Technical Strategic Plan 2021 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.

Overview

October 29, 2021

Nuclear Damage Compensation and
Decommissioning Facilitation Corporation

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1 Introduction

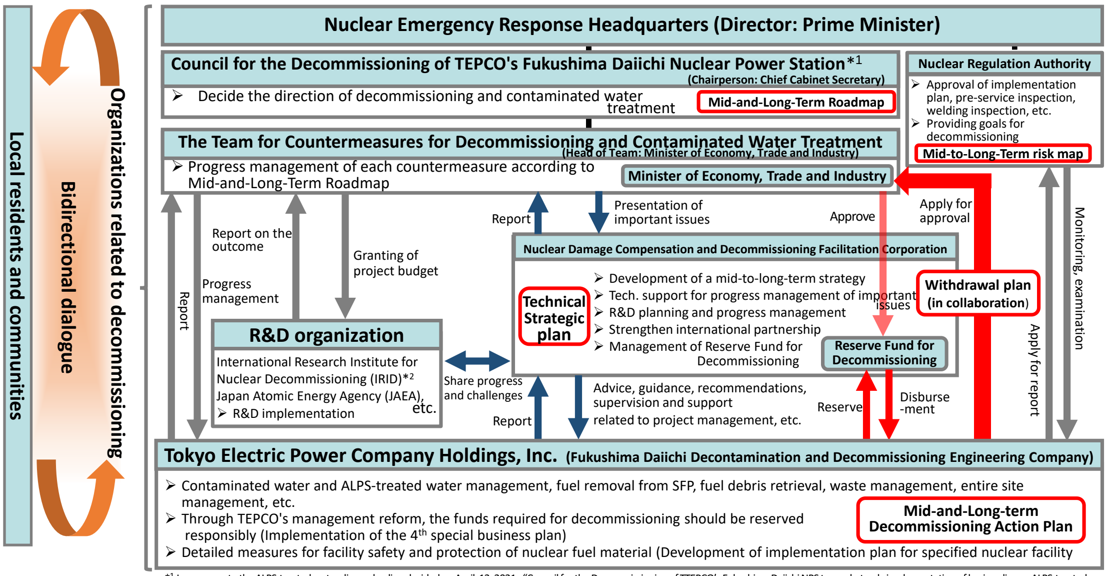
At present, contaminated water management, which required urgent measures immediately after the accident, have been stabilized, including the reduction of the amount of contaminated water generated and the completion of the treatment of stagnant water in the buildings (other than the reactor buildings of Units 1-3, the main process main building, and the high-temperature incinerator building). Fuel removal from spent fuel pools (hereinafter referred to as “fuel removal from SFP”) has been completed in Units 3 and 4, the decommissioning work is steadily in progress. In addition, countermeasures against disasters such as earthquakes and tsunamis are progressing. During the earthquake that struck off the coast of Fukushima Prefecture on February 13, 2021, the water level in the primary containment vessels of Units 1 and 3 dropped, and the medium- and low-concentration tanks and storage tanks for stagnant water in Units 5 and 6 slid (shifted), but the damage was limited to the extent that it did not affect the outside world and the impact on the decommissioning process has been reduced. As for the ALPS-treated water, the government has announced a policy of discharging it into the ocean, on the premise that safety will be ensured and that measures against reputational damages will be thoroughly taken.

On the other hand, due to the spread of the new coronavirus infection, the fuel debris retrieval from Unit 2, which was scheduled to start within 2021, is expected to be delayed by about one year, and efforts are currently being made to minimize this delay. The Tokyo Electric Power Company, Incorporated (hereinafter referred to as “TEPCO”) has updated its Mid-and-Long-term Decommissioning Action Plan, which was announced in 2020, in March 2021 to specify the outlook for decommissioning work based on the above.

The "Technical Strategic Plan 2021 for Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station" (hereinafter referred to as the "Technical Strategic Plan 2021") characteristically describes the issues to be addressed for the trial retrieval of fuel debris to minimize the impact of the new coronavirus, the issues to be discussed for the selection of a method for further expansion of retrieval scale, and the efforts for the ALPS-treated water, while offering the prospects of processing/disposal method and technology related to its safety (hereinafter referred to as the ”Technical Prospects”), that was to be presented around FY2021 in the " Mid-and-Long-term Roadmap for Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station" (hereinafter referred to as the "Mid-and-Long-term Roadmap").

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

Looking ahead to the medium-to-long-term decommissioning work, TEPCO has been working to build and strengthen the project management structure to address each issue in a systematic manner and steadily proceed with the decommissioning work. In April 2020, the organization was reorganized, and the general framework of its management structure and scheme was established. After this, it is important to enhance and upgrade the management methods and make them effective and rooted in the field operations. From the financial perspective, the Nuclear Damage Compensation and Decommissioning Facilitation Corporation (hereinafter referred to as “NDF”) has been carrying out the management of a reserve fund for decommissioning since October 2017 to ensure immediate decommissioning work. The management task aims are, in every fiscal year, (1) TEPCO will deposit the amount at NDF that is specified by NDF to implement decommissioning appropriately and steadily, as well as that approved by the Minister of Economy, Trade and Industry, and (2) based on the “Withdrawal Plan for Reserve Fund for Decommissioning” (hereinafter referred to as “Withdrawal Plan”), that was jointly prepared by NDF and TEPCO and approved by the Minister of METI, TEPCO will withdraw the reserve fund and implement decommissioning. At present, three years have passed since the decommissioning reserve management was introduced, and it is contributing to the proper and steady implementation of decommissioning. (Fig.1)



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

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

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

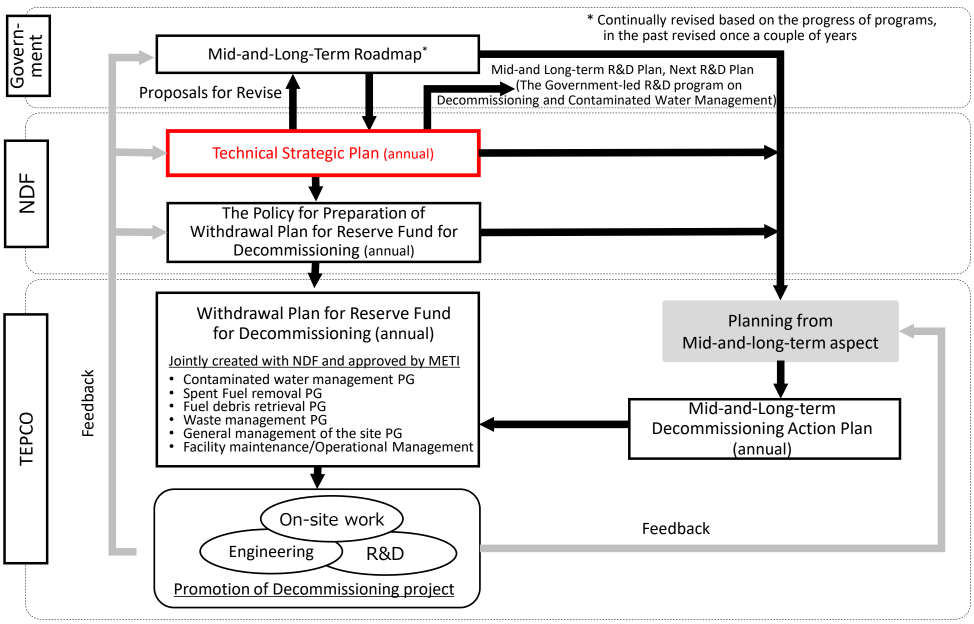


Fig. 2 Positioning of the Technical Strategic Plan based on the Reserve Fund

2) The Technical Strategic Plan

NDF has been compiling the Technical Strategic Plan every year since 2015 for the purpose of providing a solid technical basis for the Mid-and-Long-term Roadmap, contributing to its smooth and steady implementation, consideration of revisions, achievement of the goals of the Nuclear Regulation Authority's "Target Map for Reducing Medium-Term Risk at TEPCO's Fukushima Daiichi NPS," and providing a basis for the Policy for Preparation of Withdrawal Plan. The Technical Strategic Plan also makes suggestions that will contribute to the annual revision of the Mid-and-Long-term Decommissioning Action Plan from a technical perspective.

The Technical Strategic Plan 2021 presents a technical strategy from a medium-to-long-term perspective that overlooks the overall efforts at the Fukushima Daiichi NPS in order for project operators to steadily implement decommissioning work toward the goals of the Mid-and-Long-term Roadmap that was revised in 2019. In particular, fuel debris retrieval, which is a highly difficult task, is approaching, and the roles of the government, NDF, TEPCO, research institutes, etc. are becoming more significant to realize this task.

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

1) Basic policy for the decommissioning of the Fukushima Daiichi NPS

The basic policy for the decommissioning of the Fukushima Daiichi NPS is “to continuously and quickly reduce the risks arising from the radioactive materials caused by the accident that do not exist in normal nuclear power plants” by taking measures specifically designed to reduce risks.

2) Concept of reducing risks caused by radioactive materials

i. Quantitative identification of risks

The Technical Strategic Plan uses a method based on the Safety and Environmental Detriment score (hereinafter referred to as “SED”) developed by the Nuclear Decommissioning Authority (hereinafter referred to as “NDA”) to express the magnitude of risk (risk level) for radioactive materials. In this method, risk level can be expressed by the product of “Hazard Potential”, which is an index of the impact of internal exposure in the event of human intake of radioactive material, and “Safety Management”, which is an index of the likelihood that an event will occur.

ii. Identification and assessment of risk sources

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

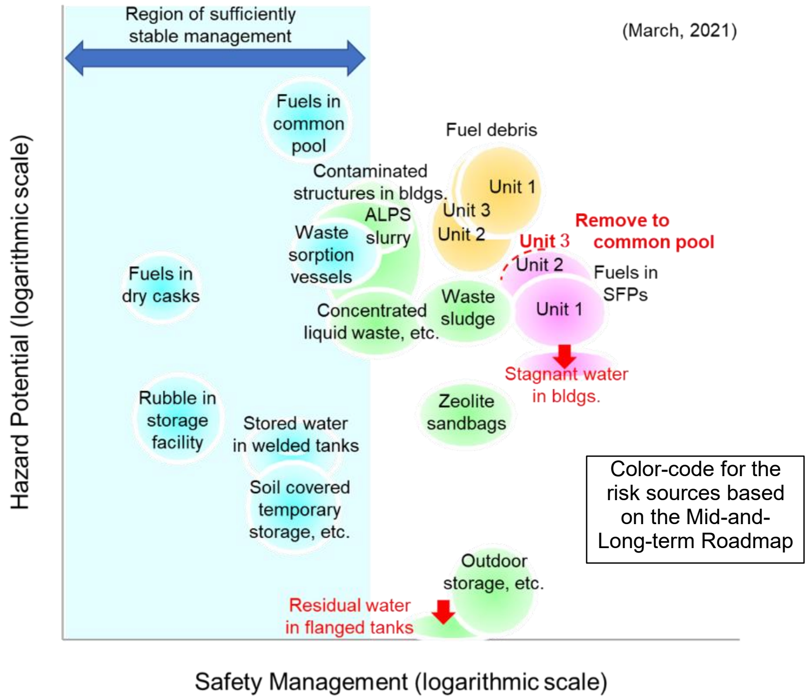
It is also important to identify risks that have not been anticipated before. Although it is not easy to identify such risks, when an unexpected event occurs, analyzing the event to clarify causes that had not been anticipated before provides a clue for risk identification.

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

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

Table 1 Major risk sources at the Fukushima Daiichi NPS

Fuel debris		Fuel debris in RPVs/PCVs in Units 1 to 3
Spent fuel	Fuel in SFPs	Fuel assemblies stored in the spent fuel pools (SFPs) in Units 1 and 2
	Fuel in the Common Spent Fuel Storage Pool	Fuel assemblies stored in the Common Spent Fuel Storage Pool
	Fuel in dry casks	Fuel assemblies stored in dry casks
Contaminated water, etc.	Stagnant water in buildings	Contaminated water accumulated in the reactor buildings of Units 1 to 3, process main building and high-temperature incinerator building, and sludge containing α-nuclides at the bottom of buildings of Units 1 to 3
	Zeolite sandbags	Sandbags containing zeolite placed on the basement floors of the process main building and high-temperature incinerator building
	Stored water in welded tanks	Strontium-treated water and ALPS-treated water, etc. (ALPS-treated water and water under treatment) stored in welded tanks
	Residual water in flanged tanks	Concentrated saltwater and sludge containing α-nuclides left at the bottom of flanged tanks
Secondary waste generated by water treatment	Waste sorption vessels, etc.	Spent sorbents used in a cesium sorption apparatus, a second cesium sorption apparatus, a third cesium sorption apparatus, advanced multi-nuclide removal equipment, mobile-type strontium removal equipment, a second mobile-type strontium removal equipment and mobile-type treatment equipment, etc.
	ALPS slurry	Slurry produced during treatment by the multi-nuclide removal equipment and added multi-nuclide removal equipment, and stored in high integrity containers (HIC)
	Sludge generated at the decontamination device	Flocculated sludge generated during the operation of the decontamination system
	Concentrated waste liquid, etc.	Concentrated waste liquid generated by evaporative concentration of concentrated salt water with further volume reduction by concentration, and carbonate slurry collected from the concentrated waste liquid
Rubble, etc.	Solid waste storage facility	Rubble (30 mSv/h and above) stored in the solid waste storage facility
	Soil-covered temporary storage, etc.	Rubble stored in the soil-covered temporary storage facility and containers (1-30 mSv/h), felled trees stored in the temporary storage pool
	Outdoor storage, etc.	Rubble stored in outdoor sheet-covered storage (0.1-1 mSv/h), rubble stored in outdoor storage (below 0.1 mSv/h), felled trees stored in outdoor storage
Contaminated structures, etc., in the buildings		Structures, pipes, components, and other items (shield plugs, standby gas treatment system pipes, etc.) inside the reactor buildings and PCVs/RPVs that are contaminated with radioactive materials dispersed due to the accident; and activated materials generated from operation before the accident



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

The red letters present risk sources that have changed significantly since last year, and the dotted lines or the starting points of the arrows indicate the locations in the previous year.

Fig. 3 Example of risk levels assigned to the major risk sources at the Fukushima Daiichi NPS

iii. Risk reduction strategy

(1) Interim targets of the risk reduction strategy

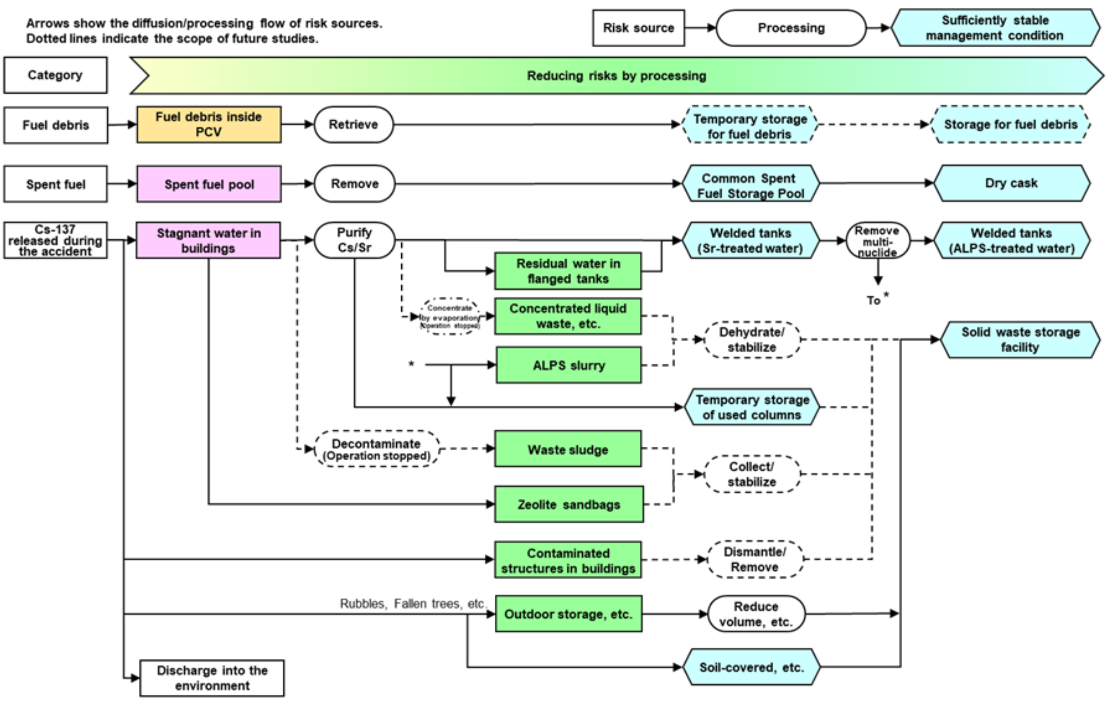
Measures for risk reduction include the reduction of the "Hazard Potential" and the reduction of the "Safety Management" level. Of the various risk reduction measures, reduction of the "Safety Management" level is generally considered to be easily realized. Consequently, the decommissioning of the Fukushima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

Regarding the progress of work from the Technical Strategic Plan 2020 towards this goal, Fig. 3 shows the completion of transfer of the fuel from Unit 3 SFP to the Common Spent Fuel Storage Pool in February 2021; the completion of treatment of the remaining water (ALPS-treated water, etc.) at the bottom of the flanged tank in July 2020 (transfer to welded tanks); and the decrease of the stagnant water in buildings (transfer to sorption vessels, etc.). In addition, Table 1 specifies that the shield plugs and the piping of the standby gas treatment system, whose state have been verified through field investigations by the NRA, are included in the contaminated structures, etc., in the buildings.

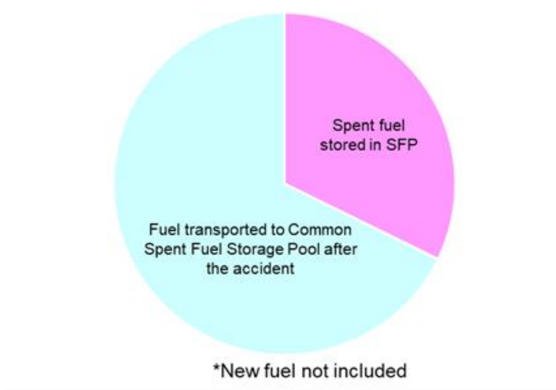
In considering the station-wide risk reduction strategy for the Fukushima Daiichi NPS, the above-mentioned SED is a quantitative indicator of risks attributable to radioactive materials at a certain time, and is an effective method for prioritizing risk sources for risk reduction.

