Technical Strategic Plan 2019
For Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.

Overview

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Nuclear Damage Compensation and
Decommissioning Facilitation Corporation
NDF

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1 Introduction

Eight years have passed since the accident at the Fukushima Daiichi Nuclear Power Station. There has been a certain outlook for the short-term response, as progress has been made at the accident site in managing contaminated water including the construction of the land-side impermeable wall and in removing fuel from the spent fuel pools as well as improving work environment at the site. Going forward, long-term approach like fuel debris retrieval is needed and mid-and-long-term responses are required. When addressing more complex, uncertain challenges over the long term, more systematic approach from mid-and-long-term perspective will be needed to solve the challenges rather than fulfilling tasks by resolving imminent issues one by one. Under the circumstances, as engineering toward fuel debris retrieval is well under way, the phase of decommissioning moves to response for mid-and-long-term vision. With that in mind, in the "Technical Strategic Plan 2019 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.", the direction from a mid-and-long-term perspective in overlooking total approach for decommissioning of the Fukushima Daiichi NPS is presented including waste management, as well as the strategical recommendation to determine methods of fuel debris retrieval for the first implementing unit in accordance with the milestone set in the Government-developed "Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station" (hereinafter referred to as the "Mid-and-Long-term Roadmap") that was revised in September 2017.

1) Structure and system toward the decommissioning of the Fukushima Daiichi Nuclear Power Station

Tokyo Electric Power Company Holdings, Inc. (hereinafter referred to as "TEPCO") is reinforcing its project management structure with the goal of implementing the ongoing activities reliably while responding to mid- and long-term issues in a strategic manner to make steady progress of decommissioning operation. In addition, to ensure the implementation of the decommissioning financially, a law to partially revise the Nuclear Damage Compensation Facilitation Corporation Act was established in May 2017 and came into effect in October of the same year. Under this revised Act, Nuclear Damage Compensation and Decommissioning Facilitation Corporation (hereinafter referred to as "NDF") has been assigned the new duty of managing the reserve fund for decommissioning. In this duty, it was determined that (1). TEPCO sets aside an amount of funds at NDF every year that NDF determines to be necessary for the appropriate and steady implementation of the decommissioning and is authorized by the competent minister (the Minister of Economy, Trade and Industry), (2). TEPCO proceeds with the decommissioning while withdrawing the reserved funds in accordance with "Withdrawal plan for reserve fund for decommissioning" (hereinafter referred to as the "Withdrawal Plan"), which was prepared jointly by NDF and TEPCO and approved by the competent minister (Fig. 1).

