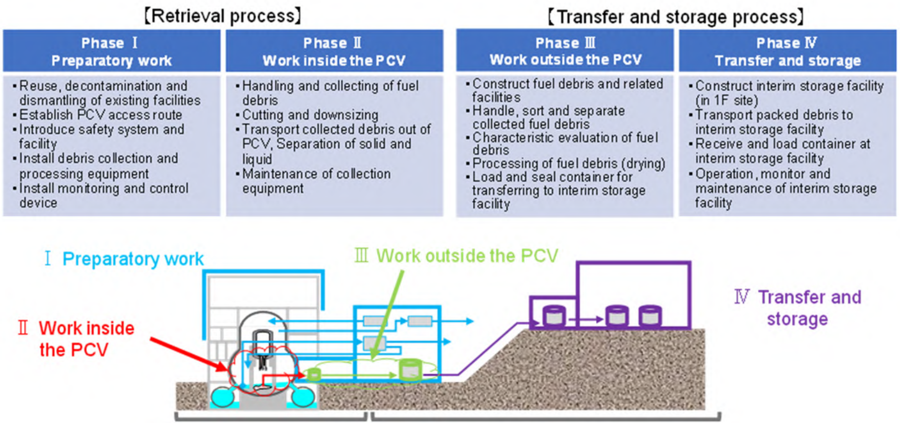
Fig. A9-4 Flow of examinations for determining the fuel debris retrieval method for the first implementing unit"

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

Lastly, the status of examining retrieval methods in the Technical Strategic Plan 2022 is shown below.

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.

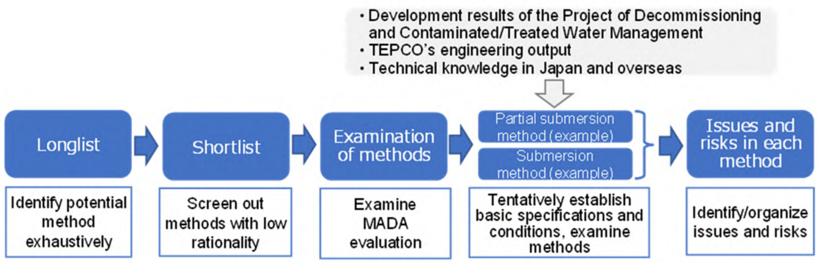
The following are the works implemented in FY 2021. In examining methods, the work process was roughly divided into two processes: retrieval and transfer/storage. The retrieval process was further divided into preparation work and work inside the PCV. The transfer/storage process was divided into work outside the PCV and transfer/storage work. This means that there were four major work phases, from Phase 1 to Phase 4 (see Fig. 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.[173] The basic specifications and conditions of these discussed methods were tentatively established to examine methods by incorporating the development results of the Project of Decommissioning, Contaminated Water and Treated Water Management, TEPCO's engineering output, and technical knowledge in Japan and overseas, and then issues and risks were identified and summarized (see Fig. Fig. A9-6).



(TEPCO material edited by NDF)

Fig. A9-5 Conceptual diagram of each work phase (a division of process)

[173] 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])

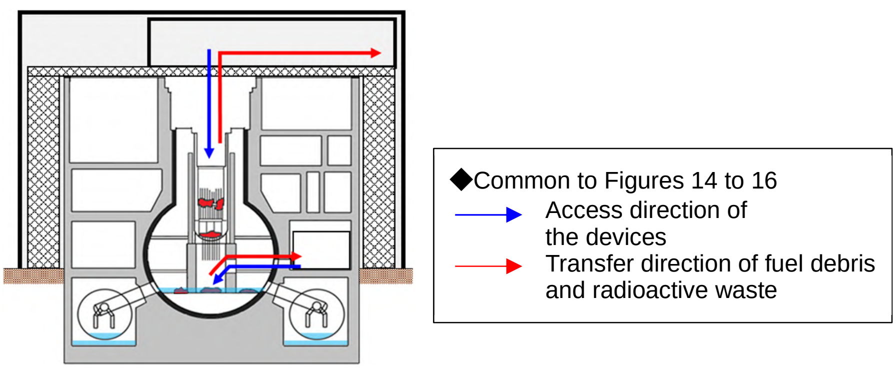


Fig. A9-7 An example of partial submersion method
(Conceptual drawing of combination of top and side access)

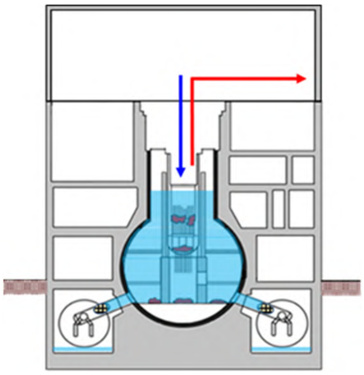


Fig. A9-8 Reference : Conventional submersion method
(Conceptual drawing of the PCV submersion method)

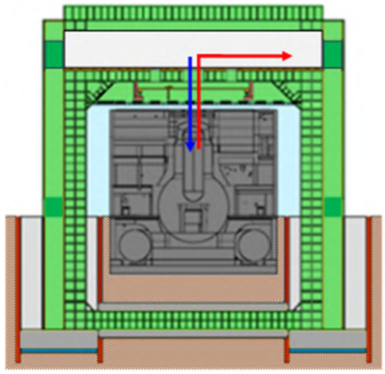


Fig. A9-9 An example of submersion methods
(Conceptual drawing of shell method)

After FY 2022, the feasibility of each method will be examined. Since there are several possible countermeasures against issues and risks, the options will be narrowed down step by step while proceeding with the design once the feasibility has been confirmed to some extent. In addition, hold points will be established to evaluate the actual site applicability, technological feasibility, and project continuity. If the criteria are not satisfied, the following items ① and ② will be considered.

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

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

Attachment 10 Continuation of accident analysis activities (clarification of events that occurred at the time of the accident) (progress of recent activities)

TEPCO is incorporating the findings obtained through the PCV internal investigations and the analysis data of the collected deposit samples into studies of fuel debris retrieval methods and storage management.

In FY 2022, PCV internal investigations in Unit 1 were conducted jointly by TEPCO and IRID/Hitachi-GE Nuclear Energy, Ltd. using an submersible ROV, and they succeeded in observing the conditions inside the pedestal for the first time since the accident.[174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187] Neutron and gamma-ray measurements revealed that fuel-containing substances were deposited extensively in the drywell area, and image analysis revealed that only the lower concrete was lost and that only the rebar remained in the vicinity of the pedestal opening and almost

[174] The 101st Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water, “Material 3-3: Status of PCV internal investigation in Unit 1,” April 27, 2022

[175] The 102nd Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water, “Material 3-3: Status of PCV internal investigation in Unit 1,” May 26, 2022

[176] The 103rd Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water, “Material 3-3: Status of PCV internal investigation in Unit 1,” June 30, 2022

[177] The 104th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water, “Material 3-3: Status of PCV internal investigation in Unit 1,” July 28, 2022

[178] The 106th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water, “Material 3-3: PCV internal investigation in Unit 1 (latter part),” September 29, 2022

[179] The 107th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water, “Material 3-3: PCV internal investigation in Unit 1 (latter part),” October 27, 2022

[180] The 108th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water, “Material 3-3: Policy of PCV internal investigation in Unit 1 (latter part),” November 25, 2022

[181] The 109th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water, “Material 3-3: Policy of PCV internal investigation in Unit 1 (latter part),” December 22, 2022

[182] The 30th Meeting of The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, “Material 1-1: Status of PCV internal investigation in Unit 1 [International Research Institute for Nuclear Decommissioning, Tokyo Electric Power Company Holdings Inc.],” June 30, 2022

[183] The 31st Meeting of The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, “Material 1-1: Status of PCV internal investigation in Unit 1 [International Research Institute for Nuclear Decommissioning, Tokyo Electric Power Company Holdings Inc.],” September 6, 2022

[184] The 32nd Meeting of The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, “Material 1-1: PCV internal investigation in Unit 1(latter part) [International Research Institute for Nuclear Decommissioning, Tokyo Electric Power Company Holdings Inc.],” October 31, 2022

[185] The 33rd Meeting of The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, “Material 1-1: Information gained from PCV internal investigation in Fukushima Daiichi Nuclear Power Station Unit 1 (Summary of the investigation of the first part) [Tokyo Electric Power Company Holdings Inc.],” December 5, 2022

[186] The 34th Meeting of The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, “Material 1-1: PCV internal investigation in Unit 1 (latter part) [Tokyo Electric Power Company Holdings Inc.],” December 20, 2022

[187] The 36th Meeting of The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, “Material 3: PCV internal investigation in Unit 1 (latter part) [Tokyo Electric Power Company Holdings Inc.],” March 7, 2023

the entire circumference of the inner wall surface. Based on these observations, the refinement of the internal PCV condition analysis of Unit 1 is underway.[188, 189, 190, 191]

In addition, TEPCO is independently investigating the reactor building of each unit. In FY 2021 and FY 2022, investigations were conducted including the following: the contamination condition of the fifth floor of the reactor building of Unit 2; the damage condition of the reactor building of Unit 3; the exterior of the reactor building of Unit 1; 3D laser scanner investigations of the reactor building of Unit 4; the interior of the SGTS, the fuel rod handling control room of Unit 2; the RCW heat exchanger of Unit 1; and the sludge on the underground floor of the turbine building of Unit 1.[192, 193, 194, 195, 196, 197, 198] The analysis of the samples collected in the residual water survey of the residual heat removal system (hereinafter referred to as "RHR") heat exchanger of Unit 3 was also performed.[199, 200] In addition, TEPCO and the JAEA jointly incorporated the results of the latest internal investigation of Units 2 and 3 to conduct an evaluation of the accident progression of Units 2 and 3 and a detailed analysis of the RPV failure and the fuel debris transfer process by using the

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[188] The 30th Meeting of The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, "Reference 1: Fuel debris distribution estimation by analysis and evaluation [International Research Institute for Nuclear Decommissioning, The Institute of Applied Energy]," June 30, 2022

[189] The 32nd Meeting of The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, "Material 1-2: Examination of events related to concrete observed in PCV internal investigation in Fukushima Daiichi Nuclear Power Station Unit 1 [Graduate School of Osaka University]," October 31, 2022

[190] The 33rd Meeting of The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, "Material 3: Report on investigation/examination results of unconfirmed and unexplained matters related to the detailed progression mechanism after the Fukushima Daiichi Nuclear Power Station accident - 6th progress report - [Tokyo Electric Power Company Holdings Inc.]," December 5, 2022

[191] The 34th Meeting of The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, "Material 1-2: Examination of events related to concrete observed in PCV internal investigation in Fukushima Daiichi Nuclear Power Station Unit 1 [Osaka University]," December 20, 2022

[192] The 30th Meeting of The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, "Material 3-1: Implementation status of on-site investigation (investigation of the fifth floor of the reactor building of Unit 2; investigation of damage to the reactor building of Unit 3; investigation of the exterior of the reactor building of Unit 1; 3D laser scanner investigation of the reactor building of Unit 4; and investigation of samples of cut SGTS piping of Units 1 and 2)," June 30, 2022