(2) Progress of risk reduction

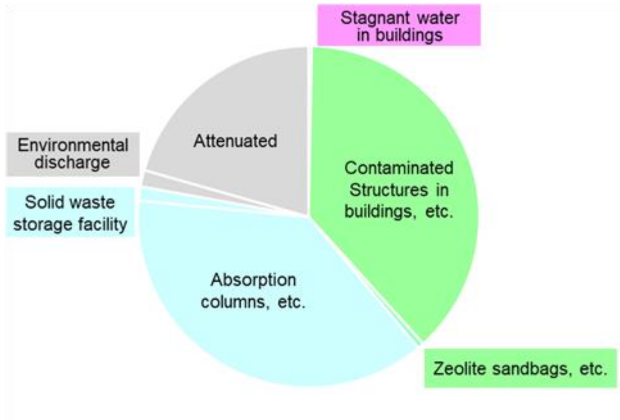
Fig. 4 shows the process to bring major risk sources into the “Sufficiently stable management” region as the interim goal, and an example of representing the decommissioning work progress along this process. Fig. 4(a) shows the outline flow of the decommissioning work to date and the future plans to represent the overall decommissioning process in a comprehensive way. Using the coloring in Fig. 3 to indicate the risk level of each risk source, Fig. 4(a) also shows the flow of risk reduction. Based on this flow, it is possible to visualize how the risk sources have changed compared with the time of the accident by applying it to fuel debris, spent fuel, and Cs-137 released during the accident. The number of spent fuel assemblies as an indicator to make the work progress easier to see in Fig. 4(b), and for Cs-137, the estimated radioactivity (Bq) common to various risk sources as an indicator in Fig. 4(c), both indicate the progress of the decommissioning work by representing the status of transition to the “Sufficiently stable management” region in a pie chart format.



(a) Risk reduction process



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



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

Fig. 4 Risk reduction process for major risk sources and its progress (example as of March 2021)

(Attenuation in Fig. 4(c) takes into account radioactive decay of Cs-137 from the time of the accident to the end of March 2021)

(3) Basic approach to risk reduction

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

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

(Five guiding principles)

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

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

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

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

3) Approach to ensuring safety during decommissioning

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

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

- A large amount of radioactive material (including α-nuclides that have a significant impact in internal exposure) is in an unsealed state, as well as in unusual (atypical) and various forms
- Barriers for containing radioactive materials, such as reactor buildings and PCVs, are incomplete
- Significant uncertainties exist regarding the state of these radioactive materials and containment barriers, etc.
- Difficulty in accessing the site and installing instrumentation devices to obtain on-site information due to constraints such as high radiation levels on site
- Since the current level of radiation is high and further degradation of containment barriers is a concern, it is necessary to take measures in consideration of the time axis without prolonging the decommissioning activities

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

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

Secondly, with regard to "field-oriented":

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

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

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

(1) Optimization of judgement with a safety assessment as its basis and ensuring timeliness in decommissioning

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

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

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

(2) Ensuring safety by incorporating “the operator’s perspective”

To ensure that safety measures are truly effective, it is necessary to satisfy the needs from the standpoint of those who actually perform the operations and tasks on site, “the operator’s perspective” (perspectives and judgements from the standpoint of those who are familiar with the site and perform operations and tasks on site) is important. In addition to this standpoint, the Fukushima Daiichi NPS is a facility that has suffered from an accident, and unlike a normal reactor its decommissioning requires an unprecedented approach that can be carried out in a peculiar environment, such as one with high radiation levels. Therefore, when determining the feasibility of safety measures on site, the peculiarities of the on-site conditions, such as high radiation levels and the environment, shall be considered.

It is also important for ensuring safety to complement the design by operations including operating controls, and to utilize information in design obtained through monitoring, analysis, etc.

ii. Preliminary implementation and utilization of the obtained information in the latter stages

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

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

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

Hereafter, it is recommended to make it clear as a policy that the information to be gained through on-site operation should be fully incorporated and accumulated as knowledge in consecutive activities for ensuring safety. For example, the same applies to risk identification associated with hydrogen at the time of fuel debris retrieval. Testing to reduce nitrogen supply for an experimental purpose may help identify hydrogen risk, and determine requirements on the necessary amount of nitrogen supply and reliability of the exhaust systems to ensure safety. It is important to accumulate successful/unsuccessful experience gained in the process of these sequential approach as a track record, allowing gradual reduction in major uncertainties in the overall decommissioning work in the future. This will lead to steady progress in decommissioning and contribute to ensuring safety in decommissioning the Fukushima Daiichi NPS from the perspective of risk reduction in the medium-and-long term.

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

3 Technological strategies toward decommissioning of the Fukushima Daiichi NPS

1) Fuel debris retrieval

i. Targets and progress

(Targets)

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

(2) Trial retrieval in Unit 2 was scheduled to begin within 2021, but the process has been delayed due to the COVID-19 pandemic. In order to limit the delay to about one year, preparations will be made for starting retrieval. Continue a series of work including the gradual expansion of fuel debris retrieval to acquire knowledge and experience necessary for the further expansion of the retrieval scale.

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

(Progress)

① Unit 1

In preparation for the start of the PCV internal investigations, which is planned within FY2021, removal of obstacles within the PCV is being promoted while taking measures to control dust dispersion and monitoring dust concentration by considering the change in dust concentration when opening the inner door at the penetration X-2. Also, at the beginning of 2021, during the preparation of the obstacle investigation in PCV, for the pressure decreasing that were expected to have occurred due to the addition of external force to the outer door of the penetration X-2, removal of obstacles within the PCV is being promoted while performing measures to suppress the occurrence.

② Unit 2

The 2019 Med-and-Long-term Roadmap specified Unit 2 as the first implementing unit for fuel debris retrieval, and its trial retrieval was supposed to launch within 2021. However, the process has been delayed due to the impact of the new coronavirus infection. In order to limit the delay to about one year, preparations are being made for starting fuel debris retrieval. The arm-type access equipment (robot arm) has arrived in Japan and started testing.

A plan for gradual expansion of fuel debris retrieval is also underway, the requirements related to the arm performance of the arm-type access equipment and the interface between the equipment and enclosures have been clarified and examined (Fig. 5, Fig. 6).

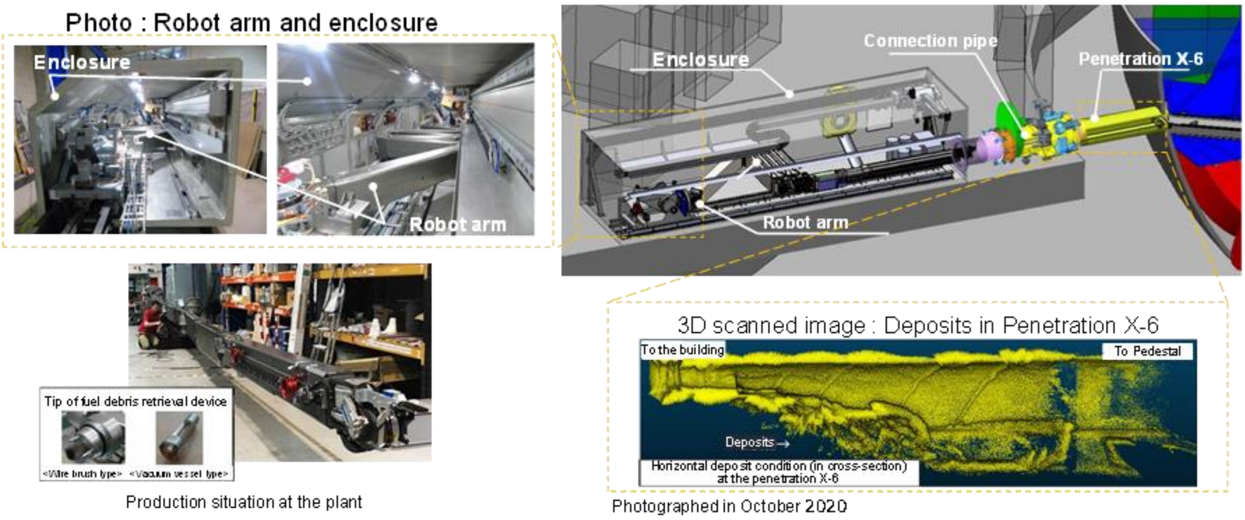
③ Unit 3

As for Unit 3, the result of sampling the suppression chamber (hereinafter referred to as “S/C”) water (conducted in 2020) using the piping connected to the S/C shows that the concentration of radioactive materials such as Cs-137 is higher than that of the stagnant water in buildings. Therefore, its impact on the treatment of contaminated water is being considered, and the analysis results are being incorporated into the PCV water intake system. In addition, the conceptual study on further expansion of fuel debris retrieval is in progress.

④ Impact of and response to the earthquake on February 13, 2021, with its epicenter off the coast of Fukushima Prefecture

Due to the earthquake that occurred off the coast of Fukushima Prefecture on February 13, 2021, lowering of the PCV water level was observed in Units 1 and 3. Water injection into the reactor is continuing, from the enhanced monitoring of plant parameters for Units 1 to 3, as there are no significant changes in plant parameters, the cooling condition of fuel debris is considered to be intact. It is assumed that this drop in water level may have been caused by an increase in leakage from inside the PCV due to changes in the condition of the damaged areas previously identified in the PCV and its newly damaged areas. Going forward, the change in parameters such as water level will be checked by water injection shutdown testing, and expansion of knowledge be considered.

In light of the recent earthquake, it is necessary to enhance monitoring systems to observe changes in plant conditions, perform impact assessment to maintain/manage systems and buildings over the med-and-long-term, and promote technical development required to understand the situation.



(TEPCO material edited by NDF)

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

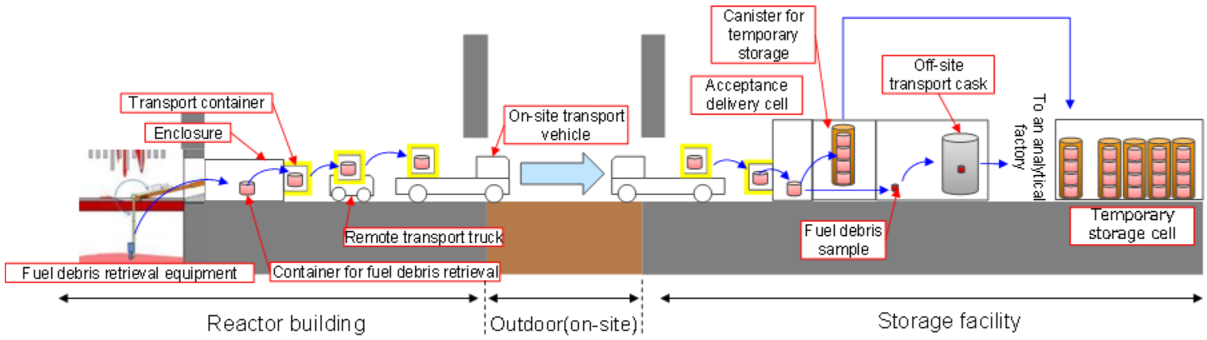


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Fig 6 Image from retrieval to temporary storage of fuel debris
(Gradual expansion of retrieval scale)

ii. Key issues and technical strategies to realize them

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

In Unit 2, trial retrieval and PCV internal investigation will be performed, and implement the gradual expansion of fuel debris retrieval based on the findings. In addition, a conceptual study on the further expansion of fuel debris retrieval for Unit 3 is planned.

(1) Trial retrieval and PCV internal investigation, and gradual expansion of fuel debris retrieval

① Development status and prospects of trial retrieval/internal investigation equipment

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

Although it is important to make efforts to minimize delays caused by the new coronavirus infection, mockup testing that takes full account of uncertainties on site is also important in terms of actual site applicability and ensuring safety. In addition to simulating the severe environment on site, this mockup testing should clarify the parts that cannot be simulated and make enough preparations for practical application. The NDF will also confirm the test plan and whether measures are sufficient.

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.

For the removal of deposits in the penetration X-6 and AWJ cutting of obstacles, it is essential to develop a detailed work plan in accordance with the preliminary implementation and use it in the later stages and ensure safety accordingly (for example, break down work steps; proceed to the next step after confirming there is no problem with the dust dispersion monitoring results in each step; and take countermeasures and proceed to the next step if any sign of abnormality is observed).

NDF will confirm whether a sufficient level of safety is secured for performing work, including whether the work plan is well-developed by TEPCO, the plan is fully implemented without fail, and work is stopped when necessary.

・ Considerations for the risk of spreading the new coronavirus infection

The performance confirmation test and mockup test simulating the on-site environment in the UK have been canceled, and it is planned to perform testing by bringing the equipment into Japan. For the performance confirmation test in Japan, it is essential to secure the UK engineers, and it is necessary to maintain the backup system on the UK side in the event of a defect, while, sharing information and communicating smoothly with the UK engineers.

It is also important to make all possible preparations for the risk of the new coronavirus infection expanding in Japan. The NDF will confirm these responses.

・ Considerations in project management

It is important to proceed with the project while paying attention to the process progress management of the contractors including overseas enterprises and subcontractors. As part of their project management activities, TEPCO needs to make further efforts to perform prior-evaluation of risk of delays, and develop alternative plans and measures to prevent the occurrence of risks. The 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 internal investigation, and incorporation into gradual expansion of the retrieval scale

In the PCV internal investigation using a robot arm, it is planned to ascertain the state of existing structures, and the distribution of deposits inside the pedestal (3D data), the distribution of gamma rays and neutron counts at the bottom and on the platform, in as wide a range as possible. However, since more structures and platforms in the pedestal remained than the initial design plan, the range in which the 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. Assuming that fuel debris at the bottom of the pedestal cannot be retrieved, it is also planned to retrieve the deposits on the platform which are highly likely to be fuel debris, as same as those at the bottom of the pedestal. Given the limited scope of investigation and trial retrieval, greater consideration is required in advance to determine what information is needed to gradually expand the retrieval scale as a next step for promoting the retrieval work in a reliable manner.

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

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

② Development status of gradual expansion of retrieval scale and prospects

The retrieval equipment to be used for gradual expansion of the retrieval scale will be improved by increasing the weight capacity and enhancing accessibility while complying with specifications of the devices for trial retrieval and PCV internal investigation.

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

The key technical issues and countermeasures are described below.

- Ensuring containment performance of enclosures for fuel debris

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

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

- Ensuring reliability of a dual arm manipulator

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

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

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

Since it is extremely important to ensure the maintenance of equipment/devices and their measures, including repairs, NDF will check the examination and preparation status for them in TEPCO. It is also important to leverage the experience gained through the in-service maintenance of equipment/devices for further expansion of the retrieval scale. Therefore, a system that can reliably preserve maintenance records, including failure histories and their measures, should be established.

③ Further expansion of fuel debris retrieval

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

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

TEPCO has been engaged in the conceptual study for further expansion of the retrieval scale. As part of this conceptual study, TEPCO will consider scenarios for fuel debris retrieval and, at the end of FY 2021, identify promising methods (top/sub candidates). Subsequently, based on the information obtained from the survey results, TEPCO will finally narrow down the possible methods (top/sub candidates), and decide the method with its design in mind.

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

・ How to select retrieval methods

In selecting the method, based on the Five guiding principles (Safe, Proven, Efficient, Timely and Field-oriented), a determination should be made not only to satisfy the target of safety level but also to use the attributes (evaluation items) such as cost and schedule as indexes for selection. It is necessary to quantify these evaluation items as much as possible by using a multi-attribute utility analysis method, etc. It is believed that the most important factors in the process of selecting methods are the evaluation items used as indexes for determination and how to weight these indexes. In setting these indexes, a decision should be made not only based on the approach of TEPCO as an operator, but also from a comprehensive viewpoint developed through discussions with experts. Normally, the selection of methods should be based on the results of internal investigation. However, in a situation with many uncertainties like at the Fukushima Daiichi NPS, it is considered necessary to proceed with examination based on the currently available information and then to feed back the results gained from the investigation. As for the results of method selection, it is also important to make efforts to disseminate information in a careful manner so that the evaluation results will be widely accepted by society.

・ 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 considering fuel debris retrieval scenarios, different cases are assumed, where fuel debris will be retrieved by the side-access or top-access methods, or combining both. Then, examinations including internal investigation required for each case will be made to consider several paths. This study intends to assume in advance different results obtained from PCV/RPV internal investigations or technical studies in the future, and then conduct examination based on the preconditions of using such results.

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

It is also important to formulate a specific schedule with considering these fuel debris retrieval scenarios.

・ Clarification of requirements

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

・ Process for narrowing down promising retrieval methods

Based on the development results of the Project of Decommissioning and Contaminated Water Management, the latest findings at home and abroad are taken into consideration to derive ideas. Then, primary/secondary screening will be performed to gradually narrow down the methods. The primary screening verifies compliance with requirements and constraints, while the secondary screening quantifies and weighs each evaluation item. A multi-attribute utility analysis method, etc., is utilized for such screening process. Diverse ideas are expected to be derived, but it is important to conduct objective evaluation based on this process and to narrow down the methods.

Based on the above considerations, NDF will evaluate the validity of the results of TEPCO's conceptual studies (Fig. 7).

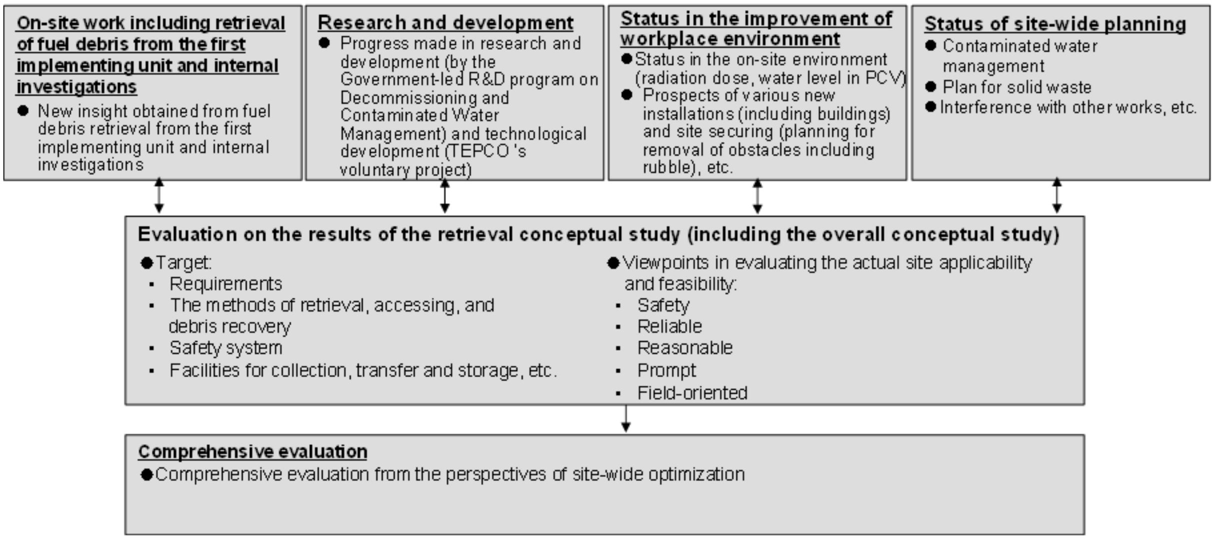


Fig. 7 Flow of retrieval method study (conceptual diagram)

Issues in each technical field for further expansion of the retrieval scale are described in (3).