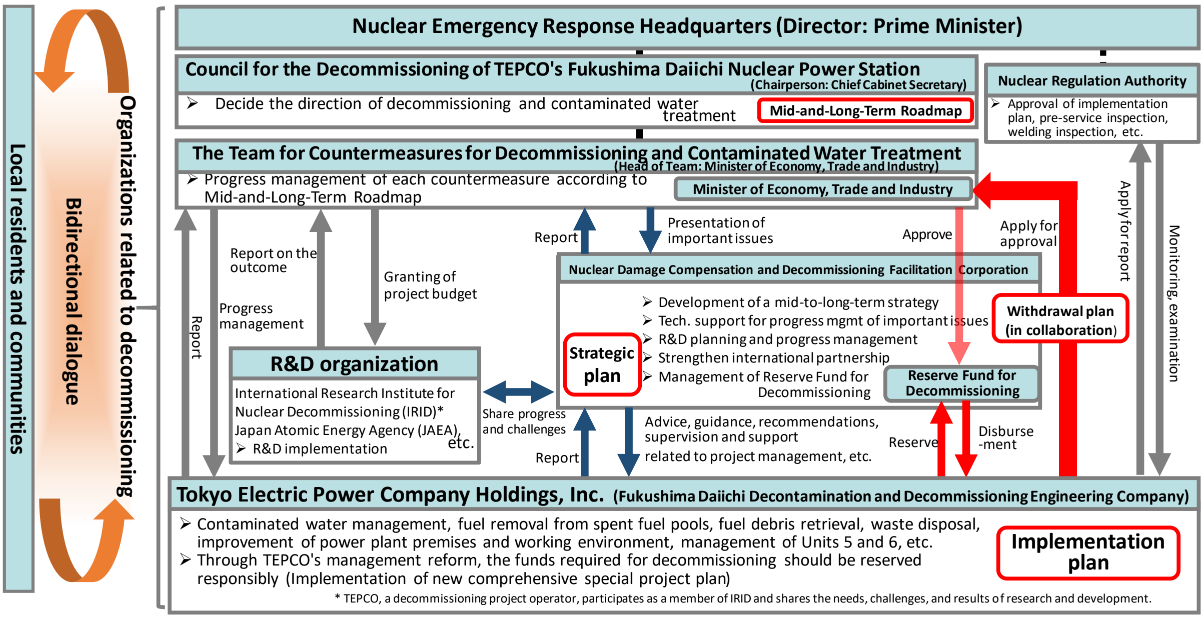


Fig.1 Division of roles of related organizations in decommissioning of the Fukushima Daiichi NPS

In this decommissioning reserve fund system, NDF plays even greater roles and responsibilities than before as the major supervisor and administrator of the decommissioning project conducted by TEPCO. These include (1) appropriate management of the funds for decommissioning, (2) maintenance of an appropriate system for executing the decommissioning, and (3) steady work management based on the decommissioning reserve fund system. Specifically, NDF presents to TEPCO the work targets and major tasks to be included in the Withdrawal Plan in accordance with “The Policy for Preparation of Withdrawal Plan for Reserve Fund for Decommissioning” (“The Policy for Preparation of Withdrawal Plan”) that was developed based on the “Technical Strategic Plan for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.” (hereinafter referred to as the “Strategic Plan”). NDF also support the appropriate and steady implementation of the decommissioning through activities such as assessing the adequacy of TEPCO’s efforts in the course of jointly preparing the Withdrawal Plan in terms of project execution (including the aspect of collaboration and communication with local communities) (Fig. 2).