[193] The 31st Meeting of The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, "Material 6-1: Investigation of Unit 2 fuel handling machine control room [Tokyo Electric Power Company Holdings Inc.]," September 6, 2022

[194] The 32nd Meeting of The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, "Material 4-3: Contamination of Unit 2 shield plug [Tokyo Electric Power Company Holdings Inc.]," October 31, 2022

[195] The 32nd Meeting of The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, "Material 6-1: Investigation of Unit 2 fuel handling machine control room [Tokyo Electric Power Company Holdings Inc.]," October 31, 2022

[196] The 36th Meeting of The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, "Material 2-1: Sampling of residual gas in the RCW heat exchanger inlet header piping and water in the heat exchanger in Unit 1 [Tokyo Electric Power Company Holdings Inc.]," March 7, 2023

[197] The 36th Meeting of The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, "Material 2-2: Condition of damage on RCW piping [Tokyo Electric Power Company Holdings Inc.]," March 7, 2023

[198] The 36th Meeting of The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, "Material 4-2: Investigation of sludge in the basement floor of the turbine building of Unit 1 [Tokyo Electric Power Company Holdings Inc.]," March 7, 2023

[199] Supplementary budget in FY 2018, the Project of Decommissioning and Contaminated Water Management (Development of analytical and estimation techniques for characterization of fuel debris), implementation results for FY 2021, International Research Institute for Nuclear Decommissioning (IRID), November 2022

[200] Supplementary budget started in FY 2021, the Project of Decommissioning and Contaminated Water Management (Development of analytical and estimation techniques for characterization of fuel debris), implementation results for FY 2022, International Research Institute for Nuclear Decommissioning (IRID), 2023

analysis code.[201] The findings obtained from these investigations and analysis, are incorporated into the diagram that estimates the condition inside the reactor vessel, which is used to determine the cause of the accident.[202, 203, 204, 205] The analysis data and diagram are available to the public on debrisWiki.[206] Concerning the analysis of the hydrogen explosion in Units 1 and 3, combustion tests using materials equivalent to actual equipment are being conducted to estimate the amount of combustible gas from cables for evaluating hydrogen explosion conditions. The generation conditions of combustible gas and its composition are also under investigation.[207, 208, 209, 210, 211]

The NRA,[212] 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.[213, 214, 215] The interim report for FY 2020 showed the study results of contamination of the SGTS piping systems of Units 1 to 4 and the high-radiation dose on the lower face of the shield plugs of Units 2 and 3 concerning the release/leakage paths and points of fission products from PCVs. Regarding the hydrogen explosion and the operating status of the reactor cooling equipment, the analysis of the

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201 Supplementary budget started in FY 2022, the Project of Decommissioning and Contaminated Water Management (Development of analytical and estimation techniques for characterization of fuel debris [technical development for estimation of RPV damage condition]), implementation results for FY 2022, Japan Atomic Energy Agency (JAEA), 2023

202 The 90th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water, “Material 3-3: Status of countermeasures against highly contaminated shield plugs of Unit 2,” May 27, 2021

203 The 91st Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water, “Material 3-3: Status of countermeasures against highly contaminated shield plugs of Unit 2,” June 24, 2021

204 The 94th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water, “Material 3-3: Investigation of drilling hole on the shield plug of the Unit 2 operating floor,” September 30, 2021

205 The 95th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water/Treated Water, “Material 3-3: Investigation of drilling hole on the shield plug of the Unit 2 operating floor,” October 28, 2021

206 debrisWiki main page: https://fdada-plus.info/wiki/index.php?title=メインページ

207 The 29th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, “Material 1-1: Analysis results of gases generated by pyrolysis of organic materials in BWR primary containment vessel [Japan Atomic Energy Agency (JAEA)],” April 26, 2022

208 The 29th Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, “Material 1-2: Evaluation test results of the amount of combustible gases generated from cables, paints, and insulators [Tokyo Electric Power Company Holdings Inc.],” April 26, 2022

209 The 31st Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, “Material 4-1: Plan for analysis of pyrolysis product gas generated from organic materials in BWR primary containment vessel [Japan Atomic Energy Agency (JAEA)],” September 6, 2022

210 The 31st Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, “Material 4-2: Evaluation plan for combustible organic gas [Tokyo Electric Power Company Holdings Inc.],” September 6, 2022

211 The 33rd Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station, “Material 1-2: Evaluation test results of the amount of combustible gases generated from cables, paints, and insulators [Tokyo Electric Power Company Holdings Inc.],” December 5, 2022

212 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”

213 Interim report on the investigation and analysis of the accident at TEPCO’s Fukushima Daiichi Nuclear Power Station - Review from September 2019 to March 2021 - March 5, 2021

214 Nuclear Regulation Authority, "Interim report on the investigation and analysis of the accident at TEPCO’s Fukushima Daiichi Nuclear Power Station," June 19, 2021

215 Interim report on the investigation and analysis of the accident at TEPCO’s Fukushima Daiichi Nuclear Power Station (2023 version)

hydrogen explosion situation in Units 1 and 3 and the examination of the pressure fluctuation in the RPV and PCV in Unit 3 were carried out.[212, 213] In addition, the interim report for FY 2022 discussed the movement mechanism of Cs -137 based on the contamination of vent pipes and shield plugs and examined the impact of core materials collapsed in Units 1, 2, and 3 on PCVs.[214] Based on these investigations, the NRA and TEPCO jointly conducted dose measurements inside the drilling holes in the shield plug of Unit 2 and geometry measurements to check for deformation of the shield plug.

The NRA established the Liaison Council on the accident investigation of Fukushima Daiichi Nuclear Power Station for communication and coordination of accident analyses and decommissioning between the NRA, the Agency for Natural Resources and Energy, TEPCO, and NDF so that they can address cases where decommissioning work, such as facility dismantling, affects on-site information necessary for accident analysis, and, conversely, other cases where efforts toward accident analyses interfere with decommissioning work. In FY 2021, the medium-term risk reduction target map in decommissioning was revised and the goal for about ten years in the future was presented at the Liaison Council.[216] In addition, the aforementioned PCV internal investigation of Unit 1, the stagnant gas[217] in the RCW heat exchanger inlet header piping, and the removal of SGTS piping in Units 1 and 2[218] were shared.

[216]The 9th Liaison Council on the accident investigation of Fukushima Daiichi Nuclear Power Station, "Material 1-1: Revision of Measures for Mid-and-long-term Risk Reduction at TEPCO's Fukushima Daiichi NPS (Risk Map)," May 13, 2022

[217]The 10th Liaison Council on the accident investigation of Fukushima Daiichi Nuclear Power Station, "Material 3-1: Residual gas in the RCW heat exchanger inlet header piping in Unit 1 [Tokyo Electric Power Company Holdings Inc.]," December 13, 2022

[218]The 10th Liaison Council on the accident investigation of Fukushima Daiichi Nuclear Power Station, "Material 3-2: Progress of removing the standby gas treatment system piping in Fukushima Daiichi Nuclear Power Station Units 1 and 2 [Tokyo Electric Power Company Holdings Inc.]," December 13, 2022

Attachment 11 Terms related to radioactive waste management

IAEA Safety Requirements GSR-Part 5 [219] explains that predisposal of radioactive waste encompass all stages of radioactive waste management from generation to disposal, including processing, storage and transportation. Terms related to the management of radioactive waste as defined in the IAEA glossary are shown in Fig A11-1. Within the pre-disposal management, processing of radioactive waste is classified into pretreatment, treatment and conditioning. Processing is carried out to be in the form of waste suitable for selected or anticipated disposal options. Radioactive waste may also be stored in for its management, therefore it is thought to be necessary that the form is suitable for transportation and storage.

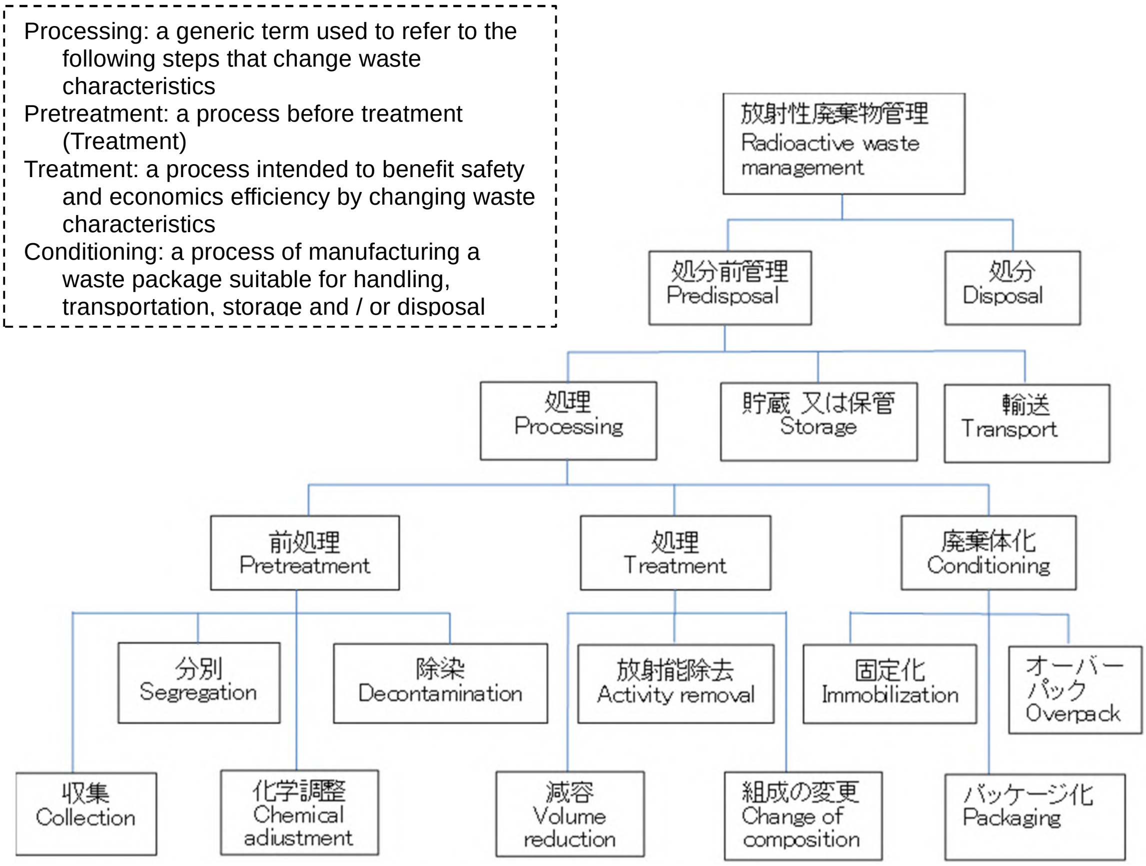

Fig. A11-1 Terms related to radioactive waste management (IAEA)[220] and their translation examples (For the Japanese translation example, refer to the materials of the Japan Atomic Energy[221,222])

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

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

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

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

Attachment 12　Disposal of radioactive waste[223,224,225]

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)[226] 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”[227] 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. A12-1. Each classification is also shown in Table A12-1.