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

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

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

The Secretariat of the Nuclear Regulation Authority responsible for continuing accident investigations/analyses established "The Study Committee on Accident Analysis of the Fukushima Daiichi Nuclear Power Station", and is also investigating the operating floor in Unit 2, the inside of the reactor building in Unit 3, and SGTS filter lines, etc., with cooperation from TEPCO, and compiling an interim report. Based on these investigations, the Nuclear Regulation Authority has assessed that a large amount of Cs exists between the first and second layers of the shield plug installed on the operating floor in Units 2 and 3. Since the information related to the accident analysis may be affected by the dismantling of facilities due to the progress of decommissioning work, a liaison/coordination meeting for decommissioning and accident investigation has been established, and has communicated and coordinated among NRA, the Natural Resources and

Energy Agency, TEPCO and NDF regarding accident analysis and decommissioning. An example of managing both decommissioning work and accident investigation, in the partial removal of SGTS piping in Unit 1 and Unit 2, TEPCO is planning to take measurements of the radiation dose rates and with a gamma cameras, and to collect piping samples for analysis after cutting. As countermeasures against radiation of radioactive dust during cutting, urethane foam injection and local exhaust ventilation are being considered, and care is being taken to ensure that decommissioning work and accident investigations do not affect the surrounding residents or the environment.

TEPCO is also planning to systematically conduct on-site investigation while estimating the state of the reactor core and PCV, and unsolved issues. After a lapse of 10 years since the accident, the radiation dose has decreased due to the decay of fission products (hereinafter referred to as "FP") and environmental improvements on site, and accessibility to the reactor buildings has improved. However, there are still many places with high radiation doses. In order to locate FP released at the accident with a low radiation exposure dose, it is important to collaborate with each organization, and continue these activities to a reasonable extent to clarify the events that occurred at the accident, the process of their progression and the equipment operation status. When new facts about the accident are revealed through further investigations and other activities, it is also important to deepen and incorporate knowledge by performing severe accident progression analysis evaluations, etc.

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

(3) Technical issues for technical requirements and future plans

The current status and issues of the following items are described below.

a. Technical issues for ensuring safety of fuel debris retrieval work

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

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

① Issues in containment functions (gas-phase)

We expect that existing safety systems will be able to cope with the retrieval of fuel debris, such as gripping and sucking, in the case of a trial retrieval or gradual expansion of fuel debris retrieval. In the subsequent work such as fuel debris cutting, it is necessary to construct the containment function of the gas phase system in consideration of re-scattering of Cs, etc., that adhere to the equipment and structures in the PCV, aerosolization of water containing radioactive materials, and generation of short-lived iodine and noble gases if criticality should occur.

In addition to re-scattering of Cs, etc., the fact that dispersed fine particles (α-dust) containing α-nuclides may be generated and the radioactivity concentration in the PCV gas-phase may increase is a concern.

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

② Issues in containment functions (liquid-phase)

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

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

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

③ Issues in cooling functions

Fuel debris generates decay heat, for example in Unit 2, the maximum heat generation is still estimated to be 69 kW. The temperature is being maintained below 100°C (cold shutdown state) currently by conducting circulating cooling with water injection into the reactor. In maintaining this cooling function, the technical issues to be addressed for the time being include setting of the target temperature inside the PCV to make each task feasible, as well as the countermeasures to be taken under the assumption of cooling function abnormalities when each task is performed. While essential countermeasures would be to continue cooling by early recovery of the cooling water circulation system or by mobile equipment, etc., it is necessary to evaluate changes in the PCV internal condition based on the time margin in an emergency and to consider emergency response measures and procedures, etc., including collection of devices. In FY 2019, water injection into the reactor was temporarily suspended with the aim of optimizing operation/maintenance management of cooling systems and emergency response procedures, etc. In light of these results of the water injection shutdown test, from FY 2020 onward, testing will be planned and performed depending on the purpose, taking into account the situation of each unit, for the decommissioning in the future. Based on this policy, water injection shutdown tests are being performed for each unit, and in consideration of the situation of lowering PCV water level during termination of water injection, it is planned to study water injection methods for the future such as further reduction of the amount of water injection.

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

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

However, it should be considered that the injection of cooling water may become redundant in the future due to further decrease in the amount of decay heat along with reduction in the amount of fuel debris.

④ Issues in criticality control

The possibility of re-criticality of the fuel debris at the Fukushima Daiichi NPS is assumed to be low based on the expected condition of the existing fuel debris from an engineering perspective. However, the possibility of changing the shape of fuel debris must be taken into account as the scale of retrieval is expanded. It is essential to ensure reliable criticality management during retrieval and to establish an appropriate control method for ensuring prompt detection and temporary shutdown/re-start of operation in case of an unexpected criticality. In order to ensure criticality control as a consideration of the work plan for fuel debris retrieval, it is necessary to establish an appropriate control method to ensure prompt detection, suspension and resumption of work even in the case of an unexpected criticality.

In the initial stage of fuel debris retrieval work, fuel debris should be retrieved by limiting the treatment amount based on methods that will not significantly change the fuel debris shape. In the process of expanding the retrieval scale, by utilizing the site information from the preceding operations for the subsequent safety evaluation, reliable criticality control should be made that combines the monitoring by the operator and the decision-making process to suspend and resume work while reducing the design uncertainty. As control measures, by combining measures such as preparation for neutron absorber insertion with continuous monitoring and subcriticality measurement of neutron flux in the vicinity of the fuel debris, technology development is underway to respond to the increase in retrieval volume.

⑤ Issues in the structural integrity of PCVs and buildings

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

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

Moreover, regarding the existing equipment/systems and buildings, the cooling function was maintained during the earthquake that struck off the coast of Fukushima Prefecture on February 13, 2021, although lowering of the water level in the PCVs of Units 1 and 3 was confirmed. In light of this earthquake, 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 and external events (earthquakes and tsunamis, etc.) anticipated during the decommissioning period. In view of the fact that the past assessment of these effects was limited, it is necessary to make maximum use of existing techniques and evaluation results for planning and implementing an investigation plan, in which remote control under a high radiation environment is a challenging issue, and to develop underlying technologies to understand the situation. In so doing, while giving priority to safety, it is useful to actively introduce the latest knowledge and achievements not only in the nuclear field but also in other fields.

As for 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, it steadily proceeds with the examination based on the latest design information.

⑥ Issues in reduction of radiation exposure during work

In accordance with the Mid-and-Long-term Roadmap and TEPCO's Mid-and-Long-term Decommissioning Action Plan, removal of obstacles and radiation dose reduction in the reactor buildings are in progress as improvement of the work environment in work areas/access routes. In the future, as work related to fuel debris retrieval, reduction of exposure during work such as removal of high-radiation dose equipment, etc. is an issue, and research and development has been promoted by the Project of Decommissioning and Contaminated Water Management to support TEPCO's engineering.

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

In particular, in fuel debris retrieval operation, access to the PCV should be made from the penetration X-6, etc., after the work environment in the reactor building is sufficiently secured. As for the reduction of the radiation exposure of workers in the reactor building, after conducting sufficient investigations on the radiation dose distribution and state of contamination, including the contribution from the surroundings of the work areas, it is important to identify the source locations and intensity as much as possible and to build the radiation dose reduction plan with the target dose rate in consideration of the margin for the radiation exposure dose limit for workers specified by laws and regulations. In the radiation dose reduction plan, it is important to plan for reducing the total radiation exposure dose to as low as reasonably achievable with respect to work hours in accordance with dose limits and required work hours to accomplish operations. Based on these, the development of the digitization technology for the environment and radiation source distribution which introduces visualization technology has been in progress since FY 2021. Moreover, in developing remote technologies for environmental improvement and removal of obstacles under high radiation dose, the obstacles to be removed have been selected and the elemental technologies have been extracted in accordance with the required functions, and technical investigation is underway since FY 2020.

In the future, it will be necessary to develop management methods and equipment that can detect leaks and contain α nuclides to prevent diffusion into the air and into the water treatment system during a series of work processes. For a further expansion of fuel debris retrieval, it is necessary to develop a database that enables information sharing and rapid feedback to the next work plan. In addition, adequate radiation exposure control should be conducted after formulated a long-term work plan that includes not to concentrate workers' radiation exposure on individual workers and to help reduce whole workers' radiation exposure. Support should be provided to establish a system that manages and operates various information on the entire Fukushima Daiichi NPS in an integrated, step-by-step manner.

b. Technical issues related to fuel debris retrieval methods

① Issues in securing access routes

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

For trial retrieval and gradual expansion of fuel debris retrieval, TEPCO is currently proceeding with specific engineering studies to conduct an access route from penetration X-6 in Unit 2.

On the other hand, toward a further expansion of fuel debris retrieval, studies are underway on the construction of access routes from the side opening of the PCV to fuel debris, based on the results of research and development conducted to date by the Project of Decommissioning and Contaminated Water Management. In the side-access method, the issue is to address containment, shielding for connecting structures between newly installed heavy structures and the side-opening of the PCV, and seismic displacement, and technical development of the method is underway using lightweight cells and fixed rails as well as access tunnel systems. As for the top-access method from operating floor, enhancing throughput is being examined including a method to retrieve and transport interfering structures as a single or large unit while ensuring containment and shielding. The NRA pointed out the possibility that a large amount of Cs might exist on the undersurface of the shield plugs of Units 2 and 3 from their evaluation of TEPCO's radiation dose measurements on the operating floor. Therefore, the top-access method requires consideration of constructing access routes with this in mind.

In the future, based on the above-mentioned issues, it is necessary to clearly define the access route to be built at the next stage from the data obtained at each phase and it is important to proceed with research and development toward a planned scale expansion.

② Issues in development of devices and equipment

Devices and equipment for fuel debris retrieval need to be developed with emphasis on safety, reliability, and efficiency. To flexibly respond to the situation, these devices/equipment should be considered radiation resistance, maintainability, remote operability, high reliability, a rescue mechanism that does not disturb the subsequent work when a problem occurs, and efficiency of fuel debris retrieval.

Equipment development for trial retrieval and gradual expansion of fuel debris retrieval has progressed as part of research and development of the Project of Decommissioning and Contaminated Water Management. After the gradual expansion of fuel debris retrieval, TEPCO needs to take over and substantiate the development results. TEPCO is proceeding with the engineering of the robot arms, etc., to be applied to Unit 2, while preparing education/training for the fuel debris retrieval operations using these remote devices.

As for devices and equipment for further expansion of fuel debris retrieval, development is underway for retrieval methods for improving efficiency, retrieval/handling systems according to diverse conditions of fuel debris, and dust collection systems, etc. for dust generated during fuel debris fabrication. TEPCO is currently conducting a concept study for selecting a method for further expanding the scale of retrieval, and plans to narrow down the number of methods for the subsequent design study by the end of FY 2021. Further development of devices and equipment should be planned and promoted in light of the selected method.

As for how to proceed with development, it is necessary to continue development for newly emerging important issues based on the information obtained from preceding investigations and retrieval work. The developed devices and equipment need to verify the results through repeated mockup tests to demonstrate that they can realize their performance safely and reliably at the actual site. The mockup tests need to be implemented in a facility simulating the severe on-site environment containing significant uncertainties. Therefore, NDF and TEPCO have been engaged in examining how to proceed with the remote mockup test plan. From 2021, it is expected that TEPCO will take the initiative in promoting examination and materialization.

③ Issues in system installations and working areas

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

The system installations include a negative pressure control system required for establishing containment functions (gas phase), a circulating water cooling and purification system required for maintaining the containment functions (liquid phase) and cooling functions, and a criticality control system required for controlling criticality. Moreover, realization of measurement systems (for pressure, temperature, water level, radiation, etc.) to monitor the PCV internal state is a significant issue, which is essential for fuel debris retrieval. TEPCO has been examining the building of safety systems incorporating the above through their engineering work.

The working area required for installing fuel debris retrieval equipment/related devices and system is now being investigated. In considering the handling of high radiation dose areas in the reactor buildings and interference with other tasks, installing systems outside of the existing buildings is also being considered.

c. Technical issues related to safe and stable storage of fuel debris

① Issues in handling fuel debris (containing, transferring, and storing)

Before initiating fuel debris retrieval work, a comprehensive system should be established that consists of a series of steps from containing and transferring to storing of retrieved fuel debris furnished with safety functions such as maintaining subcriticality, containment functions, countermeasures against hydrogen generation, and cooling. Accordingly, examination of the following is being progressed until the end of FY 2020:

- Development of basic specifications for the container, (structure, size and quality of materials) and demonstration of its structural integrity by testing.
- Examination of a practical prediction method of hydrogen gas generation from fuel debris; determination of a vent mechanism on the container by using the said results; and establishment of safe transferring conditions.
- Development of drying technology applicable to fuel debris and consideration on a drying system using this technology.

Moreover, in reference to the results of these studies, TEPCO continues their activities to materialize systems and devices/installations used for the process from containing to storing fuel debris, which are required for gradually expanding the scale of retrieval, in coordination with other associated projects. In addition, specific transferring routes, storing technologies/forms and its locations in light of the usage plan for the entire site are taking shape. At present, since the information and knowledge on the properties of fuel debris is extremely limited, the systems and devices/installations will be designed based on conservative assumptions of conditions such as the properties of fuel debris. Therefore, in the design of equipment and facilities for containing, transferring and storing of fuel debris for further expansion of retrieval scale, it is important to proceed in a streamlined manner by utilizing various measurement data such as the amount of hydrogen generation and fuel debris properties that have been collected and accumulated in the trial retrieval and gradual expansion of retrieval scale, as well as knowledge and experience on the handling of fuel debris during the operations from receiving of the onsite transport container to the temporary storage.

It is also necessary to address safeguards requirements when specifying the equipment and systems from containment to storage of fuel debris.

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

② Issues in sorting out fuel debris and radioactive waste during fuel debris retrieval

In the fuel debris retrieval work, structures to which molten fuel are partially adhered will also be removed from the PCV in addition to fuel debris in which molten core fuel are mixed with metals and solidified, and compounds (MCCI product) produced by mixing molten core fuel with concrete at the PCV bottom. Of these, if substances on which a small amount of molten fuel is adhered are all deemed as fuel debris, the amount would be enormous. It may become an obstructive factor in advancing decommissioning because scales of facilities and sites for fuel debris storage become larger. This requires the development of sorting techniques for fuel debris and radioactive waste, i.e., sorting scenarios (sorting is performed in which process from retrieval to storage), sorting criteria and necessary measurement technique/devices.

It is determined that those requiring special attention and facilities/systems for handling and storing to maintain subcriticality can be considered as fuel debris. Accordingly, it is recommended to aim for sorting out fuel debris based on the measurement results of the amount and its concentration of nuclear materials. As a first step in response to this, studies were conducted to consider which operation processes is feasible for sorting through to storage (sorting scenarios), and to Investigate which technologies may be capable of measuring the amount or content of nuclear fuel materials. Based on these studies, it is currently considered as incredibly difficult challenge to measure or estimate the amount and concentration of nuclear materials in the retrieved materials from the PCV, which required innovative technology development.

In developing measurement techniques and devices, it is important to understand the measurement errors first. Major factors affecting measurement errors include the fuel debris properties and the condition and location of nuclear fuel material in fuel debris storage condition in unit cans and containers, and there are many factors other than errors depending on the measurement device itself. The extent of such impact is highly uncertain at present due to a lack of knowledge on the properties of fuel debris. Therefore, in parallel with the development of measurement technology and actual measurement device by iterating actual measurement using mockup fuel debris, etc., it is considered beneficial for R&D in terms of cost and time saving to identify factors influencing measurement errors and its strength accumulated by a number of numerical experiments by computer and incorporate findings such as the extent of influence into the development of actual measurement technologies/devices. Thus, the impact of various condition of fuel debris with different properties and storage conditions on the measurement errors as well as modifications/improvements (e.g., specifications of shielding materials and their installation location) of measurement techniques/devices to reduce measurement errors can also be examined through numerical experiments by computer. Such research and development activities are just getting started since FY 2020 as the Project of Decommissioning and Contaminated Water Management, and this R&D is greatly desired to be accelerated in the future.

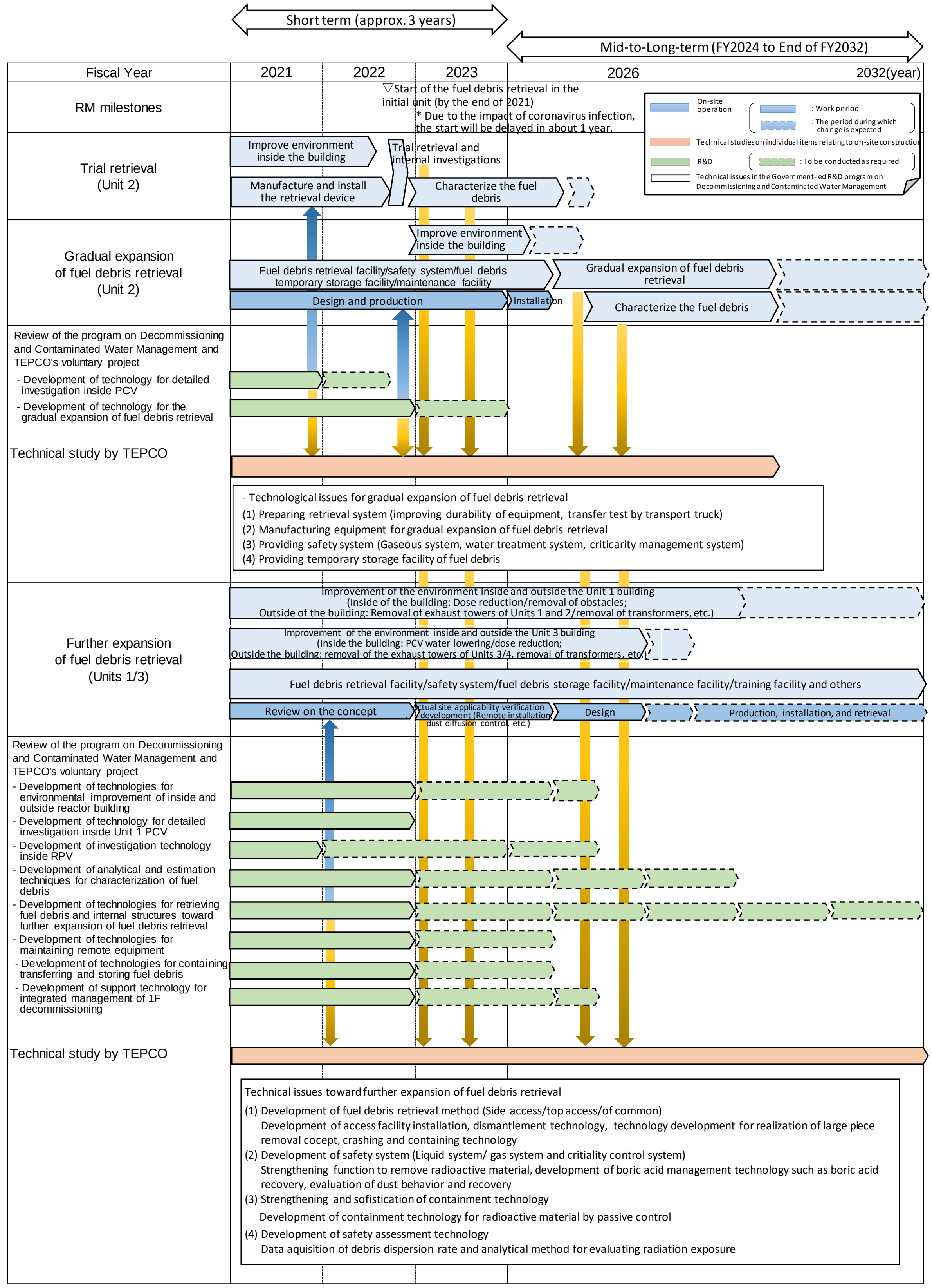
Knowledge on the properties and actual storage conditions of actual fuel debris is anticipated to be accumulated through trial retrieval and gradually expanded-scale of furl debris retrieval. By comparing the results of numerical experiments using the improved analytical model and expanded analysis condition based on these accumulated knowledge with the results of actual measurements using mock fuel debris manufactured based on the knowledge on the properties of actual fuel debris, it is possible to improve the accuracy of measurement technologies/devices and to further accelerate its development.