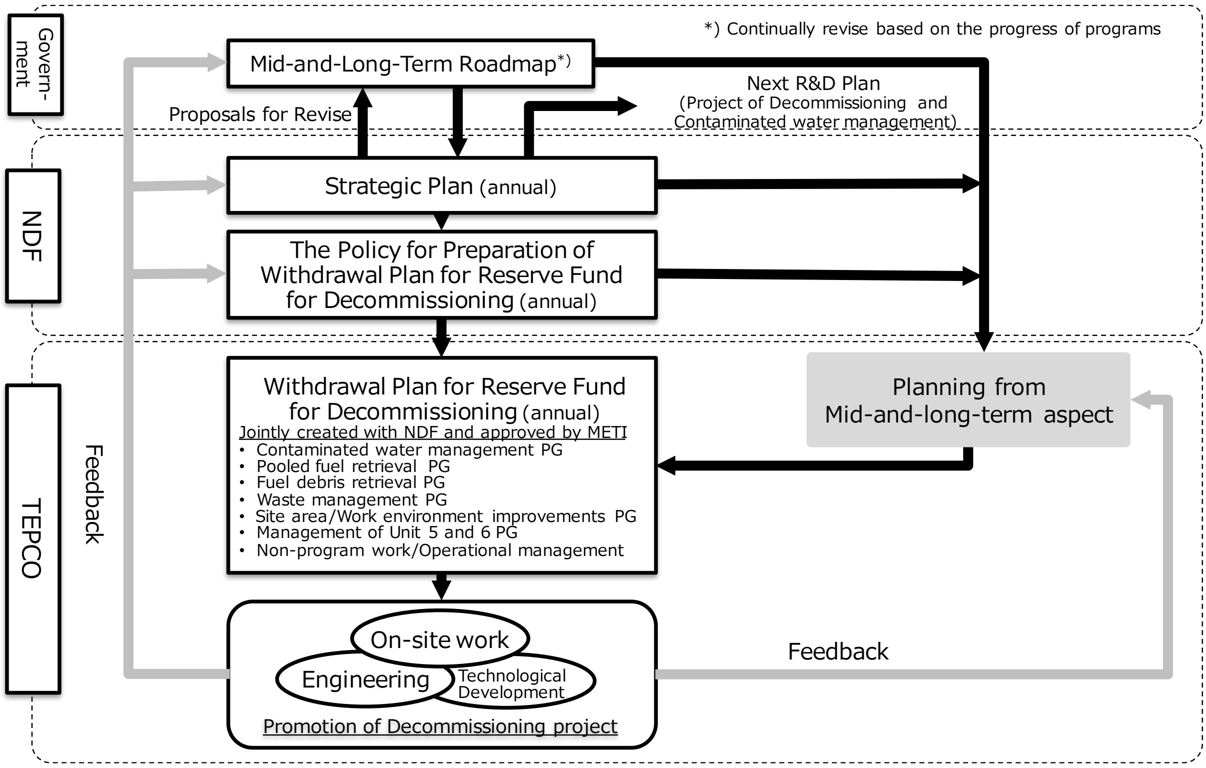


Fig.2 Positioning of the Strategic Plan based on the system of the Reserve Fund

2) Strategic Plan

NDF has issued the Strategic Plan every year since 2015 with the goal of providing reliable technological grounds for the government's Mid-and-Long-term Roadmap and contributing to its smooth and steady implementation and update. Since the Strategic Plan 2018 and future editions, it includes not only the issues focused on fuel debris retrieval and waste management but also measures against contaminated water and fuel removal from spent fuel pools by extending the study range.

As stated earlier, the Strategic Plan 2019 presents a mid-and-long-term direction that oversees the entire efforts of Fukushima Daiichi NPS including waste management, while providing the strategic recommendations to determine methods of fuel debris retrieval for the first implementing unit.

2 Decommissioning of the Fukushima Daiichi NPS as risk reduction strategies

1) Basic concept of the decommissioning of the Fukushima Daiichi NPS

Concerning to the Fukushima Daiichi NPS decommissioning, the basic concept is to continuously and quickly reduce the radioactive risk caused by the accident that does not exist in the usual NPS.

2) Progress status of the decommissioning of the Fukushima Daiichi NPS

The Fukushima Daiichi NPS has the necessary safety measures in place that are required by the NRA in “the matters for which measures should be taken” and is maintained in a state with a certain level of stability. In addition, as a result of various risk reduction measures taken so far, risk reduction has been continuously achieved as follows:

(1) Contaminated water management

Measures have been taken based on the three principles on the issue of contaminated water (“Removing” contamination sources, “Redirecting” fresh water from contamination sources, and “Retaining” contaminated water from leakage).

As a measure of “Removing” contamination source, radioactive materials are removed from contaminated water with multi-nuclide removal equipment. As measures of “Redirecting” fresh water from contaminated sources, freezing operation of the land-side impermeable walls has been completed in all the areas by September 2018. Along with the reinforcing the sub-drain system, total amount of the contaminated water is decreasing as a result of reduced inflow into the buildings and sharp decrease in the amount of the water transferred from the groundwater-drains to the buildings. As measures of “Retaining” contaminated water from leakage, the strontium treated water stored in flange tanks has been purified with multi-nuclide removal equipment and transferred to more reliable welded tanks in November 2018. In addition, transferring of treated water stored in flange tanks to welded tanks has been completed in March 2019, resulting in a drastic reduction of the risk of leakage from flange tanks.

In treating stagnant water in the buildings, the amount of stored water has been decreasing steadily by lowering the water level in turbine buildings with the goal[1] of completing the treatment in 2020. At the present time, the lowest floor level of turbine building in the Unit 1, and the lowest floor’s intermediate ceiling of turbine buildings in the Units 2 to 4 became visible. In addition, separation of the penetration between Units 1 and 2 completed in 2018 (one between Units 3 and 4 has completed in 2017). On the other hand, regard to the target decrease of the radioactive materials in the stagnant water in the buildings up to one tenth of the amount at the end of FY 2014 in FY 2018, the evaluation became difficult because high radioactive concentrations were detected in some areas with the progress in the treatment of stagnant water, though treating of

[1] Exposing the floor line for buildings other than the reactor buildings and lowering the water level of the reactor building to T.P.-1740mm (O.P. - 300 mm) or less. (Cyclic water injection cooling is carried out in the reactor building, and stagnant water continues to exist).

radioactive materials has been conducted more than scheduled. Thus, ongoing efforts will be made to complete the treatment of stagnant water in the buildings in FY2020.

Moreover, as for the water treated by the multi-nuclide removal equipment, comprehensive discussion including social aspects such as mitigation of reputational damages have been made in the Government-led subcommittee on the Water Treated by the Multi-nuclide Removal Equipment[2].

(2) Fuel removal from spent fuel pools

In Unit 1, to remove fuel from SFP, rubble removal in the operating floor continues which has started in 2018.