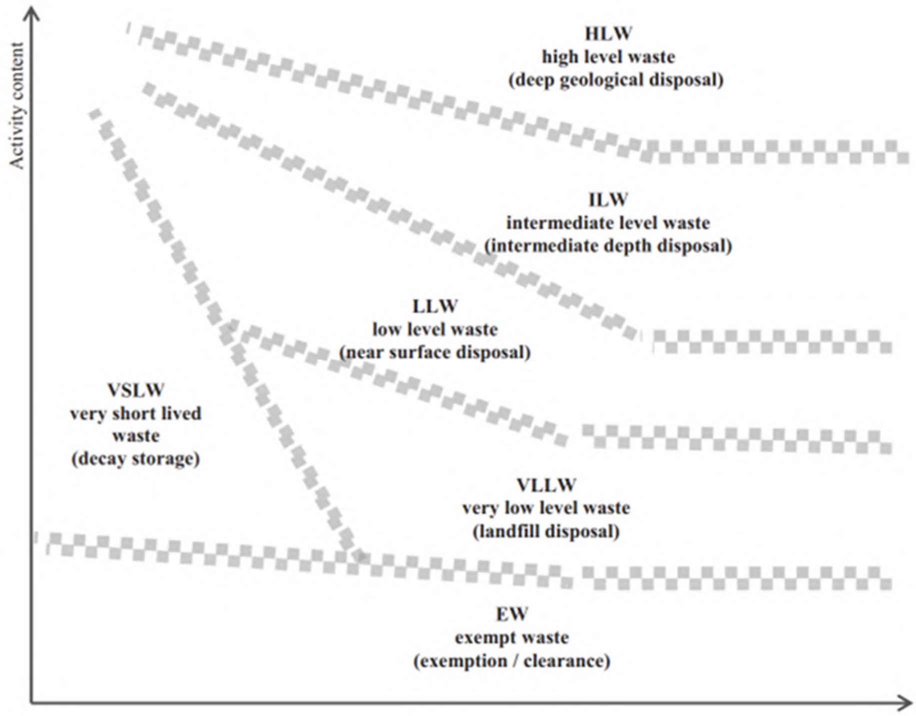


Fig. A12-1 Conceptual diagram of waste classification

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

Table A12-1 Classification of radioactive waste in GSG-1

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

2. Classification and disposal in Japan

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

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

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

The types of radioactive waste generated by the operation of nuclear power plants and the disposal methods assumed are shown in Table A12-2.

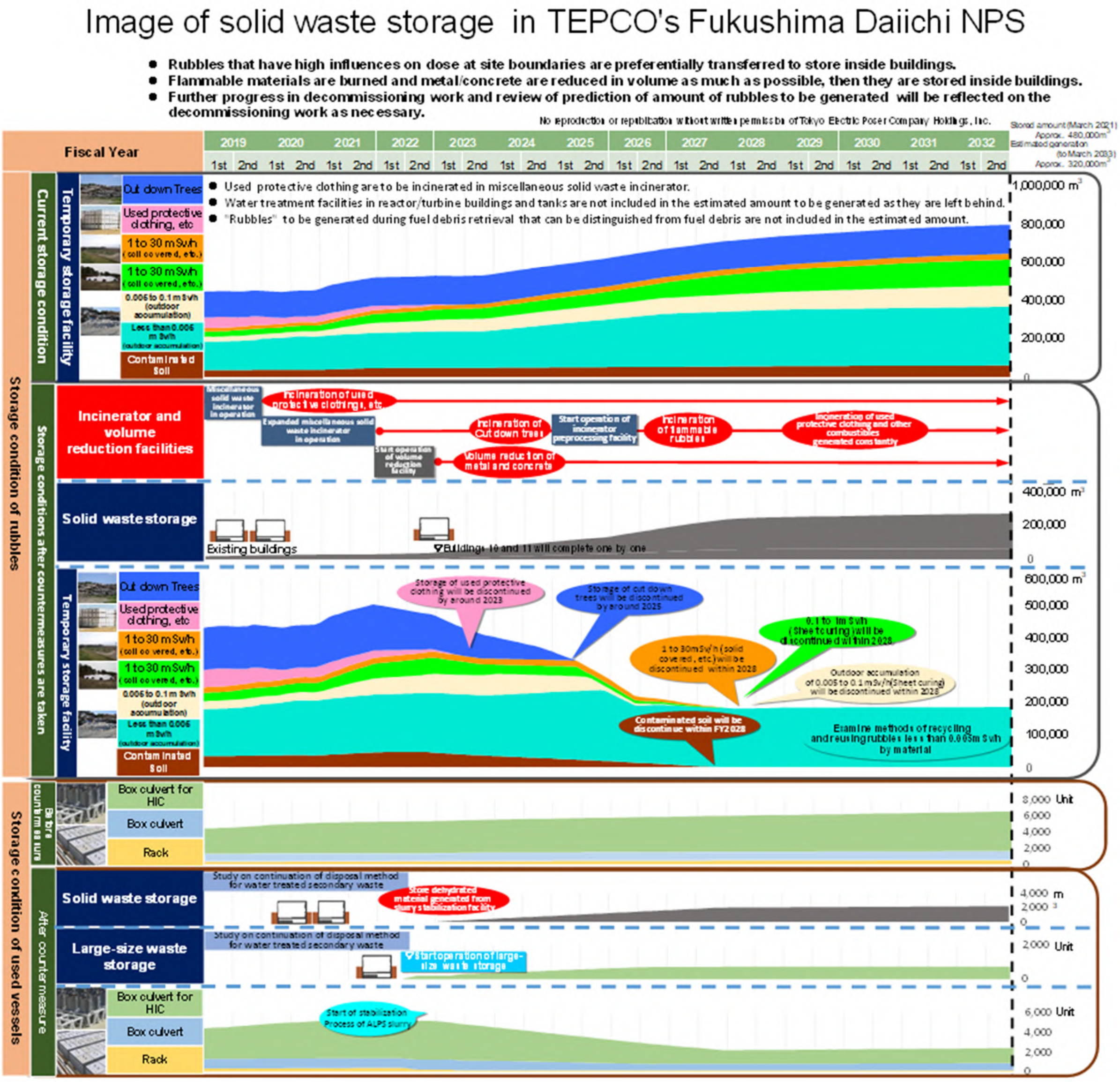
Of these, only waste with relatively low-level radioactivity generated through the operation of nuclear power plants has been subject to disposal in pits since 1992 at the Rokkasho Low-level Radioactive Waste Disposal Center of Japan Nuclear Fuel Limited in Rokkasho Village, Aomori Prefecture. Including 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 A12-2 Types of Radioactive Waste Generated by the Operation of Nuclear Power Plants

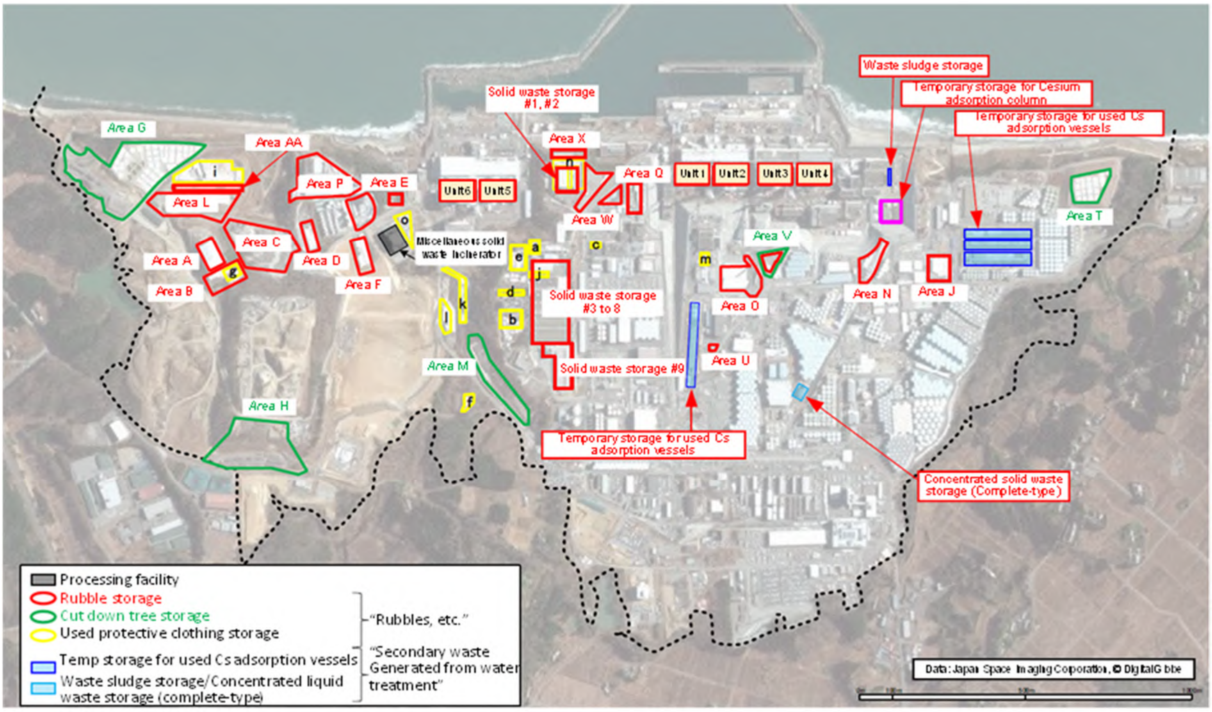
<table>
<tr><th colspan="3">Types of Radioactive Waste</th><th>Examples of Waste</th><th>Site generated</th><th>Disposal Method (example)</th></tr>
<tr><td rowspan="5">Low-level Radioactive Waste</td><td rowspan="3">Waste from Nuclear Power Plants</td><td>Waste with extremely low radiation level</td><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. A12-2 Japan Nuclear Fuel Ltd. Low-level Radioactive Waste Disposal Center