It is desirable that development of measurement techniques/devices required for sorting fuel debris and radioactive waste is to be continued in this manner. It is also important to continue activities to enhance the effectiveness and practical applicability of sorting methods (sorting criteria, scenarios, measuring techniques/devices) by leveraging knowledge and information on the fuel debris properties obtained by planned PCV internal investigation and analysis results of fuel debris samples taken during trial retrieval, and gradual expansion of fuel debris retrieval and so on.

③ Issues in examining safeguards strategies

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

The main technical issues and plans described in this section are summarized as shown in Fig. 8.



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

Fig. 8 Technical issues and future plans on fuel debris retrieval (progress schedule)

2) Waste management

i. Targets and progress

(Targets)

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

(2) Countermeasures integrated from characterization to processing/disposal of solid waste are studied from the expert point of view, and the prospects of processing/disposal methods and technology related to its safety should be made clear by around FY 2021.

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

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

(2) Reduction of solid waste volume
To reduce the amount of solid waste generated by decommissioning as much as possible.

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

(4) Thorough storage
Generated solid waste should be stored safely and reasonably according to its characteristics. Storage capacity should be secured to ensure that the waste can be stored within the site of the Fukushima Daiichi NPS.

(5) Establishment of selection system of preceding processing methods in consideration of disposal
To establish selecting methods of processing for stabilization and immobilization (preceding processing) and then select preceding processing methods before technical requirements of disposal are established.

(6) Promotion of effective R&D with an overview of overall solid waste management
To confirm required R&D tasks after cooperating with each R&D field in characterization and processing/disposal and overviewing the overall management of solid waste.

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

(8) Measures to reduce radiation exposure of workers
Thorough implementation of radiation exposure control, health and safety management based on the relevant laws/regulations.

(Progress)

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

Since a large amount of solid waste with various characteristics is generated in association with decommissioning of the Fukushima Daiichi NPS, the efforts are being made in accordance with the above "Basic Policies on Solid Waste" summarized in the Mid-and-Long-term Roadmap. TEPCO is required to ensure safe and reasonable storage of the solid waste generated. For advance technical examination of integrated measures for solid waste, from characterization to processing/disposal, NDF and the organizations concerned are working on initiatives based on their respective roles. In addition to improvements in characterization analysis abilities, the development is underway for the establishment of a flexible and reasonable waste stream (the flow of the integrated measures from characterization to processing/disposal), with the goal of providing the Technical Prospects by around FY2021.

(1) Current status of Storage in Fukushima Daiichi NPS

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

According to this Plan, temporary outdoor storage of the solid waste will be eliminated completely by FY 2028, except for secondary waste generated by water treatment and targets of reuse/recycling. Facilities needed to achieve this goal are under development. From the perspective of reducing the amount of solid waste, as for the concrete rubble that surface dose rate is equivalent to the site background radiation dose is recycled as roadbed material. For metal and concrete rubble, and scrapped flanged tanks with extremely low surface radiation dose rates, reuse/recycling are under consideration while temporary storage outside solid waste storage is continued for the time being.

(2) Prospects of processing/disposal methods and technology related to its safety

The Mid-and-Long-term Roadmap states that Technical Prospects will “present measures toward reducing the volume of solid waste”, “develop analytical and evaluation methods for efficient characterization”, and “develop methods to reasonably select safe processing and disposal methods at the time when the necessary information such as solid wastes’ properties are proven”.

On “present measures toward reducing the volume of solid waste”, the Basic Policy for Solid Waste specifies that TEPCO should reduce the burden of overall waste management (for the entire processes, from generation, storage, and processing to disposal) to the extent possible. The Technical Strategic Plan 2020 takes into consideration the possibility of further efforts based on precedents in other countries.

“Develop analytical and evaluation methods for efficient characterization” and “develop methods to reasonably select safe processing and disposal methods at the time when the necessary information such as solid wastes’ properties are proven” mean to develop and establish the methods necessary for disposing of materials that become waste even after undergoing volume reduction. The NDF has organized and examined the following specific goals in the Technical Strategic Plan 2018. Of the wide variety of types of solid waste, the secondary waste generated by water treatment, which is highly mobile and for which there is no precedent for processing or disposing of it in Japan, has been selected as the main object for examination.

① Establish a safe and reasonable disposal concept based on characteristics and volume of the solid waste generated in the Fukushima Daiichi NPS with its applicable processing technology, and develop safety assessment methods that apply the features of the disposal concept, with considering examples of foreign countries.
② Clarify radiological analysis and evaluation methods for characterization.
③ Clarify processing technology which practical application could be expected for stabilization and immobilization, considering disposal for several important waste streams such as secondary waste generated by water treatment.
④ Establish methods of reasonably selecting processing technology to stabilize and immobilize waste based on the above methodology before the technical requirements for disposal are determined (i.e., preceding processing).
⑤ Have the prospect of setting processing/disposal methods for solid waste for which the processing technology considering disposal is not clarified, using a series of methods to be developed by around FY 2021.
⑥ Clarify issues and measures concerning storage of solid waste until it is conditioned

The following shows the Technical Prospect based on the results of these studies.

a. Approach for volume reduction

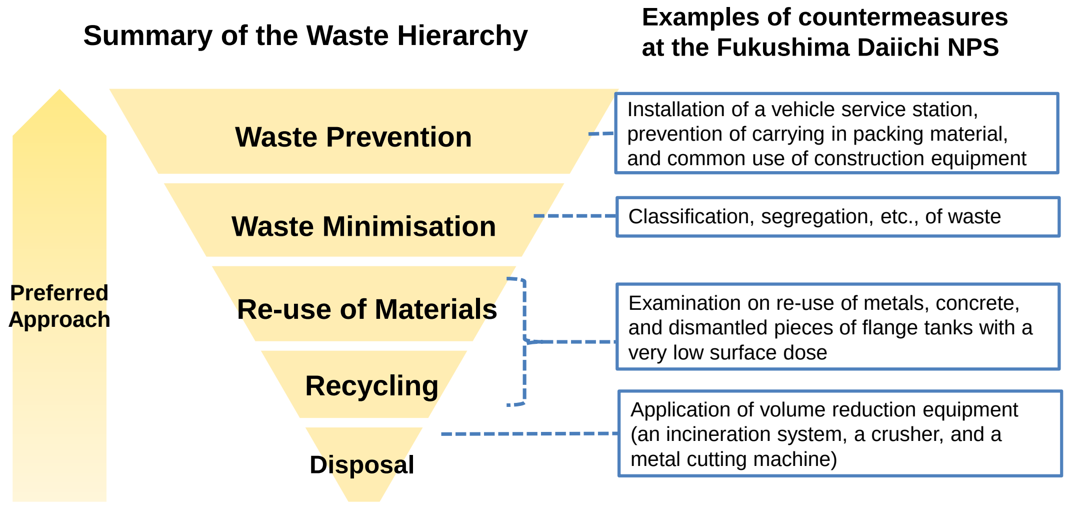
If a large volume of solid waste exists, not only does segregation and analysis take time, but the number of storage containers and the scale of storage facilities increase, and so does the load of waste management. Therefore, it is extremely important to reduce the physical volume of solid waste as much as possible.

At the Fukushima Daiichi NPS, it is important to instill initiatives on volume reduction, aimed at decreasing the burden of the overall solid waste management, into the overall decommissioning activities by referring to the examples of overseas countries that have implemented the waste hierarchy concept.

Specifically, the priorities for measures to be taken as waste management are 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 for volume reduction of waste to be stored, processed, and disposed of.

In terms of reducing waste generation, it is important to consider in the design and construction plan to reduce the volume of materials to be used. It is also important not to bring in substances that affect processing/disposal as much as possible. To minimize physical volume, consideration on preventing contamination through strict segregation, maintenance/management of manufactures, extension of product life, and waste volume reduction is important. Reuse should be promoted after contamination checks, decontamination, repair and parts replacement, and it is useful to consider ease of reuse from the design stage. Considering alternative uses is also beneficial. In recycling, it is important to consider the contamination condition of contaminated valuable sources, separate and process recyclable materials, and use them as new materials and products.

As shown in Fig. 9, TEPCO has also been implementing initiatives corresponding to this concept. As new measures to be implemented, among rubble accumulated outdoors (surface radiation dose rate ≦ 0.1 mSv/h), reuse/recycling of metals, concrete, and scrapped flanged tanks with extremely low surface radiation dose rates are under consideration. As part of this activity, decontamination methods for recycling metals are being examined. In promoting safe and reasonable waste management, it is important to examine further possibilities based on the characteristics of solid waste at the Fukushima Daiichi NPS in reference to precedent cases overseas.



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

Fig.9 Summary of waste hierarchy at the NDA, UK, and countermeasures at the Fukushima Daiichi NPS

b. Development of analytical/evaluation methods for implementing efficient characterization

Since the solid waste at the Fukushima Daiichi NPS is characterized by diverse nuclide compositions and activity concentrations, and a large physical volume, efficient characterization is required. With the aim of developing the analytical/evaluation methods necessary for this purpose, the Project of Decommissioning and Contaminated Water Management and other initiatives have developed analytical methods for simplified and speed-up data acquisition. Furthermore, as a method to perform characterization with small analysis data, the R&D program has established a method for quantifying uncertainties in evaluation values (to identify variable distribution and the width) using statistical method with a method for efficiently identifying the inventory in combination with analytical data and contamination mechanism.

As an analytical method for simplified and speed-up data acquisition, a method employing automation of pretreatment of analytical samples and the triple quadrupole inductively coupled plasma mass spectrometry (ICP-MS/MS) has been developed, which makes analytical methods simpler compared to conventional methods using radioactivity measurement. These results will be incorporated into the Building #1 of the Radioactive Materials Analysis and Research Facility under construction.

As characterization using statistical methods, in addition to using analytical data, statistical methods have been applied to the method for efficient characterization by combining with transition models, resulting in establishing the method to quantify uncertainties in evaluated values. A method that combines the Data Quality Objectives (hereinafter referred to as “DQO”) process with statistical methods has also been examined/tested to develop a medium-to-long-term analytical plan, and its effectiveness has been confirmed. In addition, a database called FRAnDLi (Fukushima Daiichi Radwaste Analytical Data Library) has been created, which contains information related to analytical data (sample information (type, sampling location, date, etc.) and analytical values of activity concentration, etc.), allowing data accumulation on a constant basis.

As described above, analytical/evaluation methods have been developed for efficient characterization and will be applied to characterization of solid waste.

c. Establishment of methods to reasonably select processing/disposal methods

In selecting processing/disposal methods in a reasonable manner, based on the waste properties, an appropriate combination of processing (waste form) and disposal (disposal facility) methods should be clarified so that the risk of buried solid waste to the public and environment can be maintained sufficiently low in the future.

In the case of solid waste from a normal reactor, its properties can be estimated to some extent by the previous findings (data) or analytical methods. Accordingly, the appropriate combination of processing (waste form) and disposal (disposal facility) methods can sufficiently reduce the risk to avoid a significant impact on the public and surrounding environment.

Even in the case of solid waste from the Fukushima Daiichi NPS, molten nuclear fuel is a major source of contamination, and the radioactivity concentration does not exceed that of spent fuel. Therefore, the risk can be sufficiently reduced by understanding the overall picture of the target solid waste (properties such as nuclide composition, activity concentration by waste, waste volume), and selecting a proper combination of processing (waste form) and disposal (disposal facility) methods, while utilizing the experience and knowledge on radioactive waste processing/disposal accumulated in domestic and overseas.

However, the overall picture of solid waste to be disposed of, including that which will be generated, will gradually become clear as the progress and plans for fuel debris retrieval, contaminated and water management, and other decommissioning work are clarified. Therefore, it is necessary to repeatedly examine processing/disposal methods and safety assessments, starting from the waste for which properties have been clarified; to give consideration to making processing/disposal methods more appropriate; and to accumulate knowledge to consider safe and reasonable processing/disposal methods for diverse solid waste collectively. Aiming for safer and not extremely conservative storage of waste with high mobility such as slurry waste, processing (preceding processing) for stabilization/immobilization may be required before determining the disposal method (disposal facility). Reprocessing would be necessary if the specifications of the waste form even after preceding processing did not conform to those required by the disposal method (disposal facility) to be determined. Therefore, in order to minimize such possibility, a selection method for the preceding processing method with disposal in mind is needed.

As mentioned below, study on an appropriate combination of processing and disposal methods, or preceding processing methods, is considered for the waste for which properties have been identified to some extent.

- Establish several feasible disposal methods suitable for waste characteristics (without specifying the feature of facilities such as their locations and sizes)
- In parallel, establish several processing methods suitable for waste characteristics to be considered, and set the specifications of waste form after applying each processing method.
- Evaluate the safety of several selected disposal methods based on the specifications of waste form after processing to verify whether risk to the public and environment can be sufficiently low, and to consider more effective processing/disposal methods based on the evaluation results.

The above examination steps are repeated to narrow down disposal methods and specifications for waste form after processing. Clarifying the overall characteristics of solid waste concurrently with characterization helps identifying an appropriate combination of processing/disposal. When preceding processing becomes necessary, candidate processing methods will be selected in consideration of the status of examination and open issues at that point.

It is also important to consider the period during which pre-disposal management is to be implemented, taking into account the risk reduction during that period, and examining necessary and feasible technologies. Since storage is important to provide flexibility to respond to the progress of processing/disposal, and to reduce radiation exposure of workers due to the decay of the radioactive materials, it is important to consider storage strategies as part of this examination process.

A series of these studies is represented as a flowchart shown in Fig.10. Technical knowledge and evaluation methods necessary for these studies (establishment of processing technology and waste form appropriate for waste, safe, reasonable and feasible disposal methods, disposal safety assessment) have been developed through research/development (verification of applicability of processing methods using engineering-scale test equipment conducted mainly on the secondary waste generated by water treatment, establishment of safe, reasonable and feasible disposal methods based on the waste properties and applicable processing technologies, and development of safety assessment methods) by the Project of Decommissioning and Contaminated Water Management, and has been established as a series of methods to select processing/disposal methods in a reasonable manner.

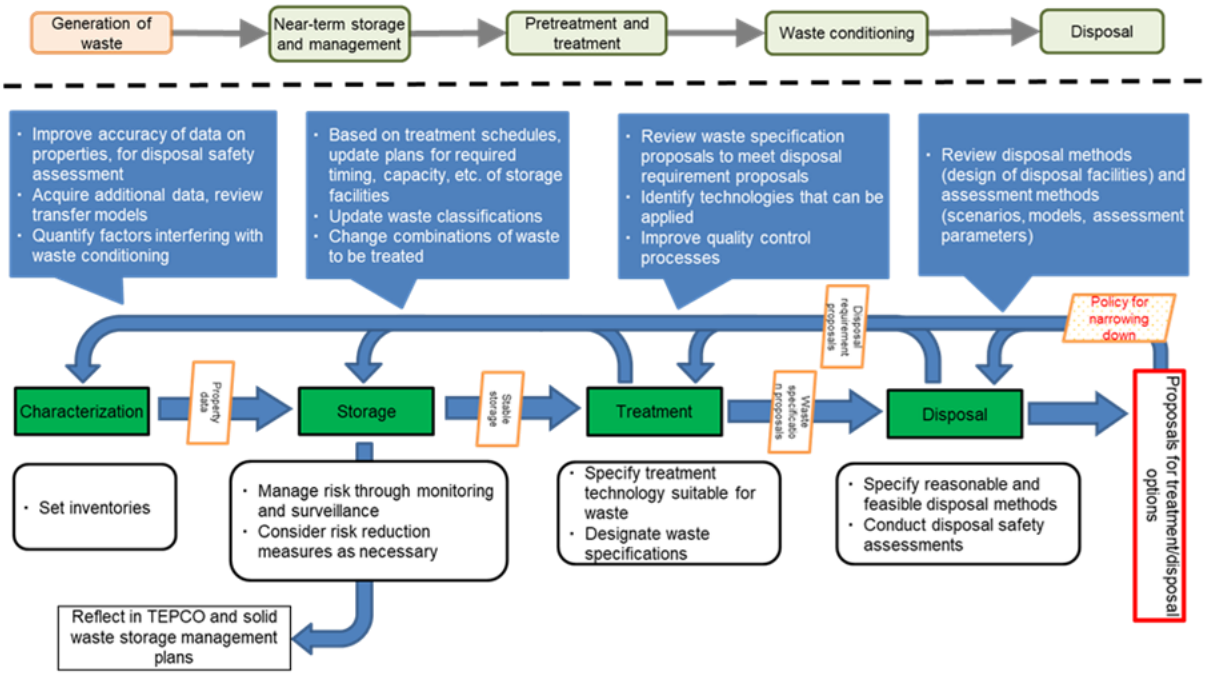


Fig.10 Development of methods to reasonably select safe processing/disposal methods of solid waste

ii. Key issues and technical strategies to realize them

After providing for future issues based on the prospects of a processing/disposal method and technology related to its safety, the technical strategies by category to realize them are show below.