In Unit 2, contamination in the operating floor was investigated from November 2018 to February 2019. Based on this investigation, process among other things has been studied for further fuel removal from SFP. In addition, the exhaust stuck for Units 1/2, in which some fractures were found at the support structure due to the impact of the earthquake, will be dismantled at the upper part in order to secure seismic safety margin and not to affect the removal operation of fuel n SFP.

In Unit 3, the fuel removal has started in April 2019 though it was behind the original schedule because of some troubles on fuel handling equipment occurred during the trial operations.

(3) Fuel debris retrieval

In Unit 1, internal investigation of Primary Containment Vessel (hereinafter referred to as the "PCV") will be conducted in FY2019 by using a boat-shaped submersible apparatus that was newly developed for access investigation, since the deposits that was identified by the investigation internal PCV in 2017 was located under the water. In this investigation, a small amount of deposit is to be sampled.

In Unit 2, as a result of the deposit contact investigation inside PCV by using a remote device in February 2019, it was observed that some pebble sized deposits can be moved at the bottom of the pedestal in PCV and the platform. In addition, grasping distribution of structures and deposits inside the pedestal and a small quantity of sampling is scheduled.in the future.

In Unit 3, study to lower the water level has been made since the water level inside PCV is high, being 6 meters. At first, quality of the water is to be examined.

(4) Waste management

For high radiation dose rubbles generated from Units 1 and 2, operation of solid waste storage building No.9 has started in February 2018. As for secondary waste generated by purification of contaminated water, it is currently being stored in temporary storage, and operation of large

[2] Subcommittee on the water treated by the multi-nuclide removal equipment
https://www.meti.go.jp/earthquake/nuclear/osensuitaisaku.html#task_force4

waste storage will start to store these waste after this. Storage management plan was revised in June 2019 based on the revised results of predicted generation of solid waste.

3) Basic concept of reducing risk of radioactive materials

i. Quantitative grasping of risk

In the Strategic Plan, the method based on the Safety and Environmental Detriment score (hereinafter referred to as "SED") developed by Nuclear Decommissioning Authority (hereinafter referred to as "NDA") is used to express the magnitude of risk (risk level) of radioactive materials. In this method, risk level is expressed as the product of "Hazard Potential", which is used to indicate the level of impact of internal exposure caused by intake of radioactive substance into the human body, and "Safety Management" which is used as an index to indicate the likelihood of occurrence of the event.

ii. Identification of risk source and risk assessment

The major risk sources of the Fukushima Daiichi NPS are indicated in Table 1. Moreover, the risk levels of each risk source expressed using Hazard Potential and Safety Management are shown in Fig. 3.

In the Mid-and-Long-term Roadmap, management of these risk sources is classified into the three broad categories: [1] Highly contaminated water and fuel in SFP, etc., relatively high risks given a high priority, [2] Fuel debris, etc., risks unlikely to appear immediately though, risks may grow in case dealing with haste, [3] Solid waste, etc. risks unlikely to increase in the future, but appropriate decommissioning efforts necessary. The appropriate measures are taken by giving these priorities. Risk reduction strategies for each of these sources will be described in Chapter 3.

In regards to fuel in SFPs, the testing on SFP cooling shutdown was performed, and it was found that rise in water temperature after cooling shutdown was slower than expected. By incorporating this finding, the risk of fuel in SFPs is lower than previously evaluated, because the time margin before this risk becomes apparent increases.

Table 1 Major risk sources of the Fukushima Daiichi NPS

Fuel debris		Fuel debris in the RPVs/PCVs in Units 1 to 3
Spent fuel	Fuel in SFPs	Fuel assemblies stored in the spent fuel pools (SFPs) in Units 1 to 3
	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 the buildings	Contaminated water accumulated in the reactor buildings and turbine buildings in Units 1 to 4, main process building, and high temperature incinerator building.