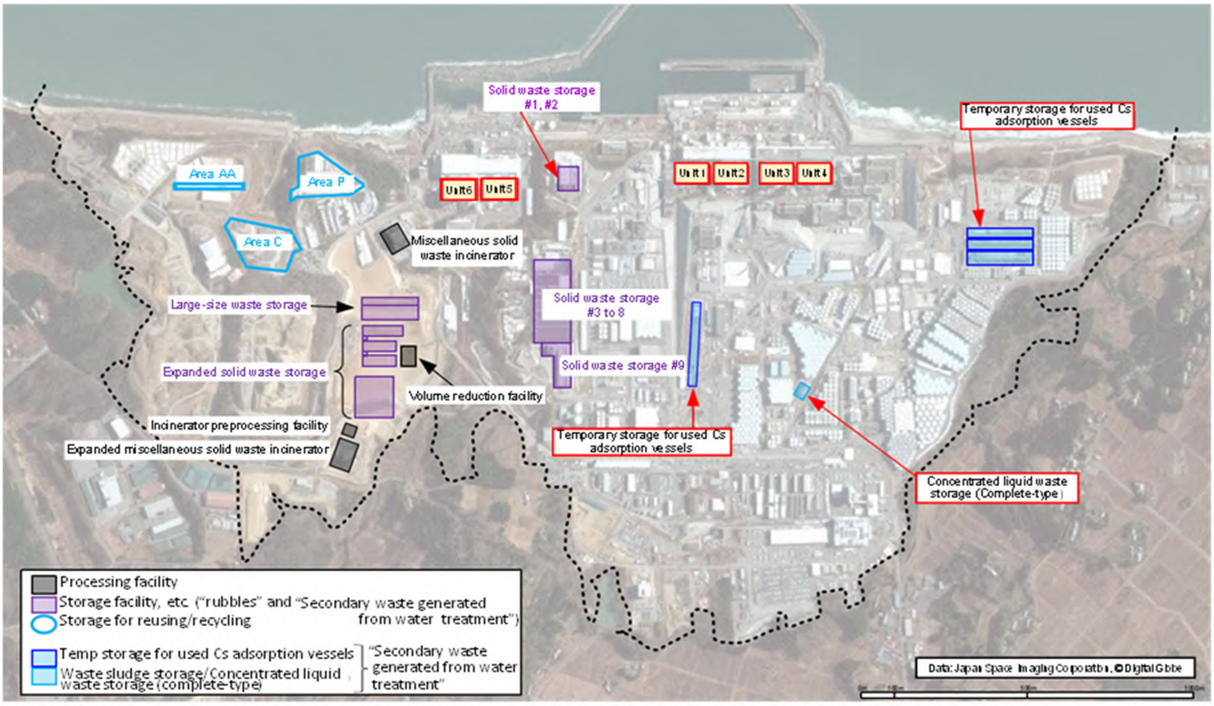
Attachment 13　Overall image of Storage Management Plan for the Fukushima Daiichi NPS [228]



228 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

Fig. A13-1 Present and future storage conditions of “rubble, etc.” and “secondary waste generated by water treatment” on site of the Fukushima Daiichi NPS

Attachment 14 Approach to the selection of nuclides to be measured and assessed when discharging ALPS-treated water into the sea

In November 2022, TEPCO described and submitted the concept of selecting nuclides to be measured and assessed for discharging ALPS-treated water into the sea in the Application Documents for Approval to Amend the Implementation Plan for Fukushima Daiichi Nuclear Power Station as Specified Nuclear Facility (Operations related to the discharge of ALPS-treated water into the sea).[229] Subsequently, after a total of five technical meetings were held by the NRA to discuss the action plans for specific nuclear facilities, and a partial revision of the application was submitted incorporating the results of these meetings and was approved in May 2023.

Based on the "Application for Approval of Change", the "Supplemental Explanatory Material on Compliance with the Matters to be Addressed Required of the Fukushima Daiichi NPS (Concerning Changes to the Operation System for Discharging ALPS-treated Water into the Sea and Selection of Nuclides to be Measured and Evaluated)[230]" and other documents, this attachment summarizes an approach to selecting nuclides to be measured and assessed, the specific selecting procedures and types of nuclides selected according to these procedures.

1. How to proceed with examination

To ensure that radionuclides other than tritium in ALPS-treated water satisfy the sum of the ratios to regulatory concentrations limits of less than 1, the policy is to select the target nuclides to be measured and assessed (hereafter referred to as the "nuclides to be measured/assessed") after thorough verification of whether the nuclides could be significantly contained in contaminated water before treated with cesium adsorption equipment, ALPS, or other treatments based on knowledge of decommissioning and disposal facilities in Japan.

To verify the nuclides that could be contained in contaminated water in significant amounts at the Fukushima Daiichi NPS, an analysis of the nuclides contained in the contaminated water and an inventory evaluation considering the fuel and structural materials of Units 1 to 3 are conducted.

- Nuclide analysis

Whether the nuclides to be assessed in the research on decommissioning and disposal facilities are also significantly present in contaminated water is verified by actual water analysis. The results of past nuclide analyses are also verified (details are provided in 2.1.4.5 (1)).

- Inventory evaluation

An inventory of fission products (FP) is assessed in the same way as in the study of nuclides subject to removal by ALPS. The inventory quantity generated by the activation of structures in reactor pressure vessels is assessed based on the studies on decommissioning and disposal

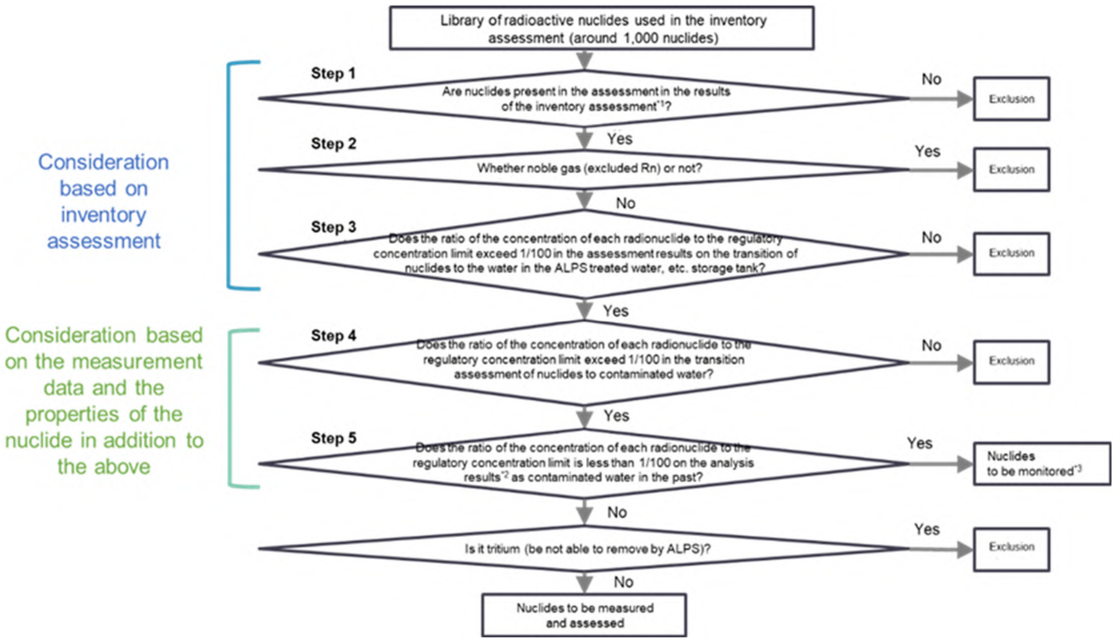
[229] NRA website, https://www.nra.go.jp/activity/earthquake/kisei/plan/140000233.html
[230] NRA website, https://www2.nra.go.jp/data/000428079.pdf

facilities. In the assessment, the period that elapses since the accident should be set appropriately, and the reduction in inventory quantity due to attenuation should be considered. The code used for the evaluation is ORIGEN (ORNL Isotope Generation and Depletion Code), as in the previous safety assessment, available findings, and previous evaluations.

According to the results of nuclide analysis and inventory evaluation, the presence of nuclides that may be contained in the contaminated water in significant amounts should be verified, considering the ease of transfer to the water and other factors.

2. Method for selecting nuclides to be measured/assessed

Based on the results of nuclide analysis and the inventory evaluation described in Section 1, the nuclides to be measured/assessed are selected according to the flow shown in Fig. A14-1.



*1: The decay period of the inventory evaluation is appropriately set according to the time when the selection result is to be used. (First time set to 2023 (12 years after the accident))
*2: Nuclides that have been detected in the past are confirmed by the maximum value of the detection value, and nuclides that have never been detected are confirmed by the minimum value of the detection limit value
*3: Nuclides that shall be continuously confirmed if significantly exists in contaminated water.

Fig. A14-1 Flow for selecting nuclides to be measured/assessed at the discharge of ALPS-treated water to the sea

2.1 Selection procedures and results

2.1.1 Step 1

In Step 1, “Are nuclides present in the assessment in the results of the inventory assessment?” nuclides will be evaluated by the criteria of whether they are found to exist through the inventory assessment (if 1 Bq or more of the nuclide exists in each core of Units 1 to 3), and nuclides that are not found to exist through the assessment will be excluded.

In this assessment, the decay period was set at 12 years after the accident (March 2023), and as a result, 210 nuclides were found to exist, as shown in Table A14-1.

Table A14-1 Nuclides that were found to exist through Step 1 (210 nuclides)

No.	Nuclide	No.	Nuclide	No.	Nuclide	No.	Nuclide	No.	Nuclide
1	H-3	21	Zn-65	41	Rh-102	61	Sb-126	81	Pr-144
2	Be-10	22	Se-75	42	Rh-102m	62	Sb-126m	82	Pr-144m
3	C-14	23	Se-79	43	Rh-106	63	Te-121	83	Nd-144
4	Na-22	24	Kr-81	44	Pd-107	64	Te-121m	84	Pm-144
5	Si-32	25	Kr-85	45	Ag-108	65	Te-123	85	Pm-145
6	P-32	26	Rb-87	46	Ag-108m	66	Te-123m	86	Pm-146
7	Cl-36	27	Sr-90	47	Ag-109m	67	Te-125m	87	Pm-147
8	Ar-39	28	Y-88	48	Ag-110	68	Te-127	88	Sm-145
9	Ar-42	29	Y-90	49	Ag-110m	69	Te-127m	89	Sm-146
10	K-40	30	Zr-93	50	Cd-109	70	I-129	90	Sm-147
11	K-42	31	Nb-91	51	Cd-113m	71	Cs-134	91	Sm-148
12	Ca-41	32	Nb-92	52	In-113m	72	Cs-135	92	Sm-149
13	Ca-45	33	Nb-93m	53	In-115	73	Cs-137	93	Sm-151
14	Sc-46	34	Nb-94	54	Sn-113	74	Ba-133	94	Eu-150
15	V-49	35	Mo-93	55	Sn-119m	75	Ba-137m	95	Eu-152
16	Mn-54	36	Tc-97	56	Sn-121	76	La-137	96	Eu-154
17	Fe-55	37	Tc-98	57	Sn-121m	77	La-138	97	Eu-155
18	Co-60	38	Tc-99	58	Sn-123	78	Ce-139	98	Gd-152
19	Ni-59	39	Ru-106	59	Sn-126	79	Ce-142	99	Gd-153
20	Ni-63	40	Rh-101	60	Sb-125	80	Ce-144	100	Tb-157