(1) Issues based on the Technical Prospects

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

For the development of analytical/evaluation methods for efficient characterization, it is necessary to improve evaluation methods and continuously incorporate them into solid waste management, including processing/disposal, while accumulating analytical data using efficient analytical methods established through achievements in research/development. In this case, efforts should be made for low-activity waste such as rubble, as well as 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.

To establish methods to select safe processing/disposal methods in a reasonable manner, the methods shown in Fig.10 should be used to proceed with the examination toward the determination of waste form specifications and manufacturing methods for Phase 3, as specified in the Mid-and-Long-term Roadmap. Specifically, through these methods, the trial examples of optimization/rationalization of processing/disposal methods will be accumulated by waste stream according to the progress of characterization and with the assumption of ensuring safety to widely acquire findings on optimization by waste stream. Moreover, consideration will be given to specify strategies for optimization/rationalization of the overall picture covering the entire waste stream, allowing clarification of approaches toward such purposes. In doing so, it is important to flexibly consider the most appropriate measures, taking into account the actual use and economic feasibility by reflecting the newest findings and applying the concept of the Best Available Techniques. As the examination progresses, and the processing/disposal methods for the overall picture of waste are finalized, it will be important to share the examination process for optimization, such as by sharing the awareness of problems with local communities and society.

(2) Technical strategy by sectors

a. Characterization

For low-activity waste such as rubble, it is not so challenging to perform the analysis work itself. However, it takes an immense amount of time to measure entire quantity because of the enormous volume of waste, and therefore, volume reduction and a corresponding efficient analysis strategy are needed. For that purpose, it is important to take an approach that efficiently ensures the required accuracy. In order to achieve this, efficient analyses should be promoted by making them simplified/speed-up, and inventory evaluation methods that combine the DQO process with statistical methods be established.

For high-activity waste, sampling and analysis themselves are difficult, and the amount of analysis data to be obtained is limited. Thus, inventory assessment based on the transition model becomes more important. It is necessary to obtain actual sample data such as by the ongoing efforts for sampling from Cs sorption vessels and its analysis, which are currently in progress. The application of inventory evaluation methods, which combine the DQO process with statistical methods, and the priority of data to be collected should also be considered to enhance the accuracy of the transition model.

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

As for facilities for analysis, in addition to the existing facilities in the JAEA's Ibaraki area, etc., it is planned to establish the Radioactive Material Analysis and Research Facilities under construction, as well as facilities for analysis by TEPCO, allowing characterization of a variety of solid waste in parallel. Since the target nuclides, analysis items, accuracy, and the number of samples for analysis depend on the target solid waste, a structure should be established based on the appropriate division of roles and according to the characteristics of facilities.

b. Storage

For storage of all waste, 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 status commensurate with the risks involved.

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

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

In considering further possibilities of volume reduction, with an aim to reuse/recycle metals with extremely low surface radiation dose, chemical decontamination (decontamination by phosphoric acid), physical (mechanical) decontamination (steel blasting), and decontamination by melting (decontamination by melting slag), are under consideration as metal decontamination methods for recycling.

As metal recycling with decontamination by melting slag has already been used in many Western countries, it is considered a promising candidate technology. Thus, it is important to focus on the areas where the conditions are different between Western countries and the Fukushima Daiichi NPS (target nuclides, etc.), and to evaluate the applicability of the method.

c. Processing/disposal

The objective is to establish safe and reasonable processing/disposal methods for all solid waste in which diverse waste streams exist, and to widely obtain knowledge for optimizing each individual stream. Therefore, it is necessary to continue development/research of processing and disposal technologies required for the series of studies as shown in Fig.10.

Regarding the processing technology, outstanding issues in low and high-temperature processing technology, for which research/development is promoted, should be addressed. Waste streams, for which the application of low and high temperature treatment technologies has not been investigated, will be evaluated as necessary, and performance such as leachability for solidified substances to be produced will be evaluated. As for low-temperature treatment technology, consideration is given to transformation of solidified substances as well as inspection methods to verify the possibility of solidification. In the case of high-temperature treatment technology, the feasibility of the whole treatment 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 treatment. Furthermore, in order to expand technological options, it is important to examine the possibility of low-temperature solidification after interim treatment such as steam reforming.

Regarding disposal technologies, to establish reliable safety assessment techniques, important issues specific to solid waste at the Fukushima Daiichi NPS will be explored and identified based on the understanding of the sensitivity structure of parameters to radiation dose and the long-term transition behavior of disposal facilities. Then, priorities will be examined and incorporated into research plans. Development and improvement of the proposed disposal options, that combine a disposal concept proposal with waste to be disposed, will also be promoted in reference to practices at home and abroad. Furthermore, while improving the reliability of this, group of disposal options will be examined with a bird-view of all solid waste at the Fukushima Daiichi NPS, after expanding the target of waste streams, on which trial assessments, will be performed by applying safety assessment technology. Then, , contributions will be made to considering appropriate measures for overall waste management, in coordination with areas other than disposal such as presenting targets for waste form performance and the accuracy required for characterization.

The main technical issues and plans in the future described in this section are summarized as shown in Fig. 11.

The Mid-and-Long-term Roadmap states that properties of solid waste will be analyzed and the specifications and production methods of the waste form will be finalized in the third phase. As a systematic approach toward this goal in the first period of this phase, studies will be conducted to present appropriate measures for overall management of solid waste.

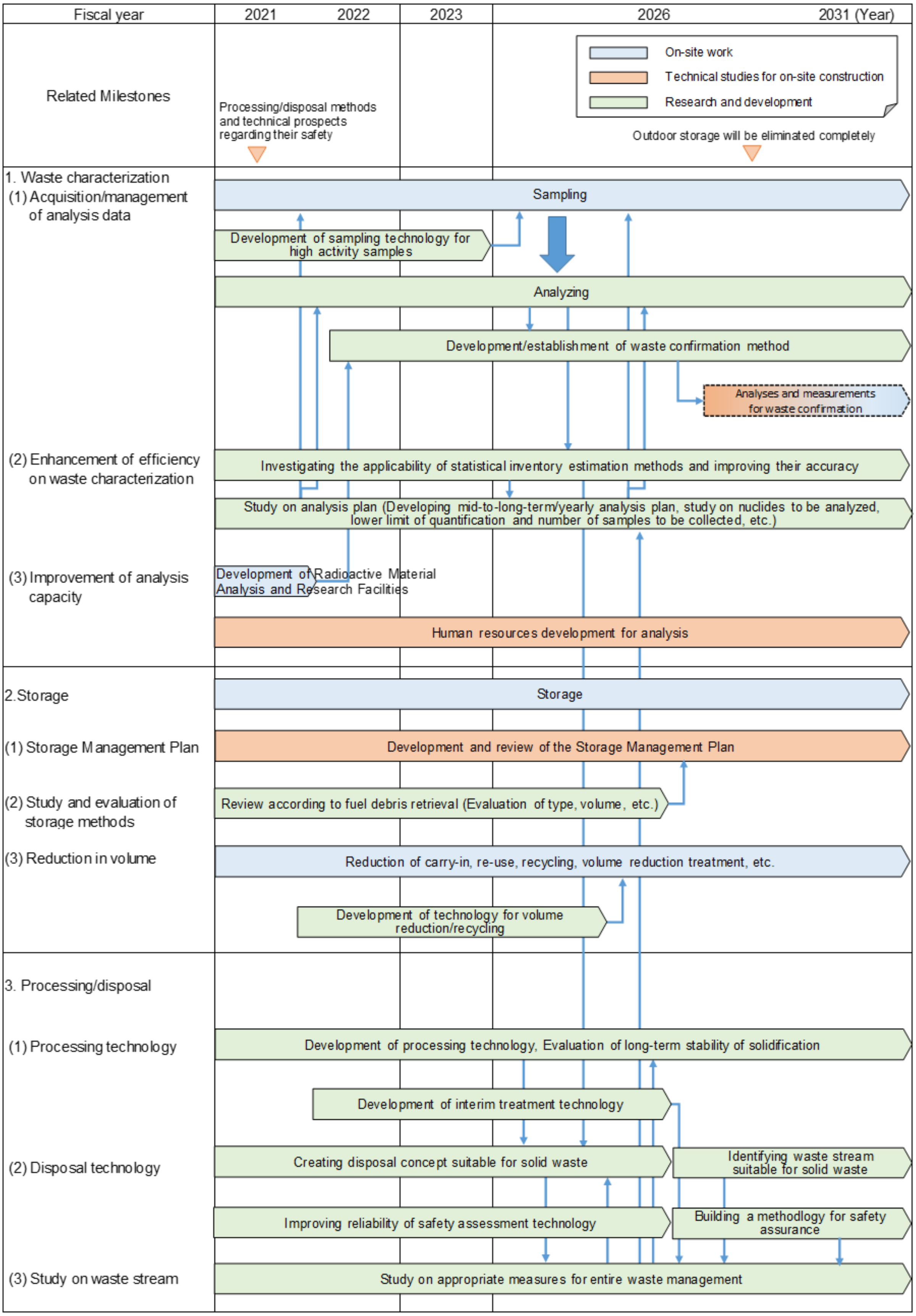


Fig. 11 Main technical issues and future plans on waste management (progress schedule)

3) Contaminated and treated water management

i. Targets and progress

(Targets)

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

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

(3) ALPS treated water currently stored in tanks will be handled in accordance with the basic policy announced by the government in April 2021.

(Progress)

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.

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

The groundwater level in the vicinity of the reactor buildings was stably controlled at low levels through multilayered contaminated water management such as land-side impermeable walls and sub-drains. The increase in the amount of contaminated water generated during rainfall also tended to be controlled by repair of damaged roofs and facings on site. As a result, the amount of contaminated water generated decreased from approx. 490 m3/day (FY 2015) before the measures were taken to approx. 140 m3/day (2020). In order to reduce the amount of contaminated water to 100m3/day or less, roof repair and expansion of facing range are being addressed while adjusting interference with other decommissioning work. Along with the completion of treating the remaining water, including ALPS-treated water, at the bottom of the flanged tanks in July 2020, measures and observation for risk reduction are being implemented through monitoring of groundwater and the harbor.

b. Efforts to complete stagnant water treatment

In 2020, the treatment of stagnant water in buildings, excluding the reactor buildings of Units 1 to 3, the process main building and high-temperature incinerator building was completed.

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

c. Efforts for stable operation of contaminated water management

The measures against tsunami have been implemented, including installation of tsunami tide walls in the Japan Trench; closure of building openings; reinforcement of land-side impermeable walls; and relocation of water collection systems such as sub-drains from the revetment side to higher ground. As a countermeasure for heavy rain, reinforcement of discharge functions of the existing drainage, etc. is underway.

d. Treated water management

For handling water treated with the multi-nuclide removal equipment (ALPS-treated water), discussions by experts, including technical aspects and the social impact, such as reputational damage, were held at a national subcommittee, and a report was published in February 2020. In April 2021, based on opinions from a wide range of people through subsequent opinion exchanges with local governments and agriculture, forestry, and fisheries industries, the Government announced the basic policy of discharging the ALPS-treated water into the ocean on the premise that safety will be ensured and that measures against reputational damage will be thoroughly taken, while TEPCO published “Actions by TEPCO in response to the Government’s basic policy on disposal of the treated water by multi-nuclide removal equipment”. Currently, the equipment needed and actions against reputation are under consideration.

ii. Key issues and technical strategies to realize them

(1) Issues in the future treatment of stagnant water in buildings

a. Prevention of spreading α-nuclides

At the bottom of the torus room of the reactor building, stagnant water containing α sludge and ionized α-nuclides exists, and relatively high concentration of α-nuclides has been detected (Fig. 12). These α-nuclides has significantly high effective dose factors when ingested by inhalation, and it is necessary to suppress this spread to a limited extent. At present, the properties of α-sludge and ionized α-nuclides are being analyzed, and removal methods for preventing the spread of α-nuclides are being studied. However, the chemical form of α-nuclides may change depending on water quality and coexisting substances. In order to ensure removal of α-nuclides, it is necessary to collect samples from as many places as possible and to understand the difference in their properties. Since α-sludge contains a high concentration of Cs -137, in addition, it is important to consider measures to reduce radiation exposure dose of workers, maintainability, and secondary waste.

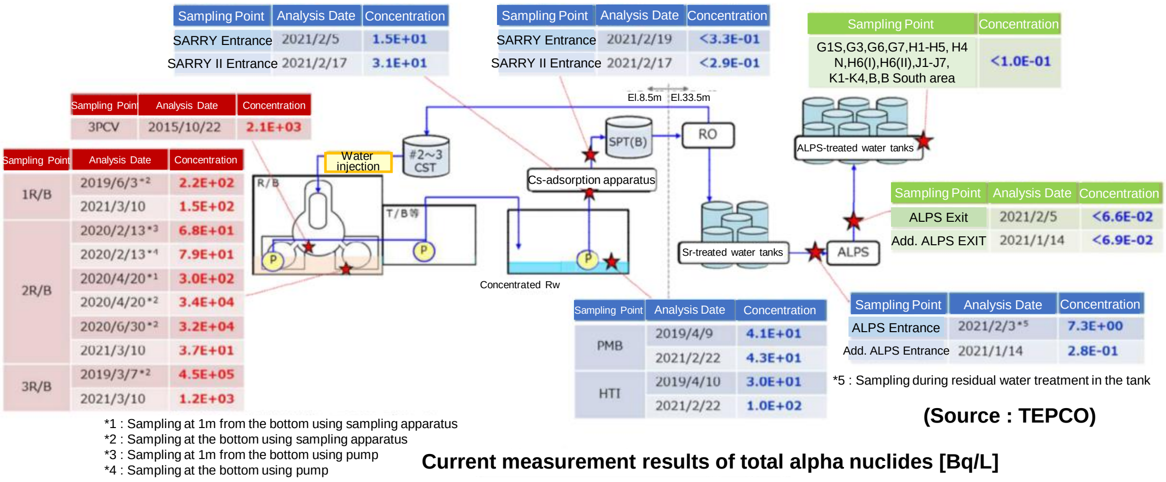


Fig. 12 Water treatment systems for stagnant water in buildings and measurement results of total α-nuclides

b. Treatment of high-concentration stagnant water

In treating stagnant water in buildings, water at the bottom of the buildings has not been pumped. Therefore, not only α-nuclides but also highly concentrated stagnant water containing radioactive materials and salt, which is close to the state immediately after the accident, exists at the bottom of the torus rooms of the reactor buildings. The S/C also contains contaminated water with higher concentration of radioactive materials and salt than usual stagnant water.

It is necessary to dispose of contaminated water containing such high concentration of radioactive materials and salt as soon as possible in terms of risk reduction. In order to suppress the fluctuation range of the contaminated water concentration for the stable operation of the water treatment system, however, contaminated water of high concentration and that of low concentration are mixed for treatment. For this reason, in order to accelerate the treatment of highly contaminated water, it is necessary to proceed steadily with careful planning that takes into account the water balance with low-concentration contaminated water.

(2) Issues of contaminated water management considering the decommissioning process such as fuel debris retrieval

a. Handling of high-concentration α-nuclides

The possibility that fine particles containing high-concentration α-nuclides are produced and mixed into the water treatment system in association with cutting, fabrication, etc., of fuel debris cannot be denied. Therefore, it is necessary to take measures, such as strengthening the monitoring of water treatment systems, installing collection systems for fine particles containing α-nuclides, and monitoring for criticality. Further, in handling such α-nuclides, the chemical characteristics of actinide elements constituting the α-nuclides needs to be sufficiently understood. Actinide elements change into various chemical forms depending on the water quality, and the dissolution rate tends to increase significantly especially in the oxidizing environment. Therefore, it is important to understand and control the water quality. When examining the method of removing α-nuclides, moreover, more effective designing becomes possible by sampling even a small amount of actual liquid at an early stage and conducting performance verification using samples. It is necessary to evaluate the safety of recovered high-concentration α-nuclides from the perspective of criticality, heat generation, radiation dose, hydrogen generation, and waste management.

b. System configuration for sustainable stable operation

The water treatment system at the time of fuel debris retrieval needs to secure reactor cooling water and purify a large amount of radioactive materials containing α-nuclides. Therefore, as a whole system, it is recommended that the cooling water circulation system has a simple system configuration that focuses on reliability. For the purification system which has a complex configuration, it is recommended to have a system configuration that takes and purifies a portion of contaminated cooling water, enabling both purification and supply of reactor cooling water. As for the purification system equipment, it is necessary to consider the evaluation of the volume of secondary waste generation and maintainability under a high radiation dose, as well as the evaluation of purification performance, and to examine purification methods in the medium-and-long term. In particular, system planning for the entire purification system equipment should be promoted with the view to improving and updating existing systems, based on the operation experience of existing systems, changes in the water quality environment up to the present, and predictions of changes.

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

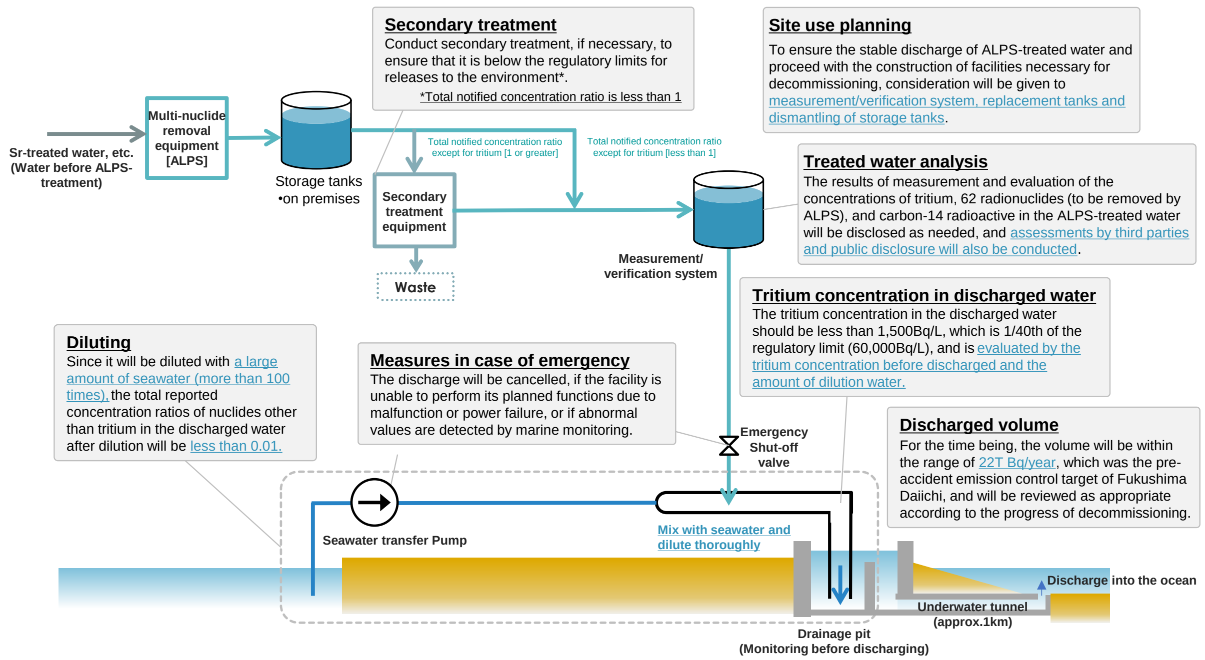
While the current contaminated water management is shifting to a certain stable state, in addition, it takes a long time to complete fuel debris retrieval. Along with the selection of methods for further expanding the scale of fuel debris retrieval currently in progress, it is important to see a medium-and-long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

(3) Issues for discharging ALPS-treated water into the ocean

The announced Government policy on discharge of ALPS-treated water aligns with the international concept, and is an important decision in terms of ensuring the sustainability of decommissioning work. In particular, discharging ALPS-treated water into the ocean enables reduction of risks associated with tank storage and allocation of limited resources to other high-risk operations, contributing to the steady progress of decommissioning work.