	Stored water in welded tanks	Strontium-treated water and ALPS treated water stored in welded tanks
	Residual water in flange tanks	Concentrated salt water, strontium-treated water and ALPS-treated water remaining in the bottom of flange tanks
Secondary waste from water treatment systems	Waste adsorption columns	Spent adsorbent used in the cesium adsorption apparatus, the second cesium adsorption apparatus, high-performance ALPS, mobile-type strontium removal equipment, second mobile-type strontium removal equipment and mobile-type treatment equipment, etc.
	HIC slurry	Slurry produced during the treatment by ALPS and stored in high integrity containers (HIC)
	Waste sludge	Precipitation from the decontamination instruments
	Concentrated liquid waste, etc.	Concentrated liquid waste generated by evaporative concentration of concentrated salt water and carbonate slurry collected from concentrated liquid waste
Rubble, etc.	Solid waste storage facility	Rubble with high radiation dose rate (30mSv/h and above) stored in the solid waste storage facility
	Soil covered temporary storage, etc.	Rubble stored in Soil covered temporary storage facility, Temporary storage tent and Outdoor container storage (1～30mSv/h), and Felled tree stored in Temporary storage tank
	Outdoor storage, etc.	Rubble stored in Outdoor seat covered storage (0.1～1mSv/h), Rubble stored in Outdoor storage (Under 0.1mSv/h), and Felled tree stored in Outdoor storage
Contaminated structures, etc. in the buildings		Structures, pipes, components, and other items inside the reactor buildings, PCVs or RPVs that are contaminated with radioactive materials dispersed due to the accident; and activated materials from operation before the accident

The previous Strategic Plans have focused on the risk source containing radioactive-rich materials. On the other hand, when aiming at the entire operation of decommissioning processes from a long-term perspective, there exist what should be addressed regardless of amounts of radioactive materials and the waste that have generated before the accident. Therefore, the survey has just begun in wider range of the target to identify what need long-term strategic study.

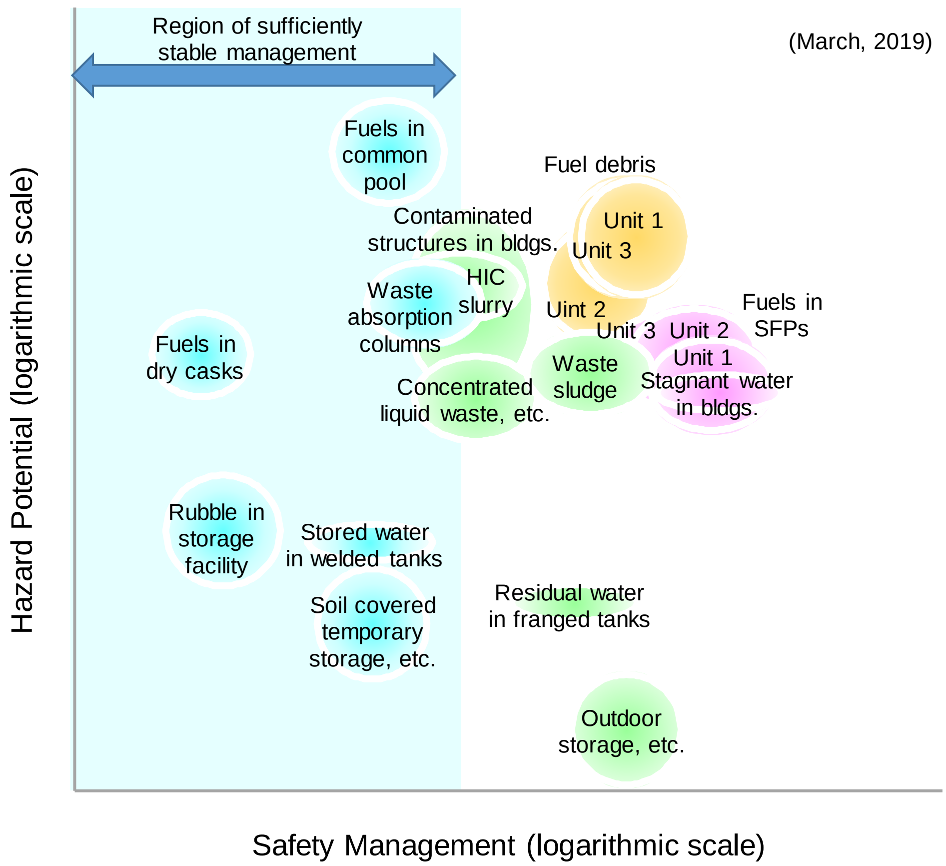


Fig.3 Example of risk levels assigned to the risk sources at the Fukushima Daiichi NPS

iii. Approach to risk reduction strategies and future direction

(1) Interim goal of risk reduction strategies

Risk reduction strategies include reduction in Hazard Potential and Safety Management in the SED. The examples of reduction in Hazard Potential include decrease in inventory and decay heat associated with radioactive decay, and changing the form of liquid and gas into the form that is hard to move. To process contaminated water to change into the secondary waste is an example of form change.