No.	Nuclide	No.	Nuclide	No.	Nuclide	No.	Nuclide	No.	Nuclide
101	Tb-158	123	Tl-207	145	Po-216	167	Th-234	189	Pu-240
102	Dy-159	124	Tl-208	146	Po-218	168	Pa-231	190	Pu-241
103	Ho-163	125	Tl-209	147	At-217	169	Pa-233	191	Pu-242
104	Ho-166m	126	Pb-205	148	Rn-219	170	Pa-234	192	Pu-243
105	Tm-170	127	Pb-209	149	Rn-220	171	Pa-234m	193	Pu-244
106	Tm-171	128	Pb-210	150	Rn-222	172	U-232	194	Am-241
107	Lu-176	129	Pb-211	151	Fr-221	173	U-233	195	Am-242
108	Lu-177	130	Pb-212	152	Fr-223	174	U-234	196	Am-242m
109	Lu-177m	131	Pb-214	153	Ra-223	175	U-235	197	Am-243
110	Hf-182	132	Bi-208	154	Ra-224	176	U-236	198	Am-245
111	Ta-182	133	Bi-210	155	Ra-225	177	U-237	199	Cm-242
112	W-181	134	Bi-210m	156	Ra-226	178	U-238	200	Cm-243
113	Re-187	135	Bi-211	157	Ra-228	179	U-240	201	Cm-244
114	Os-194	136	Bi-212	158	Ac-225	180	Np-235	202	Cm-245
115	Ir-192	137	Bi-213	159	Ac-227	181	Np-236	203	Cm-246
116	Ir-192m	138	Bi-214	160	Ac-228	182	Np-237	204	Cm-247
117	Ir-194	139	Po-210	161	Th-227	183	Np-238	205	Cm-248
118	Ir-194m	140	Po-211	162	Th-228	184	Np-239	206	Bk-249
119	Pt-190	141	Po-212	163	Th-229	185	Np-240m	207	Cf-249
120	Pt-193	142	Po-213	164	Th-230	186	Pu-236	208	Cf-250
121	Tl-204	143	Po-214	165	Th-231	187	Pu-238	209	Cf-251
122	Tl-206	144	Po-215	166	Th-232	188	Pu-239	210	Cf-252

2.1.2 Step 2

In Step 2, “Is noble gas (excluding Rn) present?,” given that noble gas nuclides generated while the reactor is in operation are not considered to exist in the core due to the release at the time of operation and the accident and that, even if they exist, noble gases are stable elements and therefore insoluble in contaminated water, they are judged not to fall within the scope of nuclides to be measured/assessed at the discharge of ALPS-treated water into the sea and are excluded. On the other hand, radon (Rn) is considered to still exist in the core due to the decay chains of uranium, neptunium, etc. Therefore, even though it is a rare gas, it is not excluded in this step.

In Step 2, four nuclides were excluded: Ar-39, Ar-42, Kr-81, and Kr-85.

2.1.3 Step 3

In Step 3, "Does the ratio of the concentration of each radionuclide to the regulatory concentration limit exceed 1/100 in the assessment results on the transition of nuclides to the water in the ALPS-treated water, etc. storage tank?," nuclides are evaluated to see whether their impacts on the dose assessment are sufficiently small (1/100 or less of the ratio to the regulatory concentration limit), and nuclides with sufficiently small impact on the dose assessment are excluded by this criteria. This evaluation assumes that all of the inventory existing in the PCV will have been dissolved in ALPS-treated water, etc., tanks (evaluated as of March 2023). Therefore, given the current status confirmed through the PCV internal investigation, it is thought that an adequate level of conservativeness is ensured under this assumption.

<< Conditions for determination >>

Concentration of nuclide i = Inventory of nuclide i (Bq) ÷ Amount of ALPS treated water, etc. stored (m^3) < Regulatory concentration limit of nuclide i × 0.01 (Bq/cm^3)

1.33 million m^3 (estimated value) as of March 2023

As a result, 93 nuclides proceeded to Step 4 (Table A14-2), and 113 nuclides were excluded. It has also been confirmed that the sum of the ratios to regulatory concentration limits (assessed values) of the nuclides excluded in Step 3 is sufficiently small at 6.7E-02, compared to 2.4E+07, the sum of the ratios to the regulatory concentration limits (assessed values) of the nuclides that proceed to Step 4. Thus, it was deemed appropriate to use 1/100 of the ratio to the regulatory concentration limit as the selection criterion.

Table A14-2 Nuclides that proceed to Step 4 (93 nuclides)

No.	Nuclide	No.	Nuclide	No.	Nuclide	No.	Nuclide	No.	Nuclide
1	H-3	46	Ag-108m	81	Pr-144	159	Ac-227	189	Pu-240
3	C-14	49	Ag-110m	82	Pr-144m	162	Th-228	190	Pu-241
7	Cl-36	50	Cd-109	86	Pm-146	164	Th-230	191	Pu-242
16	Mn-54	51	Cd-113m	87	Pm-147	165	Th-231	194	Am-241
17	Fe-55	55	Sn-119m	93	Sm-151	167	Th-234	195	Am-242
18	Co-60	56	Sn-121	95	Eu-152	168	Pa-231	196	Am-242m
19	Ni-59	57	Sn-121m	96	Eu-154	169	Pa-233	197	Am-243
20	Ni-63	59	Sn-126	97	Eu-155	172	U-232	199	Cm-242
21	Zn-65	60	Sb-125	104	Ho-166m	173	U-233	200	Cm-243
23	Se-79	61	Sb-126	106	Tm-171	174	U-234	201	Cm-244
27	Sr-90	62	Sb-126m	120	Pt-193	175	U-235	202	Cm-245
29	Y-90	67	Te-125m	121	Tl-204	176	U-236	203	Cm-246
30	Zr-93	70	I-129	130	Pb-212	177	U-237	208	Cf-250
33	Nb-93m	71	Cs-134	136	Bi-212	178	U-238		
34	Nb-94	72	Cs-135	141	Po-212	182	Np-237		
35	Mo-93	73	Cs-137	145	Po-216	183	Np-238		
38	Tc-99	74	Ba-133	149	Rn-220	184	Np-239		
39	Ru-106	75	Ba-137m	153	Ra-223	186	Pu-236		
43	Rh-106	79	Ce-142	154	Ra-224	187	Pu-238		
44	Pd-107	80	Ce-144	157	Ra-228	188	Pu-239		

2.1.4 Step 4

In Step 4, "Does the ratio of the concentration of each radionuclide to the regulatory concentration limit exceed 1/100 in the transition assessment of nuclides to contaminated water?," the nuclides that were advanced to Step 4 are grouped according to their radioactive equilibrium, isotopes, the similarity of nuclide properties, etc., and the relative relationship of dose effects (inventory/regulatory concentration limit) is confirmed within the group, and nuclides with sufficiently small dose effects (relative ratio 1/100 or less) on representative nuclides are excluded.

Then, based on the actual analysis results of individual groups or nuclides that could not be grouped, the ease of transfer into water is calculated by radionuclide (hereinafter referred to as the "transfer coefficient"). Then, the concentrations in contaminated water of individual radionuclides are evaluated using the coefficient.

2.1.4.1 Progeny nuclides in radioactive equilibrium

Among the nuclides that have proceeded to Step 4, those that exist in radioactive equilibrium are shown in Tables A14-3 and A14-4. The progeny nuclides shown in Table A14-3 have short half-lives, and 12 years after the accident, when ALPS-treated water is set to be discharged into the sea, they exist only as nuclides produced by the decay of parent nuclides. Therefore, in evaluating the transfer to contaminated water, they are assumed to behave the same as the parent nuclides. In the meantime, the progeny nuclides shown in Table A14-4 have relatively long half-lives, and it takes time for the parent and progeny nuclides to reach radioactive equilibrium. Based on this, the parent and progeny nuclides are assessed separately in this evaluation.

Table A14-3 Progeny nuclides that are in radioactive equilibrium and assumed to behave the same as the parent

No.	Parent nuclide		Progeny nuclide	
	Nuclide	Half-life	Nuclide	Half-life
1	Sr-90	2.9E+01 [y]	Y-90	2.67 [d]
2	Ru-106	1.0E+00 [y]	Rh-106	30.07 [s]
3	Sn-121m	4.4E+01 [y]	Sn-121	1.13 [d]
4	Sn-126	2.3E+05 [y]	Sb-126 Sb-126m	12.35 [d] 19.15 [m]
5	Sb-125	2.8E+00 [y]	Te-125m	57.40 [d]
6	Cs-137	3.0E+01 [y]	Ba-137m	2.552 [m]
7	Ce-144	7.8E-01 [y]	Pr-144 Pr-144m	17.28 [m] 7.2 [m]
8	Pu-241	1.4E+01 [y]	U-237	6.752 [d]
9	Am-242m	1.4E+02 [y]	Np-238	2.117 [d]
10	Am-242m	1.4E+02 [y]	Am-242 Cm-242	16.02 [h] 162.9 [d]
11	Am-243	7.4E+03 [y]	Np-239	2.356 [d]

Table A14-4 Progeny nuclides that are in radioactive equilibrium but assumed to behave differently from the parent

No.	Parent nuclide		Progeny nuclide	
	Nuclide	Half-life	Nuclide	Half-life
1	Zr-93 Mo-93	1.6E+06 [y] 4.0E+03[y]	Nb-93m	1.6E+01 [y]

2.1.4.2 Nuclides produced from decay chains of uranium, neptunium, etc.

Among the nuclides that have proceeded to Step 4, those produced from decay chains of uranium and neptunium, etc., are outlined in red in Fig. A14-2. In evaluating the transfer to contaminated water, those nuclides are evaluated assuming they behave the same as the parent nuclides (neptunium and uranium). That is, nuclides produced from the uranium, actinium, and thorium chains are evaluated as a subgroup of uranium isotopes because they are considered to behave the same as the original uranium.

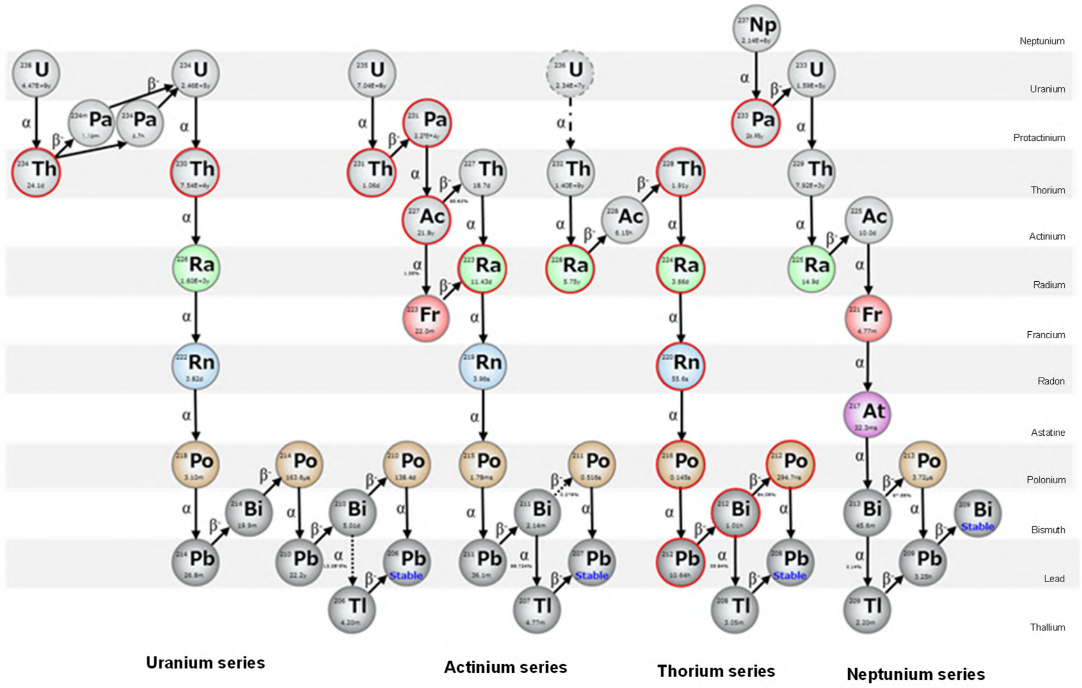


Fig. A14-2 Nuclides produced from the decay series of uranium, neptunium, etc.