On the other hand, it is also a fact that there have been concerns about reputational damage due to the discharge of ALPS-treated water into the ocean. Therefore, efforts should be continued to deepen understanding to eliminate such concerns. The reliability of TEPCO has declined due to inappropriate incidents in terms of physical protection of nuclear materials at the Kashiwazaki-Kariwa Nuclear Power Station and insufficient provision of information during earthquakes at the Fukushima Daiichi Nuclear Power Station. TEPCO needs to take this reality seriously and respond more carefully than before. One of the reasons for this incident might be insufficient communication with local communities and commercial distributors. Therefore, greater transparency is required, for example, by repeatedly providing explanations in an easy-to-understand and careful manner, mainly by TEPCO, in order to increase understanding of (1) an operation plan for offshore discharge; (2) the effects of tritium contained in the water to be discharged to the ocean on the human body; and (3) the method for verifying the operation status as the basics for implementing safe offshore discharge, and by verifying these through reliable third parties such as IAEA in cooperation with organizations concerned, and by delivering accurate information.

[Conceptual diagram of the discharging system]



(TEPCO material edited by NDF)

Fig. 13 System for discharging ALPS-treated water into the ocean

① Operation plans for offshore discharge

The conceptual diagram of the discharge system planned by TEPCO is shown in Fig.13. In this discharge facility, the concentration of radioactive materials other than tritium in the ALPS-treated water is confirmed to be below the regulatory standard value for the discharge to the environment in the measurement and verification facilities. Then, the discharged water is mixed and diluted with seawater so that the tritium concentration is less than 1,500 Bq/L, which is 1/40 of the regulatory standard value (60,000 Bq/L).

Then, the diluted water is planned to discharge into the ocean from the discharge outlet through an underwater tunnel, as well as to perform marine monitoring. A set of discharge systems covers from [purification], [analysis/verification], [dilution], [discharge] to [continuous monitoring in the sea area]. In addition, an emergency shut-off valve is planned to be installed in the process between [analysis/verification] and [dilution] so that the discharge can be suspended in the event of system failure or detection of any abnormal values during marine monitoring.

This discharge system planned by TEPCO is based on the past results in Japan and overseas, and safe offshore discharge will be possible by ensuring that these results are reflected in the system, developing operational procedures and manuals for equipment operation and analysis, thoroughly educating, training, and observing operators, and strictly adhering to the implementation plan. By strictly following the implementation plan, safe offshore discharge will be possible.

② The effects of tritium contained in the water to be discharged to the ocean on the human body

The annual discharge of tritium is planned to be within 22 trillion Bq, a target value of controlling discharge set by the Fukushima Daiichi NPS before the accident. Tritium is a radioisotope of hydrogen, and is contained in any water, including water vapor in the atmosphere, rainwater, seawater, tap water, and even in the human body. In addition, its properties are similar to those of ordinary water molecules. As its characteristic, therefore, it is difficult to separate tritium from water. The impact of tritium on the human body due to the disposal of ALPS-treated water has also been evaluated using the UNSCEAR method, and it has been confirmed that the impact is extremely small compared with that of natural radiation (2.1 mSv/yr). TEPCO will review the annual discharge of tritium according to the progress of decommissioning, etc.

③ The method for verifying the operation status

In the operation phase, it is necessary to confirm that the planned facilities are installed and operated reliably, that the analysis is conducted reliably in accordance with the established procedures, etc., and to publish the results.

Moreover, it is necessary to increase the transparency of the implementation status of the plan by involving third parties other than TEPCO in analysis/verification before the discharge, and marine monitoring after the discharge. For third-party involvement, it is important to develop a quality assurance system because the results may vary depending on the institution and facility for analysis due to the fluctuation of the lower detection limit caused by the detection accuracy of measuring instruments or analysis techniques. It is also necessary to consider a structure for verifying the operation status of the developed system.

TEPCO's planned discharge system, if operated reliably in accordance with the implementation plan approved in the review by the NRA, will have no adverse effects on humans and the environment, including other radionuclides, and therefore it is an important issue to operate the system "reliably" “as planned”. Going forward, TEPCO will need to proceed with the following preparations; they include developing of a specific system plans for system and its operation, education and training on system operation and analysis, etc. for parties concerned, impact assessment on the human population and the natural environment, development of strategies to provide accurate and understandable information domestically and internationally, and timely dissemination of the status of preparations. During actual operation, it is necessary to ensure the implementation of the plan (system, operation, information distribution, etc.) established in the preparation stage, to perform check and review, and to review and expand the plan as needed, as well as to ensure its transparency.

NDF will provide technical and professional support for TEPCO in designing the discharge system and considering discharging methods, while promoting distribution of accurate information and increasing understanding through various opportunities in Japan and abroad in line with changes in the interests of those who will receive the information. We will also make sure that TEPCO implements measures to minimize reputational damage, and that TEPCO takes appropriate and sufficient actions with compensation in the event of reputational damage.

The main technical issues and plans described in this section are summarized as shown in Fig. 14, and Fig. 8 shows the future plans for the water treatment system for fuel debris retrieval.

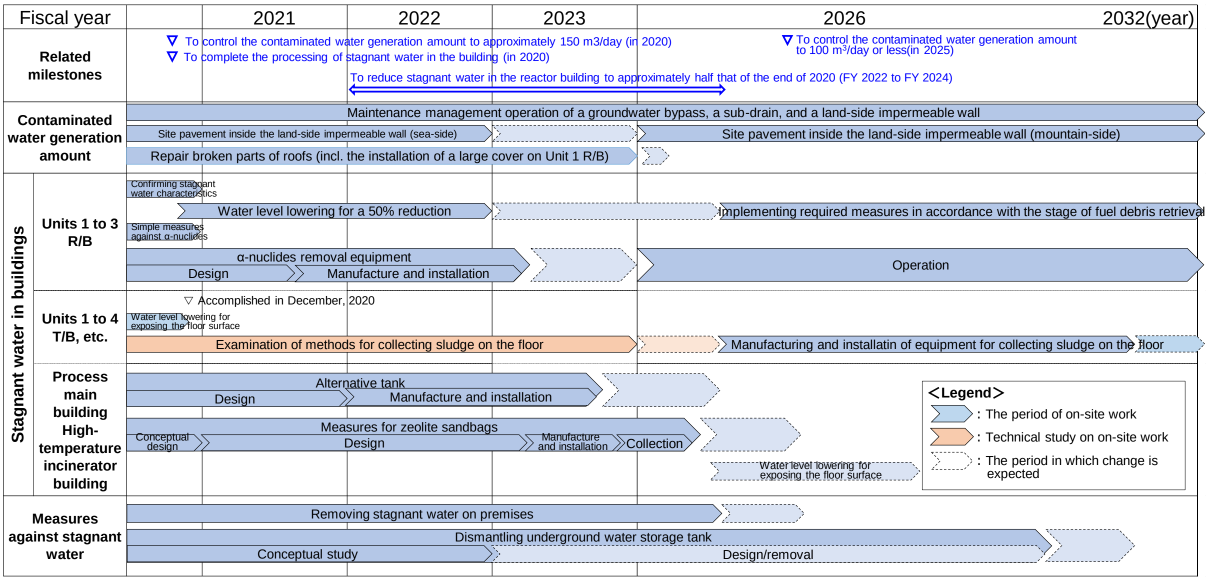


Fig.14 Key technical issues and future plans on contaminated water management (progress schedule)

4) Fuel removal from spent fuel pools

i. Targets and progress

(Targets)

(1) While the return of residents and reconstruction in the surrounding area is gradually advanced, to carry out a risk assessment and ensure safety including preventing dispersion of radioactive materials and to start removal of fuel in SFPs in FY 2027 to FY 2028 for Unit 1 and FY 2024 to FY 2026 for Unit 2. To complete fuel removal from SFP in FY 2020 for Unit 3. (Completed in February 2021)

(2) The fuel in Units 1 to 4 that were affected by the accident are retrieved from the SFPs and transferred to the Common Spent Fuel Storage Pool, etc., where they are appropriately stored so that they are in a stable management state. In order to secure the Common Spent Fuel Storage Pool capacity, the fuel stored there is transferred to and stored in Dry Cask Temporary Custody Facility.

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

(Progress)

In Unit 1, removal of the building cover (remaining parts) that interferes with installation of the large covers has been completed, and installation of the large covers is in progress within the area where the cleanup around the reactor building has been completed. In addition, in order not to affect fuel in SFPs, measures to prevent and mitigate the dropping of rubble, such as installation of supports for overhead cranes and fuel handling machines, and curing of the SFP, were completed in November 2020.

For Unit 2, yard cleanup and soil improvement work are underway as preparatory works for installing the fuel removal platform. In addition, based on the measurement results of the air dose rate and surface contamination of the operating floor conducted in March and April 2021, decontamination of the operating floor is ongoing to further reduce radiation dose.

Removal of all fuel from Unit 3 was completed in February 2021. It is important to roll out the knowledge and lessons learned from this experience concerning procurement and remote control to planning and implementation of future decommissioning work. Therefore, TEPCO has compiled internal documents for reference, organizing their results, including efforts for troubleshooting and recurrence prevention. Moreover, as part of its approaches to strengthen quality control, TEPCO has revised the “Basic Design Management Manual” common to all Fukushima Daiichi NPS to improve its design and procurement processes.

For Units 5 and 6, fuel will be appropriately stored in the SFPs of the units for the time being. Then, they will be retrieved in a range so as not to affect the work in Units 1 and 2.

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

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

ii. Key issues and technical strategies to realize them

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

(1) Fuel removal from SFPs

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

For Unit 1, although overhead crane support is installed for fall prevention, it is still in an unstable state. Therefore, removing the overhead crane in a safe and reliable way is one of the main issues to prevent it from collapsing onto the fuel handling machine and falling into SFP.

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

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

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

(2) Decision of future treatment and storage methods

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

The main technical issues and plans described in this section are summarized as shown in Fig. 15.

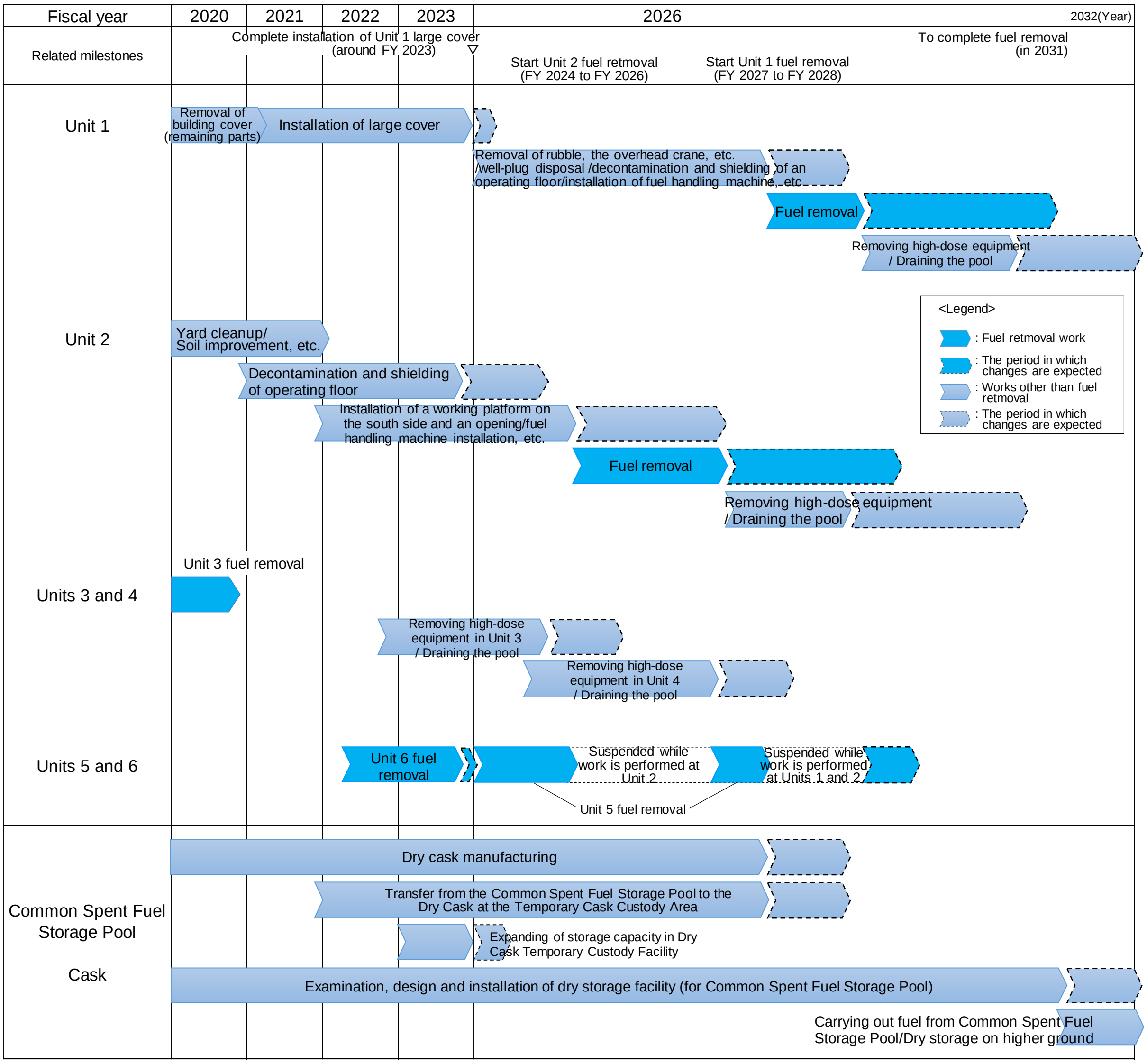


Fig. 15 Key technical issues and future plans for fuel removal from SFPs (Progress schedule)

4 Analysis strategy for promoting decommissioning

1) Uncertainty of fuel debris, etc. and importance of analytical results

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

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

2) Three elements of analysis strategy

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

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

3) Current status of establishing an analysis system and strategy

As an essential facility for decommissioning of the Fukushima Daiichi NPS, the JAEA is proceeding with the construction of Radioactive Material Analysis and Research Facilities (facility management building, building #1, building #2) adjacent to the Fukushima Daiichi NPS under the supplementary budget of the Government (FY2012). At commencing operations in buildings #1 and #2, they will be designated as controlled areas of the Fukushima Daiichi NPS, which has the advantage that off-site transportation is not required. Leveraging this, it is effective to promptly identify basic physical properties, and incorporate them into safety assessment and work procedures. The purpose of building #1 is to analyze solid waste, and building #2 is to analyze fuel debris. The facility management building began its operation from 2018, building #1 commenced comprehensive functional tests from February 2021, and building #2 is undergoing safety review. However, the operation start of building #1 scheduled for June 2021 has been delayed due to a malfunction of the air supply/exhaust system. Therefore, it is necessary to examine further utilization of facilities for analysis in the Ibaraki area and to organize division of roles according to the characteristics of the facilities for analysis in and near the Fukushima Daiichi NPS and those in the Ibaraki area. However, since all the facilities for analysis in the Ibaraki area have been in operation for more than 30 years, considerations on measures are required for aging facilities that will be used continuously.

Not only the facilities for analysis in the Ibaraki area, but also the Radioactive Material Analysis and Research Facilities to be operated in the area adjacent to the Fukushima Daiichi NPS are short of the human resources required for stable facility operation, and the securing and maintaining of analytical engineers needs to be considered. In this respect, it is necessary to consider in advance the qualities expected of analytical engineers in various analytical works, and to develop a plan so that the required roles are appropriately achieved. In order to develop human resources for fields where there is little experience in as short a time as possible, it is necessary for TEPCO to promptly work on developing analytical technicians with the cooperation of JAEA and Japan Nuclear Fuel Limited that have accumulated sufficient knowledge and experience on the handling of α-nuclides and fuel analysis techniques. Since there are few talented personnel (analysis evaluators) who can design the analytical range and items in anticipation of how to use the analysis results in advance, it is also important to make efforts in increasing such personnel.

4) Improvement of the quality of analysis results, diversification and expansion of analysis methods

i. Improvement of the quality of analysis results

Fuel debris contains difficult-to-measure nuclides, interfering elements, insoluble materials, etc., and it is considered difficult to conduct complete composition analysis. It is also an important perspective to question the analytical result of the samples in consideration of the impact of the error factor. Monitoring data, sampling analyses, PCV internal/on-site investigation, analyses using SA codes, and past knowledge and experimental results have been accumulated. As part of verification of sample analysis results, deriving consistent property evaluations in reference to analysis, surveillance and test results leads to improving reliability of analysis results, and thereby quality of the analysis results.

Fuel debris caused by the accident is a mixture of fuel and materials in the core. It is important to comprehensively review/evaluate at what stage of the accident progression the substance was produced, what elements were mainly contained, and what properties they have. This also enables provision of feedback on instructions for necessary sampling to cascade analysis results, instead of unnecessarily increasing the number of samples to be analyzed. As shown in the conceptual diagram shown in Fig. 16. it is expected that a flow will be established from [(1) Fuel debris sampling], [(2) Sample analysis], [(3) Evaluation of the characteristics] to [(4) Safety Assessment] and the cycle from [(1) Fuel debris sampling], [(2) Sample analysis], [(3) Evaluation of the characteristics] to [(6) Instructions for the next sampling]. TEPCO and JAEA are already cooperating in implementing forensic activities that estimate accident behavior and causes by comparing the results of sample analyses with mock-up testing on progression of meltdown and past scientific knowledge, and it is recommended to further expand these activities.