The examples of reduction in Safety Management include transfer of fuel in SFPs to the common spent fuel storage pool, and placement of rubbles stored outside to the storage. Of the various risk reduction measures, the reduction in Safety Management is considered generally to be easily achieved. Therefore, the interim goal of risk reduction strategies is to bring the risk levels into the "Region of sufficiently stable management" (pale blue area) indicated in Fig. 3.

SED quantitatively shows a current condition of a risk of radioactive materials, and this is an effective method to determine the order of priority for measures against risk sources. When conducting actual risk reducing approach, it is required to take measures from engineering aspect in order to inhibit development of risks from radioactive materials associate with its operation.

(2) Basic approach to risk reduction

The decommissioning of the Fukushima Daiichi NPS is a project with inherent considerable uncertainty. To date, internal status of the Units 1 to 3 is estimated to some extent by simulation of the development process of accident, estimation of location of fuel debris by measurement of muon, projection of inspection equipment into PCV, radiation dose measurement in the buildings and others. However, to eliminate uncertainty, many resources, especially a considerably long time, are required. To realize prompt risk reduction, it is necessary to make integrated decisions taking flexible and prompt approach, based on the directions determined with previously obtained experience and knowledge and with experiment- and analysis-based simulation, placing safety at the top priority, even though a certain extent of uncertainty remains. At this time, it is important to flexibly address the issues with experiences, reflecting the internal information, technical feasibility and other information obtained in advance in a certain unit on the subsequent works and the works in other units. As the viewpoint to make integrated decisions like this, NDF summarizes the following five guiding principles.

(Five guiding principles)

- Safe — Reduction of risks posed by radioactive materials and ensuring work safety
- Proven — Highly reliable and flexible technologies
- Efficient — Effective utilization of resources (e.g. human, physical, financial and space)
- Timely — Awareness of time axis
- Field-oriented — Thorough application of Three Actuals (actual field, actual things and actual situation)

These guiding principle are the viewpoint necessary to discuss priority of approaches and total optimization.

(3) Order of priority

It is important to be aware of position of each project and their mutual relationship in their respective fields in managing progress of overall project based on the five guiding principles. Specifically, as the situation on site is gradually becoming clear along with progress in decommissioning operation, when applied this five guiding principles into the actual site, at present, decommissioning which optimal balance is considered is needed while focusing on “safety” and “certainty” including radiation exposure inhibition or ensuring safety and reliability of devices and equipment during operations. In the decommissioning of the Fukushima Daiichi NPS that aspires to a continuous and prompt risk reducing, it is important to aim at choosing the best option among the various possible options, with the integrated viewpoint of looking at the entire site on a long-term basis and considering time axis. Taking into account such point of view, TEPCO and NDF have just introduced project management mechanism and addressed to enforce the efforts.

(4) Concept of securing safety and promotion of cooperation

While the approaches to facilitate decommissioning such as fuel debris retrieval will contribute to stabilizing the Fukushima Daiichi NPS, conducting these approaches comes with certain risks. Although these risks must be minimized, excessive protective measures are taken to these risks may make conducting these risks difficult. Meanwhile, it is also necessary to determine an appropriate approach to safety by taking the unpreceded situation into consideration, such as significant uncertainties of the situation and the difficulties in implementing measures due to high radiation dose conditions on site.

In light of these circumstances, the concept for determining an appropriate approach to safety (Concept of securing safety) during decommissioning is being examined in cooperation with TEPCO and the manufactures and designers of facilities at the initiative of NDF. Specific items on the agenda for these discussions include;

- Establishment of the judgement criteria and safety assessment methods that are applicable to the decommissioning work at the Fukushima Daiichi NPS; and
- Safety assessment of typical accident scenarios set up for fuel debris retrieval work, and ways to determine appropriate safety measures based on the assessment results.

TEPCO and the Agency for Natural Resources and Energy and other organizations will continue to cooperate and proceed with those discussions under the initiative of NDF, as well as communicate actively with the Nuclear Regulation Authority, because it is needed to develop the consensus on the concept for determining rational safety measures for the decommissioning operation of Fukushima Daiichi NPS.