2.1.4.3 Isotopes

Of the nuclides that have advanced to Step 4, the nuclides that exist as isotopes are shown in Table A14-5. Since the outermost electrons determine the chemical properties of materials, the chemical properties of isotopes with the same number of electrons are almost identical. Therefore, each isotope is considered to behave together in evaluating the transfer to contaminated water.

Table A14-5 Nuclides that are assessed to behave together because of their isotopes

No.	Element	Nuclide
1	Ni isotope	Ni-59,Ni-63
2	Nb isotope	Nb-93m,Nb-94
3	Ag isotope	Ag-108m,Ag-110m
4	Cd isotope	Cd-109,Cd-113m
5	Sn isotope	Sn-119m,Sn-121m,Sn-126
6	Cs isotope	Cs-134,Cs-135,Cs-137
7	Ce isotope	Ce-142,Ce-144
8	Pm isotope	Pm-146,Pm-147
9	Eu isotope	Eu-152,Eu-154,Eu-155
10	U isotope	U-232,U-233,U-234,U-235,U-236,U-238
11	Pu isotope	Pu-236,Pu-238,Pu-239,Pu-240,Pu-241,Pu-242
12	Am isotope	Am-241,Am-242m,Am-243
13	Cm isotope	Cm-243,Cm-244,Cm-245,Cm-246

2.1.4.4 Chemical similarity underwater

There are some nuclides for which no analytical data is available because the analytical techniques have not been established as of 2022, making individual analysis difficult. These nuclides are evaluated as having characteristics similar to those of the nuclides with which the similarity has been confirmed after the similarity of chemical forms of nuclides in water (Eh-pH diagram, etc.), ionic radii, adsorption characteristics in water treatment, etc. is verified.

(1) Lanthanoids (Pm, Sm, Ho, Tm)

Lanthanoids have not previously been detected, except for Ce-144 and Eu-154, which were detected in the analysis of stagnant water in the PCVs of Units 2 and 3. The results of these two nuclides are used in evaluating the transfer to contaminated water for other lanthanoids. Therefore, the validity was checked with Eh-pH diagrams.[231] As a result, verification has revealed that lanthanoids are similar in that they are stable trivalent cations at hydrogen-ion exponents (pH) of 6 to 8 in reactor injection water and building stagnant water.

Rare earth ions, including lanthanoids, generally have similar chemical properties and behaviors, and they are produced together in minerals, and it is difficult to separate them from each other during the refining process. Therefore, assessing all lanthanoids as the same group is deemed appropriate.[232]

The transfer coefficients of Ce-144 and Eu-154, which belong to this group and have been analyzed, were evaluated in Section 2.1.4.5 to be described later, and it was confirmed that they were almost the same value and that they actually behaved similarly on the 1F site.

(2) Platinum group (Ru, Pd, Pt)

As for the platinum group, Ru-106 (Rh-106) has been detected (Rh is produced from the decay of Ru), and Pd-107 has been detected at a very low concentration in stagnant water in buildings and Sr-treated water. Although Pt-193 has proceeded to Step 4, it has yet to be analyzed due to the lack of a measurement method that can measure the nuclide independently.

Therefore, when evaluating the transfer of Pt to contaminated water based on the analysis results of Ru-106 and Pd-107, the validity was examined with Eh-pH diagrams and solubility. As a result, the verification has revealed that the platinum group exists in a solid state at hydrogen-ion exponents (pH) of 6 to 8 in reactor injection water and stagnant water in buildings. Ru was found to exist as a single metal or solid of oxides, and Pd and Pt as solids of single metals. Their solubility in water was found to be very small.[233] Given that the physical and chemical properties of the platinum group elements are generally similar to one another and that they do not react with water and are not easily affected by acids and bases, it is deemed appropriate to treat Pt-193 together with Ru-106 and Pd-107 as one group in evaluating the transfer to contaminated water.

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[231] Naoto Takeno, Eh-pH Atlas - Intercomparison of the thermodynamics database, Geological Survey of Japan, Research Material No. 419, Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (2005)

[232] Jiro Shiokawa, "Characteristics of Rare Earth Elements and Their Applications"

[233] Excerpt from “The technical reliability of geological disposal of high-level radioactive waste in Japan - Second summary of research and development on geological disposal” (2000 Report)

The transfer coefficients of Ru-106 and Pd-107, which belong to this group and have been analyzed, were evaluated in Section 2.1.4.5 as will be described later, and it was confirmed that they were almost the same value and that they actually behaved similarly on the 1F site.

(3) Thallium (Tl)

As for thallium, although Tl-204 has proceeded to Step 4, it has yet to be analyzed due to the lack of a measurement method that can measure the nuclide independently.

According to the Eh-pH diagrams, it has been revealed that Tl, which is element 13,[234] is a stable monovalent cation at hydrogen-ion exponents (pH) of 6 to 8 in reactor injection water and stagnant water in buildings. In addition:

- The ionic radius is between the alkali metal Cs and K ions.
- The adsorption selectivity by zeolites has been evaluated as equal to that of K ions.[235]
- It has the same level of adsorption property as Cs to soil.[236]

Given the above, it is reasonable to evaluate thallium together with alkali metals as the same group while assuming that it will behave similarly throughout the process, from the transfer to contaminated water to water treatment.

(4) Californium (Cf)

Although Cf-250 has proceeded to Step 4 for californium, no analysis has been performed.

For californium, although it was not possible to check the validity with Eh-pH diagrams, it is considered a stable trivalent cation in a solution whose chemical behavior is very similar to that of trivalent trans-plutonium elements (Am, Cm).[237] It has also been confirmed that the trivalent cations, Am, Cm, and Cf, have almost the same radii.[238] Given the above, it is reasonable to evaluate the transfer of californium to contaminated water together with Am and Cm as one group. The transfer coefficients of Am-241, Cm-242, and Cm-244 were evaluated in Section 2.1.4.5 and found to be almost the same values. It has been confirmed that this group actually behaves similarly even on the 1F site.

2.1.4.5 Evaluation of transfer coefficients

Among the nuclides that have proceeded to Step 4, the ease of transfer into water is calculated by radionuclide (hereinafter referred to as the “transfer coefficient”) based on the actual analysis results of individual nuclides. Then, the concentrations in contaminated water of individual

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[234] It is also referred to as the boron group element, and it includes boron, aluminum, gallium, indium, and thallium.
[235] Nitta and Aomura, "Study on the Site Selectivity of Exchangeable Cations in Synthetic Zeolite A”
[236] John E. Till, Helen A. Grogan, "Radiobiological Risk Assessment and Environmental Analysis," Oxford University Press (2008).
[237] Lester R. Morss, Norman M. Edelstein, Jean Fuger, "The Chemistry of The Actinide And Transactinide Elements - 4th Ed."
[238] R.D. Shannon, “Revised Effective Ionic Radii and Systematic Studies of Interatomic Distances in Halides and Chalcogenides”

radionuclides are evaluated using the coefficient. The transfer coefficient is evaluated using the following formula:

Evaluated concentration of radionuclides in contaminated water (Bq/L) = inventory*1 (Bq) × transfer coefficient*2 (1/L)

*1: In consideration of the timing when ALPS treated water is to be discharged into the sea, the evaluation result in 12 years after the earthquake is used.
*2: Calculated by the equation of Analysis result of contaminated water (Bq/L) ÷ Inventory (Bq).
For this evaluation, the analysis date for the results of detected value is set to March 11, 2011, and the date for the results of detection limit value is set to the actual analysis date.

(1) Analysis results to be used for the evaluation of transfer to contaminated water

The analysis results to be used in the calculation of the transfer coefficient were classified and summarized into four types as shown in Table A14-6 and Fig. A14-3.

Since all the contaminated water is collected in the Centralized Rw (the process main building (PMB) and the high-temperature incinerator building [HTI]) and then treated with a cesium sorption apparatus (SARRY/SARRY2), and this water finally becomes ALPS-treated water, the analysis results of Centralized Rw will be used in principle. However, it is impossible to obtain data on all radionuclides with only the analysis results of Centralized Rw, and because detection limits are high for stagnant water in buildings due to high Cs concentration, there are some nuclides for which there is not enough data available. Therefore, for those nuclides, the analysis results of stagnant water, etc. from Units 1 to 4 buildings, and water before ALPS treatment will be used to complement the data.

Table A14-6 Classification of analysis results

No.	Classification of analyses	Details
(1)	Stagnant water in Unit 1 to 4 buildings	Analysis results of stagnant water in Unit 1 to 4 PCVs and buildings
(2)	Stagnant water in Centralized Rw building	Analysis results of water in Centralized Rw (PMB/HTI), at the inlet of SARRY, etc.
(3)	Cesium adsorption system - inlet of ALPS	Analysis results of water from the outlet of cesium adsorption system to the inlet of ALPS
(4)	Outlet of ALPS	Analysis results of water after ALPS treatment

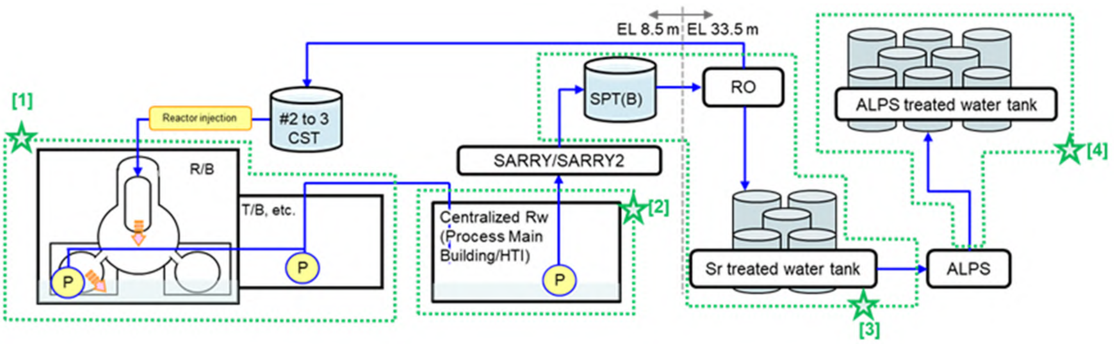


Fig. A14-3 Classification of analysis results to be used for the evaluation of transfer

The results of the analysis of the radionuclides that have proceeded to Step 4 are summarized in Fig. A14-4 for each sampling point. The figure shows the concentration ranges of individual radionuclides throughout the process from the stagnant water in buildings to ALPS-treated water.

It also shows regulatory concentration limits to allow comparison of the analysis results with regulatory limits.

Fig. A14-4 was developed using the following data: FRAnDLi data published by the JAEA that is available as of September 2022 (including data published by TEPCO), analyses of 62 nuclides at the time of ALPS performance verification, etc. (FY 2013 to 2021), data of water before and after ALPS treatment which is available on the Treated Water Portal Site, data on tanks, etc. containing ALPS-treated water, etc.