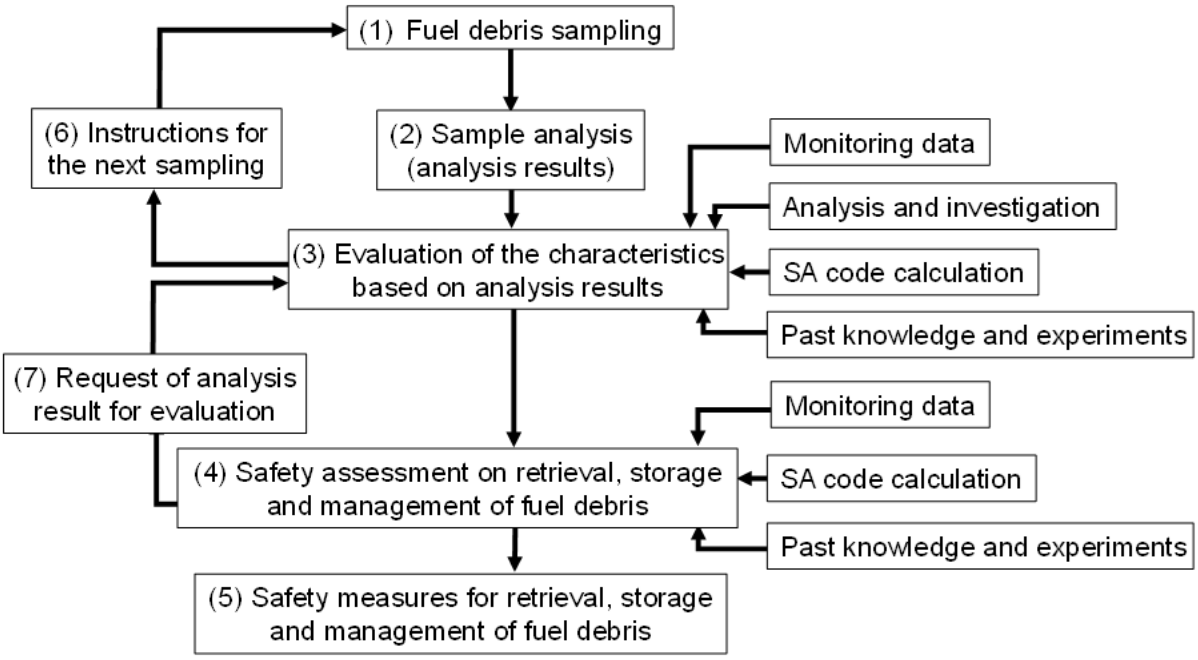


Fig. 16 Conceptual diagram from fuel debris analysis to evaluation/countermeasures

ii. Diversification and expansion of analysis methods in light of sample size and quantity constraint

The current sample analysis is mainly performed using an electronic microscope after transporting smear samples to a facility for analysis in Ibaraki area. Since the density, hardness, and other items cannot be measured for micro or small samples, it is necessary to increase the size and quantity of the samples in accordance with the progress of the fuel debris retrieval process. It is difficult to analyze a sufficient number of samples because the analysis is performed by using a manipulator in each process in a hot cell, and by about 0.5 to 1 samples per month in one facility. Consequently, there is a large gap between the amount to be retrieved/stored and the amount to be analyzed.

Since fuel debris has heterogeneity, the analytical values vary depending on the sampled parts, and the situation is such that a sufficient amount of fuel debris cannot be analyzed, resulting in a wide range of uncertainty in evaluation. It is effective to diversify and expand the analysis methods and to perform comprehensive evaluation in order to increase good analytical results, regardless of the restrictions on the improvement of analysis quality and sample quantity. For example, in addition to performing unsealed sample analysis in a facility for analysis, it is recommended that in-situ analysis (simplified analysis) and non-destructive measurement are performed to increase the amount of information on the sample, including coordinating information during collection, and to consolidate the results to perform evaluations for controlling the range of uncertainty within a certain level. However, there are no practical examples of in-situ analysis or non-destructive measurement of fuel debris, and remote operation is required because of the high radiation dose of the subject. Therefore, it is necessary to promote research and development focusing on specific items such as uranium content.

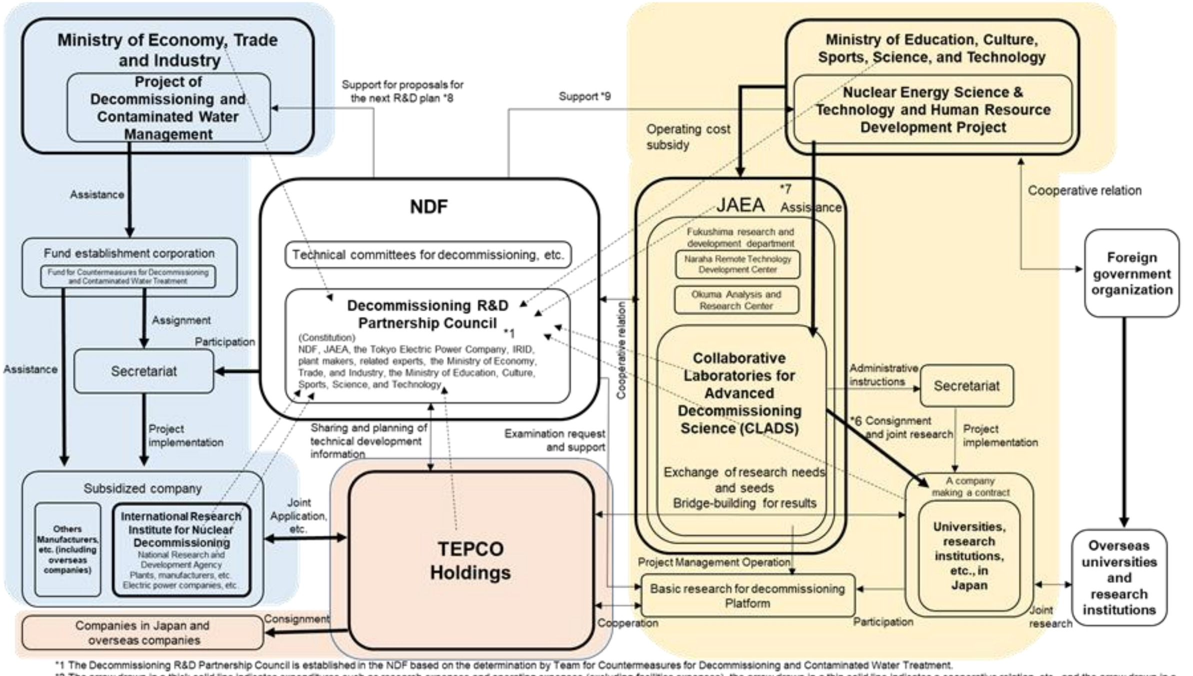
5 Efforts to facilitate research and development

1) Significance and the current status of research and development

There are many difficult technical issues requiring research and development to promote the decommissioning of the Fukushima Daiichi NPS from the perspectives of safe, proven, efficient, timely, and field-oriented. At present, when trial retrieval of fuel debris is imminent, it is necessary to accelerate research and development in consideration of the practical application for a gradual expansion of retrieval scale and further expansion of fuel debris retrieval.

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

The Government is supporting highly-difficult ones among application research, practical application research and field demonstrations by “the Project of Decommissioning and Contaminated Water Management”, and ones regarding basic/fundamental research by “The Nuclear Energy Science & Technology and Human Resource Development Project (hereinafter referred to as "World Intelligence Project")”. TEPCO is engaged in technical development directly leads to practical application. NDF considers R&D medium-to-long term plans, next-term R&D plans, and promotes these plans and supports the World Intelligence Project. With institutes involved as its members. Moreover, NDF has established the Decommissioning R&D Partnership Council, which considers information sharing on needs and seeds for R&D, adjustment of R&D based on the needs of decommissioning work, and issues on promoting cooperation in R&D and human resource development. Based on the discussions at this council, NDF set up “a task force on research collaboration”, and identified six Essential R&D Themes mainly in the area of basic/fundamental research to be addressed with priority, in light of investigational issues and problem awareness on the side of the needs. The R&D implementation system is shown in Fig. 17.



*1 The Decommissioning R&D Partnership Council is established in the NDF based on the determination by Team for Countermeasures for Decommissioning and Contaminated Water Treatment.
*2 The arrow drawn in a thick solid line indicates expenditures such as research expenses and operating expenses (excluding facilities expenses), the arrow drawn in a thin solid line indicates a cooperative relation, etc., and the arrow drawn in a dotted line indicates the participation in the Decommissioning R&D Partnership Council.
*3 Some organizations such as JAEA are located at two or more places.
*4 Each organization has cooperative relations with foreign organizations based on MOU, etc., respectively.
*5 Research and development uniquely conducted by the Central Research Institute of Electric Power Industry, etc., are omitted in this figure.
*6 Although among the World Intelligence Project for Nuclear S&T and Human Resource Development the part adopted up to FY 2017 is the consignment from the Ministry of Education, Culture, Sports, Science, and Technology to a company making a contract, it is omitted in this figure.
*7 Although the subsidy for the World Intelligence Project for Nuclear S&T and Human Resource Development is delivered to JAEA, it is expressed as what is delivered to CLADS, to make it easier to understand.
*8 With regard to the Government-led Project of Decommissioning and Contaminated Water Management, based on the policy in the Mid-and-Long-term Roadmap or Strategic Plan and the progress situation of research and development, the NDF formulates a draft plan of the next research and development, and the Ministry of Economy, Trade, and Industry determines it.
*9 The NDF participates as a member in a steering committee of the World Intelligence Project for Nuclear S&T and Human Resource Development.

Fig. 17 Overview of the R&D implementation system related to the decommissioning of Fukushima Daiichi NPS

2) Key issues and strategies

i. Updating the R&D medium-and-long term plan

In October 2020, NDF and TEPCO developed the R&D medium-to-long-term plan overlooking the overall research and development for about ten years for decommissioning. The R&D medium-to-long term plan has been updated based on the Mid-and-Long-term Decommissioning Action Plan 2021 revised in March 2021, Progress in R&D and Prospect of Processing/disposal methods and technology for waste related to its safety.

In reviewing the R&D medium-to-long term plan, TEPCO, the Agency for Natural Resources and Energy and NDF have held R&D planning meeting, and also shared the plan with the Ministry of Education, Culture, Sports, Science and Technology (MEXT) to discuss the required results and timing, and implementation system, etc.

ii. Initiatives for the Project of Decommissioning and Contaminated Water Management

(1) The Project of Decommissioning and Contaminated Water Management

The Ministry of Economy, Trade and Industry is providing support through the Project of Decommissioning and Contaminated Water Management for research and development to solve technical issues that are difficult to solve in decommissioning.

Since last fiscal year, NDF has been participating in the secretariat to strengthen the functions of project planning and progress management, while TEPCO jointly applies for issuance in cooperation with research leadership and provides project management to incorporate requirements in terms of actual site applicability. As a result of strengthening this system, project proposals have been made, which incorporate TEPCO's on-site needs and actual site applicability in more detail, and the projects have been executed so that the results of such proposals can be effectively applied to the engineering work by TEPCO.

While actively participating in this system, it is important for TEPCO to increase their focus on their own R&D activities, and strengthen their structure. In August 2021, TEPCO has enhanced the system to promote the examination and implementation of technology development in the future.

(2) Next-term R&D Plan

In order to support the Project of Decommissioning and Contaminated Water Management, based on the R&D Medium-to-long-term plan, every fiscal year NDF discusses the research and development to be carried out in the next two years with the parties concerned at the R&D planning meeting, and then develops the Next-term R&D Plan . The plan is first deliberated on by the Fuel Debris Retrieval Expert Committee and Waste Management Expert Committee, and then by the Decommissioning Strategy Committee. After this, it is summarized as an NDF proposal. This plan was reported by the Ministry of Economy, Trade and Industry (METI) to the Secretariat Meeting of the Team for Countermeasures for Decommissioning, and Contaminated Water/Treated Water Treatment, then, The Project of Decommissioning and Contaminated Water Management has been implemented accordingly.

In considering the next-term R&D plan, it is necessary to evaluate the R&D results to date, moreover, to identify issues that should improve its achievement and issues to be newly addressed, as well as to identify emerging issues and organize technical issues with a view to the R&D Medium-to-long-term plan. When identifying the issues, it is also important to identify them exhaustively, to confirm whether each issue is in line with the needs of TEPCO, as the entity responsible for decommissioning, and to aim for the R&D results to be used for TEPCO's engineering.

(3) Research and development implementation system for the Project of Decommissioning and Contaminated Water Management

The IRID has played a major role in research and development for decommissioning for about ten years since the time that the post-accident situation inside the reactors was unknown. In particular, the IRID has established a good track record in internal PCV condition analysis through its internal investigations, and in developing fuel debris retrieval equipment and storage containers.

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

In the Project of Decommissioning and Contaminated Water Management, it is important to establish a proper R&D implementation structure. The continuity of R&D activities that have been conducted mainly by the IRID should be ensured (including accessing its R&D results), and researchers/developers should cooperate more closely with TEPCO.

iii. Promotion of cooperation between decommissioning sites and universities/ researching institutions

(1) The Nuclear Energy Science & Technology and Human Resource Development Project

As the World Intelligence Project since FY 2015, the MEXT has been promoting fundamental/basic research and human resource development activities, which contribute to solving issues such as decommissioning of the Fukushima Daiichi NPS. The project is bringing together domestic and overseas intelligence from universities/researching institutions, crossing barriers of the nuclear field, and through close coordination and alignment including international joint research . From new subjects adopted in 2018, the leadership was transferred from the MEXT to JAEA/CLADS to strengthen cooperation between JAEA/CLADS and universities, and establish a system to implement medium-and-long term R&D and human resource development, contributing to decommissioning more stably and continuously.

In soliciting applications for the current World Intelligence Project, JAEA/CLADS is using the "overall map of the basic/fundamental research", which provides an overview of the entire decommissioning process from contaminated water management to waste processing/disposal, including these 6 Essential R&D Themes, and identifies the R&D needs and seeds required.

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

Some basic/fundamental research contributing to problem-solving in on-site decommissioning have recently obtained outstanding research results mainly in the World Intelligence Project. It is an important issue to directly apply the results in on-site of decommissioning. At the 9th Decommissioning R&D Partnership Council held in February 2021, it was proposed that the MEXT and METI work together to resolve decommissioning issues to further deepen needs-driven R&D. In response to this, it is important to further strengthen ties by sharing R&D planning meetings and the results of both projects, and to deepen alignment between the World Intelligence Project and the Project of Decommissioning and Contaminated Water Management. In this manner, the Decommissioning R&D Partnership Council is required to continuously serve as a general coordinator, such as by promoting effective alignment between the R&D seeds and the needs of the decommissioning work as the initial task of the Council.

Since FY 2019, TEPCO has also started joint research with universities based on the results of the World Intelligence Project to discover the technological seeds owned by universities for decommissioning. The Government, JAEA/CLADS, NDF, TEPCO, and other organizations involved need to further strengthen their cooperation for better matching needs with seeds and serve as a bridge to share outcomes.

(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 technologies and collect basic data, building up research centers, facilities and equipment, and human resource development.

In the building for International Research Collaboration of JAEA/CLADS (Tomioka-machi, Fukushima Prefecture), universities, researching institutions, industries, etc., inside and outside Japan form a network and promote research and development and human resource development in an integrated manner. The “Program for Decommissioning Research by Human Resource Development” was newly established in the World Intelligence Project in FY 2019. It created a hub of research and human resource development (Collaboration laboratory) in both educational researching institutions and JAEA/CLADS, and has started R&D and a human resource development project that connects these organizations by cross-appoint system. It contributes to functional enhancement of JAEA/CLADS bases.

For research and development infrastructures as hardware, development and utilization of the Naraha Remote Technology Development Center of JAEA and construction of the JAEA Okuma Analysis and Research Center (Radioactive Material Analysis and Research Facility) are ongoing.

6 Activities to support our technical strategy

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

i. Significance and current status of project management

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

The individual work in each work area of a decommissioning project generally proceeds through the following processes: research and development, conceptual design, basic design, detailed design, manufacturing, on-site installation, inspection, and operation. In addition, the Nuclear Regulation Authority (NRA) will conduct reviews and inspections, as necessary. In order to carry out such a series of processes without omission or delay, it is effective to set up the major workflow defined in the long-term plan as individual projects, which are management units of an appropriate scale. It is then important to optimize the interrelationships and chronological relationships among the projects, and to proceed with overall consistency under a sophisticated project management system so that the risks inherent in the projects can be appropriately managed. From this perspective, TEPCO has been working to build and strengthen its project management system, and in April 2020, then it was reorganized, and the general framework of the management system and the structure was established. Examples of major approaches until FY2020 include strengthening the authority of project manager through reorganization, improving safety and quality levels, preparing a plan focusing on long term perspective (Med-to-Long-term Decommissioning Action Plan) and formulating R&D medium-to-long-term plan, etc.

ii. Key issues and strategies to be strengthened in the future

(1) Safety and Operator’s Perspectives and promulgating the "Safety First”

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

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

In order to establish safety an organizational culture, not only a slogan, it is not enough to just ask employees to prepare themselves, but each and every employee needs educational materials and opportunities to learn about safety in a systematic way.

(2) Owner's engineering capability

In iterative engineering, the contract between the project executor and the supply chain is not conventional, so TEPCO, as a project executor, is strongly required to "make a judgment on engineering and is responsible for the results". To do so, in addition to project management capability, TEPCO needs to improve the capabilities that the project executor should have, to optimize the entire supply chain, specifically the engineering ability that TEPCO, the project executor, proactively performs as the owner (owner's engineering capability) such as the ability to make engineering judgments, the ability to evaluate business risks, and the ability to specify order specifications. For example, in the evaluation of fuel debris retrieval method selection, it is necessary to evaluate from the viewpoints of quality (fuel debris retrieval status, safety, etc.), project (cost, time and other visions), and technical feasibility. Alternatively, a project that would previously have been ordered by a single company can be divided among multiple companies, and TEPCO can oversee and manage the entire construction. It is also important for the enhancement of owner's engineering abilities to accumulate and feedback various field experiences, such as by these activities and the promotion of insourcing to be described later.