(5) Addressing temporary increase of risk level associated with the decommissioning operations

As mentioned earlier, the implementation of the decommissioning work is striving for prompt risk reduction from the mid-and-long-term viewpoint. However, it requires careful consideration of the possibilities that the performance of decommissioning work may temporarily change the risk levels and may increase the radiation exposure of workers. This possibility of a temporary increase in the risk level and a rise in workers' radiation exposure arising from the decommissioning work must be addressed by ensuring measures to prevent and restrict them. It is imperative to limit the increase in the risk level during the decommissioning work within the permissible range by thorough preparations for the work. In particular, the radiation safety of workers should be ensured in accordance with the concept of ALARA (to suppress radiation exposure As Low As Reasonably Achievable).

Note that the basic stance of promptly implementing the decommissioning must be firmly maintained because if the decommissioning work is delayed excessively, existing high risks will remain over the long term and their risk levels can gradually increase as the buildings and facilities deteriorate over time. For this reason, regard to the selection of the method of work, the design and production of equipment and safety systems, and the development of work plans for the decommissioning work, cautious and comprehensive decision making is required for the early implementation of the decommissioning in consideration of many constraints such as time, cost and workers' radiation exposure needed for associated preparations and work, while giving priority to limiting the risks involved in the decommissioning work.

Moreover, the decommissioning of the Fukushima Daiichi NPS as a risk reduction project should be promoted, gaining the broad understanding and support by wide range of public local residents as well as parties concerned. Therefore, it is important to implement an easy-to-understand mechanism of monitoring of risks such as how the overall risks at the NPS have been continuously reduced through the decommissioning work. Such mechanism is now being studied in NDF and it is also important for TEPCO to study on introducing it in the future.

3 Technological strategies toward decommissioning of the Fukushima Daiichi NPS

1) Fuel debris retrieval

i. Sectoral target

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

(2) Toward determination of fuel debris retrieval method for the first implementing unit in FY 2019, and start of fuel debris retrieval work for the first implementing unit in 2021, necessary approaches will be taken, according to the “Policy on Fuel Debris Retrieval”.

<Key Points of the "Policy on Fuel Debris Retrieval">

[1] Step-by-step approach

- In order to reduce associated risks as early enough, flexibly coordinate the direction based on information that comes out as retrieval proceeds, after setting method of fuel debris retrieval to be started first.
- Retrieval operation and internal investigation should be performed in a coordinated, integrated manner.
- Retrieval starts from a small-scale and the scale of retrieval should be expanded by step up.

[2] Optimization of entire decommissioning work

- Examine retrieval work as a comprehensive project aimed at total optimization, including coordination with other construction works at the site.

[3] Combination of multiple methods

- Combine the optimum retrieval methods for each unit, depending on the locations where fuel debris is considered to be present.

[4] Approach focused on partial submersion method

- Make efforts to focus on a more feasible partial submersion method

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

- It should be considered that the accessibility to fuel debris and the removal of spent fuel can be accomplished in parallel from the view point of mitigating risks from fuel debris as early enough while minimizing any increase in risks that might be caused by retrieval.

ii. Sectoral Strategies

(1) Approach to risk reduction in fuel debris retrieval work

It is hard to consider that the fuel debris immediately appears as a risk, but it is a risk source that risk may grow in case of dealing with rush and haste. On the other hand, the fuel debris is currently maintained in a state with a certain level of stability; however, on a long-term, the possibility of changes in the form and physical property due to aging degradation is considered. For this reason, as indicated in (1) of Sectoral targets, fuel debris should be retrieved safely after thorough and careful preparations such as safety measures and bring it to the state of stable storage that is fully managed as early as possible. To realize this, it is important to well organize and examine the matters to be considered, such as securing of safety during fuel debris retrieval and technical requirements including feasibility of fuel debris retrieval methods and stable storage of fuel debris.

According to the concept of the fuel debris retrieval policy, the retrieval starts from accessing to the bottom of PCV from its side by partial submersion method using a remote operation equipment. Retrieving of fuel debris by partial submersion method is unprecedented project in the world. It is necessary to proceed with operation carefully upon enough and well making preparations in order to properly inhibit increase of risk associated with its operation, due to the limited information on the internal condition of PCV in Units 1 to 3. At the beginning, it should be appropriate to start from retrieval based on use of existing safety system, with no significant changes in the state of the site including condition of PCV. Specifically, retrieval should start from small-scale from the scope that can be conducted by utilizing existing penetration, without making major changes in the state such like processing PCV wall. This allows continuations a series of operations from containing and transferring through storing steadily after retrieving fuel debris without giving non-reversible state changes to PCV, and to reduce the risk from fuel debris and to conduct confirmations of effectiveness of systems and internal conditions required for further operations to be developed.