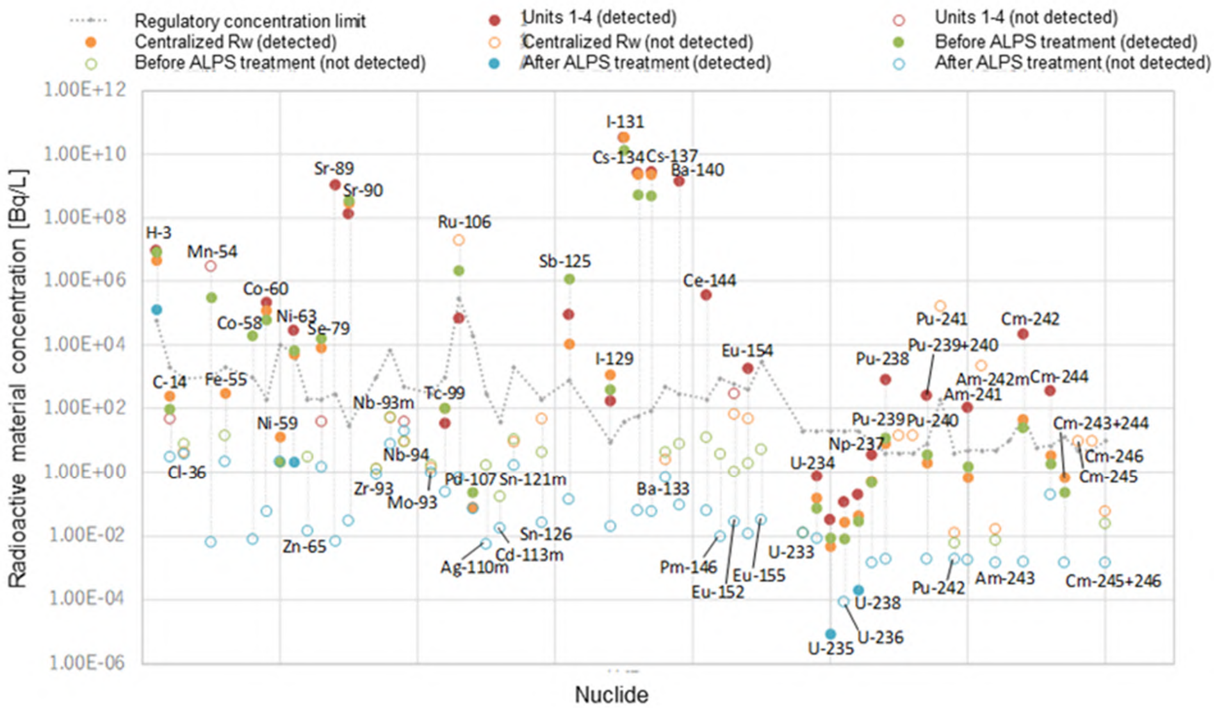
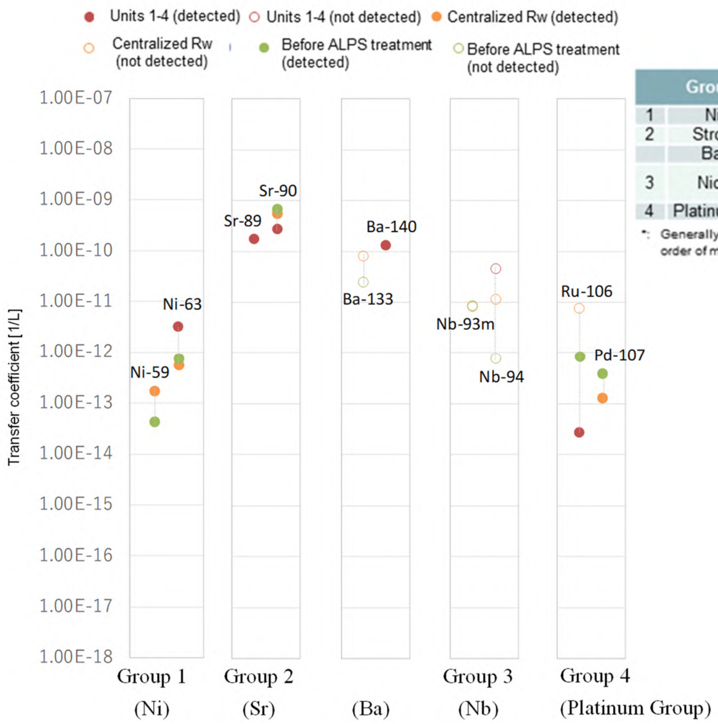


Fig. A14-4 Summary of analysis results to be used for the evaluation of transfer coefficients

(2) Evaluation results of the transfer coefficients to contaminated water

The analysis results shown in Fig. A14-4 and the results of the inventory evaluation as of March 11, 2011, are used to calculate the transition coefficients. As described previously, the maximum value among the results of the centralized Rw is generally used to evaluate transfer coefficients, and transfer coefficients rounded up to a higher order of magnitude are used to account for the variation in the analytical values.

As an example of the evaluation results, Fig. A14-5 shows the results for Ni, Sr, Ba, Nb, and platinum group elements. It was confirmed that these tended to be similar in each group. In addition, though the results of barium, which is also an alkaline earth metal, were shown next to Sr, it was confirmed that Ba-140 of the FP nuclide (excluded in Step 1 due to short half-life) showed the equivalent transfer coefficient as Sr-89 and Sr-90 of the same FP nuclide.



	Group	Transfer coefficient* [1/L]	Applicable element	Remarks
1	Nickel	1.0E-12	Ni	
2	Strontium	1.0E-09	Sr	
	Barium	1.0E-09	Ba	
3	Niobium	1.0E-10	Nb	No detected value
4	Platinum group	1.0E-12	Ru	

*: Generally, the maximum value of the centralized Rw rounded up to a higher order of magnitude is indicated.

Fig. A14-5 Example of transfer coefficient evaluation results

2.1.4.6 Evaluation results of Step 4

In Step 4, the nuclides were narrowed down by grouping based on their radiative equilibrium, isotopes, and similarity in nuclide properties, and the transfer coefficients evaluated in Section 2.1.4.5 were used to evaluate the transfer to contaminated water. As a result, 36 nuclides proceeded to Step 5 (Table A14-7), and 57 were excluded.

Compared to the sum of the regulatory concentration limit ratios (evaluated value) of 7.7E+07 for nuclides proceeding to Step 5, the sum of the regulatory concentration limit ratios (evaluated value) for nuclides excluded in Step 4 is 3.6E-02, which is sufficiently small, and it was judged appropriate to use 1/100 of the regulatory concentration limit ratio as the selection criterion.

Table A14-7 Nuclides to proceed to Step 5 (36 nuclides)

No.	Nuclide	No.	Nuclide	No.	Nuclide	No.	Nuclide	No.	Nuclide
1	H-3	*27*	Sr-90	*60*	Sb-125	*93*	Sm-151	*189*	Pu-240
3	C-14	*29*	Y-90	*67*	Te-125m	*96*	Eu-154	*190*	Pu-241
7	Cl-36	*33*	Nb-93m	*70*	I-129	*97*	Eu-155	*194*	Am-241
16	Mn-54	*34*	Nb-94	*71*	Cs-134	*174*	U-234	*201*	Cm-244
17	Fe-55	*35*	Mo-93	*73*	Cs-137	*178*	U-238		
18	Co-60	*38*	Tc-99	*74*	Ba-133	*182*	Np-237		
20	Ni-63	*39*	Ru-106	*80*	Ce-144	*187*	Pu-238		
23	Se-79	*51*	Cd-113m	*87*	Pm-147	*188*	Pu-239		

2.1.5 Step 5

In Step 5, "Is the ratio of the concentration of each radionuclide to the regulatory concentration limit less than 1/100 on the analysis results as contaminated water in the past?," the nuclides that have proceeded to this step are checked if they have been detected in significant amounts (1/100 or more of the regulatory concentration limit). Then, the nuclides confirmed to be less than 1/100 of the regulatory concentration limit are defined as nuclides to be monitored. Therefore, those nuclides are not to be measured upon each discharge into the sea but monitored constantly to check for a significant presence in contaminated water. The nuclides to be monitored will be analyzed continuously and re-evaluated based on the selection flow according to such analysis results.

This time, six nuclides to be monitored were selected: Cl-36, Nb-93m, Nb-94, Mo-93, Cd-113m, and Ba-133.

2.2 Results of selecting nuclides to be measured/assessed

After selected in accordance with the approved flow shown in Fig. A14-1, the nuclides excepting tritium to be measured/assessed are 29 as shown in Table A14-8. The table also shows the quantification methods that are currently planned for these nuclides. When checking the discharge standard (the sum of the ratio to the regulatory concentration limits of radionuclides other than tritium is less than 1) in the measurement and confirmation facility, the ratio to the regulatory concentration limit of α-nuclides is calculated by dividing the gross α value by the lowest regulatory concentration limit (4 Bq/L) among the selected α nuclides.

In addition to the 29 nuclides shown in the table below, the H-3 concentration is measured before discharge into the sea to set the dilution ratio.

Table A14-8 Nuclides to be measured/assessed and quantification methods

No.	Nuclide	Quantification method	*No.*	Nuclide	Quantification method
1	C-14	After chemical separation, measure β-rays	*16*	Ce-144	γ-ray nuclide analysis
2	Mn-54	γ-ray nuclide analysis	*17*	Pm-147	Assessed from the activity concentration of representative nuclide (Eu-154)
3	Fe-55	After chemical separation, X-ray measurement	*18*	Sm-151	
4	Co-60	γ-ray nuclide analysis	*19*	Eu-154	γ-ray nuclide analysis
5	Ni-63	After chemical separation, measure β-rays	*20*	Eu-155	γ-ray nuclide analysis
6	Se-79	After chemical separation, measure β-rays	*21*	U-234	Assessed as included in the gross α radioactivity
7	Sr-90	After chemical separation, measure β-rays	*22*	U-238	
8	Y-90	Radioactive equilibrium with Sr-90	*23*	Np-237	

9	Tc-99	ICP-MS	24	Pu-238	
10	Ru-106	γ-ray nuclide analysis	25	Pu-239	
11	Sb-125	γ-ray nuclide analysis	26	Pu-240	
12	Te-125m	Radioactive equilibrium with Sb-125	27	Pu-241	Assessed from the activity concentration of representative nuclide (Pu-238)
13	I-129	ICP-MS			
14	Cs-134	γ-ray nuclide analysis	28	Am-241	Assessed as included in the gross α radioactivity
15	Cs-137	γ-ray nuclide analysis	29	Cm-244	

3. Regular confirmation of nuclides to be measured and evaluated

In view of the possibility that the nuclides to be measured and evaluated may change with the progress of future decommissioning work, the nuclides to be measured and evaluated are analyzed continuously, the validity of the nuclides to be measured and evaluated is regularly confirmed and, if necessary, re-evaluated.