Fuel debris retrieval is not a job like the design and construction of a nuclear power plant, where the finished product is delivered with a performance guarantee. Therefore, unless TEPCO, the executor of the project, bears the technical and business risks at the end of the project, the cost will be astronomically inflated. The fact that the project executor bears the technical risk also means that the project executor itself must have the ability to assess the reliability of the functional settings and engineering design, which requires more technical skills than TEPCO had in the past. Here, the most important point is to incorporate “safety and operator's perspectives” as upstream as possible in engineering.

a. Ability to assess and manage process risks

It is fundamental to project management to identify and respond to project risks such as cost, process, and safety, which have a significant impact on project execution, and to complete the project within a certain margin of error by making full use of forecasting skills and know-how, while giving top priority to safety and taking into account the constraints and uncertainties surrounding the project. It is necessary to complete the project within a certain margin of error in terms of period and cost. In particular, project risk management for work with high technical difficulty and uncertainty (e.g., fuel debris retrieval) will become even more important in the future.

b. Acquisition management capability

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

To deal with such a making type project, it is necessary to improve the owner's engineering capability, such as the ability to concretize specifications, as well as to become familiar with acquisition management, which focuses on acquisition.

c. Promotion of insourcing

In order to meet the many challenges of decommissioning, it is essential to strengthen engineering capabilities, and TEPCO is promoting insourcing as a means to achieve this. "Insourcing" means to develop an ability that enables TEPCO to implement planning, design, maintenance, and operation on its own. It aims at reducing unreasonableness and waste, further deepening the level of productivity improvement, and improving the operation quality of TEPCO employees including the quality of design and procurement. The improvement of these qualities will ultimately contribute to the improvement of safety. While insourcing is effective for a wide range of issues, it is advisable to proceed with an awareness of the issues that are expected in the future to gain more benefits.

(3) Securing and developing human resources

a. Securing and developing human resources for smooth implementation of decommissioning projects

① Securing and developing human resources based on the Medium-to-long term human resources development plan

The development of human resources is essential as a basis for the smooth implementation of long-term decommissioning projects. For this purpose, project management and engineering capabilities should be enhanced. In addition, it is important to assume occupational categories, the number of engineers and the time required in the future (design, operation, maintenance, chemical analysis, safety assessment, radiation control, etc.) in light of the Medium-and-Long-term Decommissioning Action Plan, to summarize them as the medium-to-long term human resources development plan, and to promote human resources development and securing of staff systematically.

As an initiative to enhance project management capabilities, TEPCO has given responsibility and authority to project managers so that they can devote themselves to project management. In addition to basic education for project management, TEPCO is expanding the efforts such as to newly introduce training program for systematic learning in accordance with international standards. As an initiative to enhance engineering capabilities, while collaborating with other electric power companies, as well as manufacturers, general contractors and engineering companies, TEPCO has been making use of the knowledge of external experts including overseas experts, and accumulating and transferring their technical capabilities and know-how including engineering capabilities. Based on the medium-and long-term decommissioning action plan, measures are being considered to develop human resources and to secure personnel, assuming the number of engineers and the time to be required in the future.

② Secure and develop human resources with a "safety and operator’s perspectives”

It is necessary to secure and train human resources with "safety and operator’s perspectives" systematically and promptly.

TEPCO recognized early on that it is important to secure and train human resources who are well versed in the field and have acquired sufficient knowledge of the field to have an "operator’s perspective”. The “core technologies” required for the decommissioning of the Fukushima Daiichi NPS have been established, and the “Decommissioning Core Technology Course” has been held to foster them. Since 2015, the company has been implementing initiatives to improve on-site capabilities with in-house veteran instructors. In addition to the above general familiarity with the Fukushima Daiichi NPS decommissioning site and acquisition of on-site knowledge, in case where special skills specific to the facility or work to be handled are required, it is necessary to secure and train personnel with such special skills individually.

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

In order to continue decommissioning of the Fukushima Daiichi NPS for a long period of time and to continue R&D activities necessary for that, it is important to secure solid technical capabilities on a constant basis. For that purpose, it is essential to train and secure future researchers and engineers, and ensure technical transfer. The entire industry, academia, and government should promote initiatives for each stage of higher and secondary education.

For students in higher education, it is important for the industry and higher education institutions to cooperate and continuously implement activities to promote understanding of the nuclear industry. For the development of next-generation human resources, it is fundamentally important that young researchers/engineers are constantly produced from these higher education institutions. In particular, the World Intelligence Project by MEXT and JAEA/CLADS has introduced a system in which students and young researchers are made to be aware of decommissioning as an important research area, and is engaged in decommissioning research.

It can be said that the mechanism of and implementation by the World Intelligence Project have produced some results for researchers and students in higher education institutions. Hereafter, it is important to implement this project so that the perspectives of decommissioning sites in TEPCO and those of the activities in higher education institutions can be more aligned.

For students in the stage of secondary education, it is important to introduce appealing points of engaging in the nuclear field including decommissioning, and to make efforts to attract their technical interests with a focus on decommissioning, as well as to increase their understanding of decommissioning and reconstruction of Fukushima Daiichi NPS, and in a broad sense, of the career path in science and technology fields. NDF has held “student sessions” for high school students, etc. to give thought to the reconstruction of Fukushima along with the International Forum on the Decommissioning of the Fukushima Daiichi NPS (hereinafter referred to as “International Forum”), Through these efforts, high school students are given an opportunity to think about activities to achieve both decommissioning of the Fukushima Daiichi NPS and reconstruction, enabling them to increase their awareness that decommissioning is an important issue in reconstruction of local communities, and foster interest in and willingness to contribute to decommissioning and reconstruction efforts. Such activities have achieved some positive results.

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

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

It is important for many citizens and local residents to acquire basic knowledge of the accident and decommissioning, disaster response, radiation safety, and food safety related to the Fukushima Daiichi NPS from the perspective of future resilience of the whole country. This is because it will serve as basis for discussions on decommissioning, and related radiation safety, etc., based on accurate information and for promoting public understanding. In addition, although it is not directly aimed at fostering human resources who will play a leading role in the nuclear field in the next generation, it is also an aspect of indirectly broadening the range of human resources who are interested in not only in the nuclear field but in science in general. Particularly in the field of nuclear energy, it is necessary to learn about the relationships in local communities and society through various opportunities according to the development stage of children, as well as to acquire knowledge and experience on nuclear energy and decommissioning. To do so, since it is important that children take an interest through the knowledge and experiences of adults around them, such as teachers and parents. Therefore, it is important to further spread knowledge on nuclear energy and decommissioning based on scientific evidence, which to a wide range of people including those involved in primary education institutions.

2) Strengthening international cooperation

i. Significance and the current status of international cooperation

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

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

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

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

In addition, although the global outbreak of new coronavirus infections is a major obstacle to the above-mentioned international cooperation, many meetings and events are held online, and Japan has participated by utilizing the online system. NDF has also been actively utilizing the online system, etc., to gather the world's wisdom, maintain and enhance the international society's continuous understanding and interest, and maintain and develop cooperative relationships with international community. In the future, it is important to further expand the opportunities for communication with other countries by taking advantage of the experience gained so far.

ii. Key issues and strategies

(1) Integrating and utilizing wisdom and knowledge from around the world

As we move forward with decommissioning, Japan has received support from the international community through the dissemination of information to the international community and participation in international joint activities. More than ten years have passed since the accident, and it is necessary to continue the mutually beneficial relationship while also working to return the know-how and results accumulated so far to the internal community.

The difficulty in traveling to and from other countries due to the pandemic outbreak of new coronavirus infections has become an obstacle to the continuation of such mutually beneficial relationships. It is important to secure opportunities for communication and work to maintain and develop relationships by utilizing online systems and other means so that the unprecedented situation, not limited to the new coronavirus infection, does not dilute relationships with relevant organizations, experts, and international organizations in other countries. Through a series of the International Forums, NDF has collected the wisdom including lessons learned and technologies derived from decommissioning around the world. It is important to continue to make the International Forum an effective opportunity to gather wisdom from all over the world by using the online system, even in the situation where direct participation from other countries is difficult.

As the engineering of Fukushima Daiichi NPS is in full swing, it is important to grasp the latest status of excellent technologies and human resources in the world and to utilize them effectively. In this context, TEPCO has been actively engaged in technological exchanges with overseas private companies. It is necessary for TEPCO to continue to keep abreast of the latest information from around the world, including the situation in the private sector, and to engage in continuous communication with these private companies, sharing information on the progress of decommissioning work and forming an environment in which the necessary technologies can be accessed when needed.

(2) Maintaining and developing the international community's understanding of and interest in decommissioning and cooperative relationships

In order to mobilize the wisdom of the world for the decommissioning of the Fukushima Daiichi NPS, it is important to maintain and develop the understanding, interest, and cooperative relationship of the international community. To this end, it is important for the government and other domestic organizations to disseminate accurate information on the decommissioning of the Fukushima Daiichi NPS, considering the fact that more than 10 years have passed since the accident and the interests of the recipients of the information have changed since the time of the accident. It is also important to participate in international joint activities and disseminate information to return the knowledge obtained in the course of decommissioning to the international community. From the aspect of returning the results, it is important to maintain the level of interest while responding to the changes in the international community, such as the growing interest in not only the accident and decommissioning itself but also the application to other issues.

On the premise of ensuring safety and taking thorough measures against reputational damages, some countries, in fact, issued comments expressing concern about the impact on the environment and questioning the transparency in disposal in response to the Japanese government's announcement of a policy to discharge ALPS-treated water into the ocean. On the other hand, foreign governments, related organizations, and international organizations that understand the situation of Japan's decommissioning have issued comments supporting Japan's decision. In addition, the IAEA announced that it would actively cooperate with the discharge of ALPS-treated water into the ocean from a third-party standpoint by dispatching a review mission and supporting environmental monitoring. These actions are pushing to gain international understanding of offshore discharge, and the importance of ensuring transparency and building cooperative relationships through accurate information dissemination was reaffirmed.

It is important to continue to obtain the understanding and cooperation of the international community for the steady implementation of decommissioning, including the future discharge of ALPS-treated water into the ocean, and it is necessary for the government and other relevant domestic organizations to disseminate accurate and easy-to-understand information. It is also important for NDF, through various opportunities, to disseminate information that is accurate meets the changing interests of the recipients, and to return to the international community the knowledge obtained through the decommissioning process.

3) Local community engagement

i. Significance and the current status of local community engagement

(1) Basic concept

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

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

(2) Specific measures under the current situation

Based on their "Commitment to the people of Fukushima to achieve both reconstruction and decommissioning” established in March end, 2020 (hereinafter referred to as “Commitment”), TEPCO has summarized their efforts for the accumulation of decommissioning work into the following 3 categories: ① Increased participation of local enterprises, ② Support for local enterprises to step up and ③ Creation of new local industries, and has started to implement them in a phased manner. With regard to ① and ②, in cooperation with the Fukushima Innovation Coast Framework Promotion Organization and the Fukushima Soso Reconstruction Promotion Organization, TEPCO has set up and are operating a joint consultation service to support matching between local companies interested in participating in decommissioning projects and prime contractors who are considering placing orders with local companies. In addition, it is also conducting a survey of the needs of both prime contractors and local companies regarding human resource development, and has started joint research with several universities. Moreover, the contents of the "Medium- to-Long-Term Outlook in the Decommissioning" prepared in September 2020 are being updated as necessary to reflect the progress of decommissioning work, and briefing sessions are being held for local governments, commercial and industrial organizations, and local contractors as well as the prime contractors, paying close attention to the spread of the new coronavirus infection.

In addition, with regard to ③, in order to build an integrated decommissioning project implementation system locally, from "development and design" to "manufacturing," "operation," "storage," and "recycling," TEPCO is planning to establish and operate several new facilities in the 2020s (announced on May 27, 2021), so that technologies and products of relatively high difficulty and importance, which have been ordered outside Fukushima Prefecture, including overseas, can be completed in the Hamadori region. In particular, with regard to local manufacturing, TEPCO has established a joint venture with partner companies that have a proven track record in the field of high-function products that had to be manufactured outside of the prefecture, the plan is to set up a manufacturing base in the Hamadori region with the aim of creating local employment, placing orders with local companies, and promoting collaboration.

ii. Key issues and strategies

(1) Communication issues and strategies

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

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

In particular, the disposal policy of the ALPS-treated water has been the subject of anxiety and concern not only from locally but also domestically and internationally, and local governments and related organizations are strongly urged to provide accurate information and take all possible measures to prevent rumors. In light of these circumstances, TEPCO must do its utmost to suppress rumors by steadily implementing the measures outlined in the "TEPCO's response based on the government's basic policy on the disposal of treated-water by multi-nuclear removal facilities" (released on April 16, 2021), and by making additions and revisions as necessary.

(2) Issues and strategies related to the creation of a regional industrial and economic base through decommissioning

TEPCO is making various efforts to realize the "Commitment", but these efforts will not produce visible results immediately and will require a certain period of time. In addition, for “(3) Creation of new local industries” which will be promoted in the future, it is a relatively large-scale investment and is expected to have a great economic effect on the Hamadori area. However, as advanced techniques are required to produce high-performance products, the issue is how to eliminate the technical gap between experienced prime contractors and local communities and connect this to promoting active participation in local companies. Therefore, for the time being, it is important to continue and strengthen the current activities in a credible manner, including "(1) Increased participation of local enterprises" and "(2) Support for local enterprises to step up". It is also important to carefully explain to local governments, commercial and industrial organizations, and other organizations concerned the location and scale of new decommissioning-related facilities, the schedule from construction to operation, and the status of considering engagement with local communities in terms of employment, cooperation and order placement, and to proceed with the activities while gaining understanding and cooperation.

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

In addition to research and development related to decommissioning, as companies from outside the region move into the region and provide technical guidance to local companies, the number of engineers and researchers visiting and staying in the region is expected to increase. Therefore, it is necessary to establish the necessary environment and support system so that such external personnel can integrate into the local community and play an active role as a member of it. In particular, it is necessary to take into consideration a wide range of functions such as daily life and education so that not only single people but also families can live together with peace of mind.

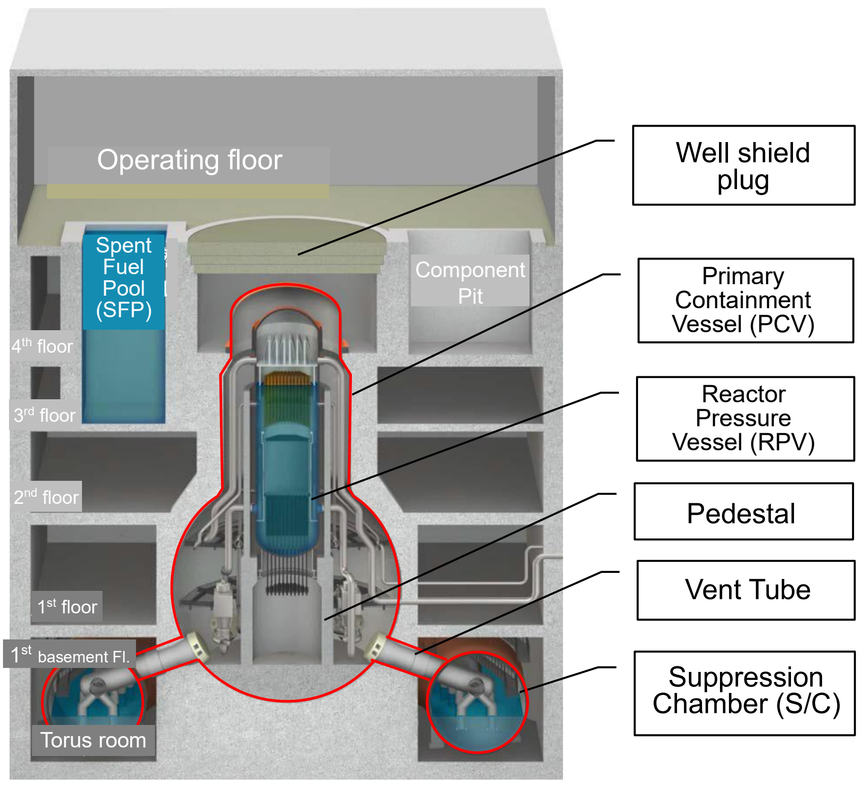
In this regard, as well as promoting the return of residents, Fukushima prefecture opened "Fukushima 12-municipality Migration Support Center" that helps people move and settle in the 12 municipalities, mainly from outside the prefecture for accelerating the reconstruction of the evacuated areas by promoting wide-area migration and settlement. The prefecture has been disseminating information to people throughout the country who are interested in migration and providing various types of support to those who wish to move to the 12 cities, towns and villages. It is also important to consider the possibility of collaboration and cooperation with these local initiatives.

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

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

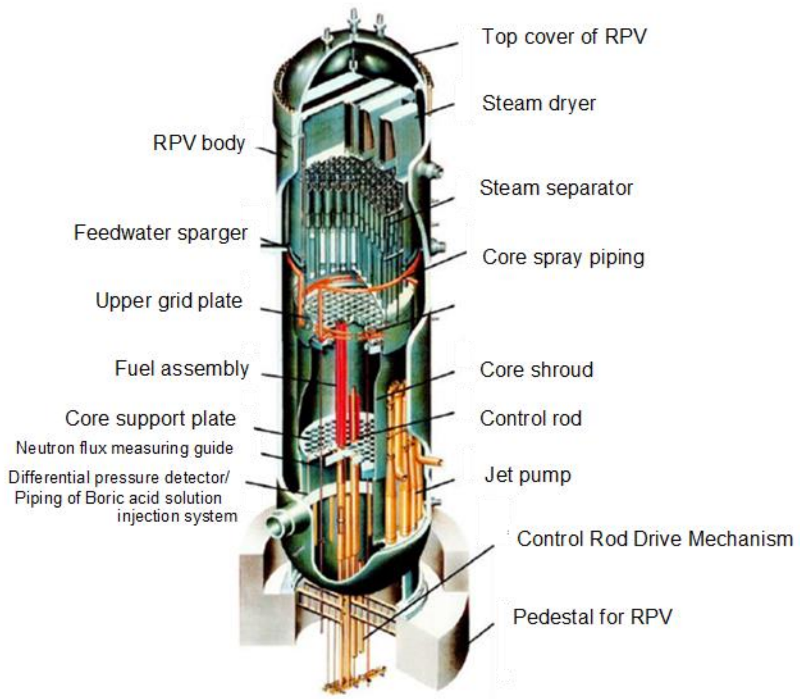
List of Acronyms/Glossaries

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 by decontamination device (waste sludge)	Sludge containing high level of radioactive material generated by the decontamination device (AREVA), which was operated for contaminated water treatment from June to September 2011
Sludge	Muddy substance, dirty mud
Slurry	A mix of dirty mud and mineral, etc. in water
Zeolite	Adsorbent used to recover radioactive materials such as cesium
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
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. 18 Structural drawing inside Reactor building



(Courtesy of IRID)

Fig. 19 Structural drawing inside Reactor Pressure Vessel (RPV)