Attachment 15 Individual Action plans of relevant organizations pertaining to analysis

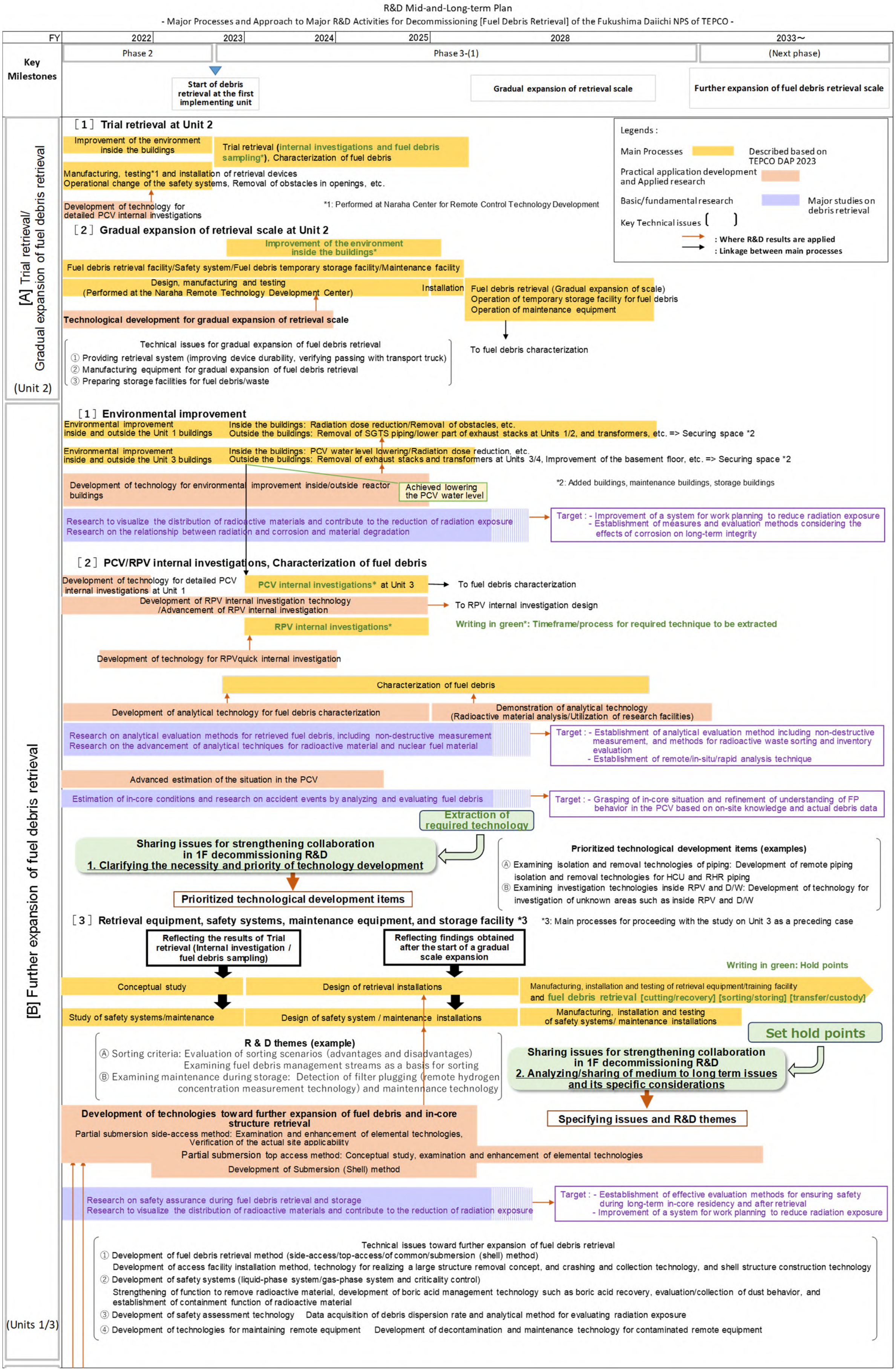
Agency for Natural Resources and Energy, TEPCO, the JAEA and NDF

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.	【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. [Others] ・In order to broaden the base of human resources to become analysis workers, the Fukushima International Research and Education Organization will launch a human resources training program for radioactivity analysis and start a training program.	【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. 【Others】 ・Conduct training for human resource development for analysis workers [Continued] ・Examine human resource development training programs to become analysis managers and analysis technicians, and conduct training sequentially.	【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. 【Others】 ・Continue to conduct human resource development training for analysis workers, managers and engineers, and review training programs as necessary.

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. 【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.	【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. ・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. 【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] ・The development of the analysis planning method which sets the analysis point statistically is continued. ・R&D on new analytical tequniques (ICP-MS/MS, SIMS, etc.) are continued to improve the accuracy, simplify and accelerate analysis of fuel debris.	【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・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 measures② : 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]

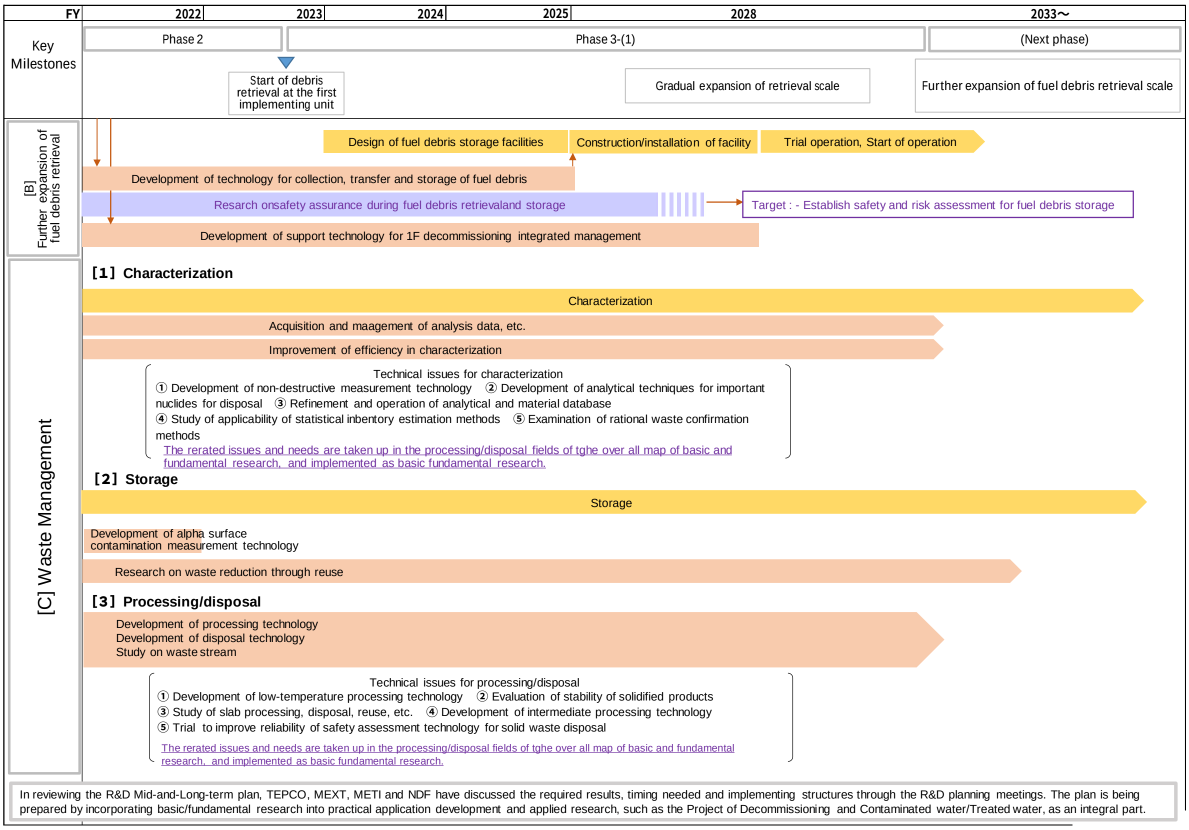
Core measures② : Development of a framework for steady implementation of analysis		
Measure 7: Coordination of Overall Processes related to collection of analytical samples, transportation, securing of facilities, etc		
Efforts to date	**Short-term Efforts (in the next two years)**	**Mid-to long-term 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 16　R&D medium-to-long-term plan



R&D Mid-and-Long-term Plan

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



Attachment 17 Past Research and Development initiatives in the Project of Decommissioning, Contaminated Water and Treated water Management

Japnese Calender	H23	H24	H25	H26	H27	H28	H29	H30	R1	R2	R3	R4	R5	R6	R7
Fiscal Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1. Waste management															
1.1 Tritium separation technologies				□	□										
1.2 Development and verification of high-performance multi-nuclide removal equipment (high performance ALPS)				□											
1.3 Large-scale verification of impermeable walls (frozen wall)				□											
2. Spent fuel management															
2.1 Evaluation of long-term integrity of fuel assembly removed from SFPs	□	□	□	□	□	□									
2.2 Investigation of method for processing damaged fuel, etc. removed from SFPs			□	□											
3. Grasping of state inside reactor/Grasping properties of fuel debris/internal															
3.1 Grasping conditions inside reactor	□	□	□	□	□	□	□								
3.2 Characterization of fuel debris	■	■	■	■	■	■	■	■	■	■	■	■	■		
3.3 Investigation of PCV inside	□	□	□	□	□	□	□	□	□	□	□	□			
3.4 Investigation of RPV inside			■	■	■	■	■	■	■	■	■	■	■		
3.5 Technologies for the detection of fuel debris (using muon)				□	□										
4. Environmental improvement															
4.1 Remote decontamination technology in the building	□	□	□	□	□										
4.2 Development of evaluation technology for the structural integrity of RPV and PCV	□	□	□	□	□	□	□								
4.3 Repair methods for leak spots in PCV (including water circulation systems)	□	□	□	□	□	□	□	□	□						
4.4 Envitonmental improvement inside the buildings (Removal of interference objects, dose source deginalization, cathodic protection of S/C)										■	■	■	■		
5. Fuel debris retrieval															
5.1 Technologies for retrieving fuel debris to be gradually expanded in scale (Development of sampling technologies)							■	■	■	■	■	■			
5.2 Technologies for further expansion of fuel debris retrieval and in-core structure remova in scale (Study on retrieval methods, development of safety system, development of element technologies)			■	■	■	■	■	■	■	■	■	■	■		
5.3 Technologies for collecting, transportation and storage of fuel debris			■	■	■	■	■	■	■	■	■	■	■		
5.4 Technologies for maintaining remote equipment											□	□			
5.5 Support technologies for integrated management											■	■			
6. Waste management															
6.1 Research and development of processing and disposal of solid waste	■	■	■	■	■	■	■	■	■	■	■	■	■		

Legend
□ Terminated or Transited to TEPCO's voluntary projects
■ Ongoing

* See below for links to the results of the Project.
< List of the projects of The Secretariat for the Project of Decommissioning, Contaminated Water and Treated Water Management >
https://dccc-program.jp/project
< Decommissioning R & D Information Portal Site >
http://www.drd-portal.jp/

Attachment 18 Selected subjects in the Nuclear Energy Science & Technology and Human Resource Development Project (the World Intelligence Project)

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 19 Major activities related to enhancing international collaboration

Table A19-1 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 A19-2 Inter-organizational Cooperation Agreement

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

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

Table A19-3 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 A19-4 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 A19-5 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