Through small-scale retrieval in the first implementation unit, the following effects can be expected:

① Enables verification of equipment, facilities and safety systems, including remote operations in the phase of small-scale retrieval by obtaining information (including radionuclide migration rate to gas phase and liquid phase) on the effectiveness and work efficiency reviews of equipment, facilities, and safety systems from fuel debris retrieval to containment, transfer, and storage.

② Enables use of work experience gained from fuel debris retrieval to containment, transfer, and storage including remote operations as the process to master fuel debris retrieval operations for TEPCO.

③ Enables acquisition of information that contributes to understanding situation inside the PCV (fuel debris distribution [Including characteristics], information on access routes, information on structural conditions, etc.).

Since then, amount of retrieved fuel debris shall be increased or further retrieval shall be started from units other than the first implementing unit after taking necessary measures such as expansion and modification of PCV openings, installation of new openings, expansion of scale of remote operation equipment, and addition of new equipment for securing safety, based on the new findings including information and experiences acquired through this small-scale retrieval operation of the first implementing unit. Fuel debris retrieval at expanded-scale mentioned above or at units other than the first implementing unit will require following items of development.

a) Consideration of actual site applicability based on such as conceptual study on safety system

b) Information organization such as radio nuclide airborne release fractions for examining necessary and sufficient safety systems
c) Site environment preparation such as radiation reduction, water level lowering in PCV and area planning
d) Further understanding of inside condition of PCV and RPV
e) Technologies to make efficient fuel debris retrieval including removing obstacles
f) Technologies to reduce dispersion of radionuclide airborne particles during fuel debris retrieval
g) Consideration on sorting and distinction of fuel debris and radioactive waste
h) Technologies to analyze and estimate fuel debris properties and distributions for understanding

In such manner, fuel debris retrieval of the first implementing unit will be contentiously examined. Also engineering regarding new safety systems on its site applicability, site environmental preparation, PCV internal investigation and necessary R&D shall be conducted continuously.

(2) Fuel debris retrieval method for the first implementing unit (Outline of the strategic recommendation for determining the fuel debris retrieval methods for the first implementing unit)

The Mid-and-Long-Term Roadmap revised in September 2017 stipulates that "Regarding the method of fuel debris retrieval for the first implementing unit to begin the operation, which will start within 2021 by determining the method of containing, transfer and storage (by 2019) after due consideration of the results of the preliminary engineering and R&D".

In response to this, the first implementing unit and its fuel debris retrieval method have been investigated, and the results are summarized as the “Strategic Recommendation for Determining the Fuel Debris Retrieval Methods for the First implementing unit”. The recommendations for determining the fuel debris retrieval methods for the first implementing unit has been concluded through the examination of overall optimization of the combination of the whole site planning and fuel retrieval scenarios of each unit which were established based on the evaluation of the conceptual design of fuel debris retrieval systems and its field applicability to each unit created as a result of preliminary engineering by TEPCO using the past research and development results and the PCV internal investigation results The flow of the above mentioned process is as shown in Fig.4.

As a result of the above mentioned examination, selected “fuel debris retrieval work”, which can be defined as a series of operation from containment, transferring and then storing in steady condition, is to start promptly from small-scale retrieval operation keeping in a minimum risk increase caused by fuel debris retrieval work and to accumulate experiences and knowledge immediately for expanded-scale retrieval work as well as units other than the first implementing unit. This approach of fuel debris retrieval operation enables to reduce risk existing in Units 1, 2 and 3. In particular, operation starting from gripping and sucking by using an arm-type access equipment that field applicability is getting in sight and the air tightened enclosure that contains arm-type access equipment combined with existing safety system and without significant modification is evaluated possible to retrieve fuel debris “safely”, “reliably” and “promptly”.

Moreover, proposed method of containing, transfer and storage of retrieved fuel debris, that retrieved fuel debris firstly contained in a small container is transferred and contained in the canister and stored in dry condition at the temporary storage facility built within Fukushima Daiichi NPS site, is also judged to be able to contain, transfer and storing the retrieved fuel debris “safely”, “reliably” and “promptly”. The schematic drawing about fuel debris retrieval and handling (containing, transfer and storage) is shown in Fig.5.

From the view point of optimization of entire decommissioning work of Fukushima Daiichi NPS, Unit 2 is currently judged to be appropriate for the first implementing unit. Its reasons are that the sufficient information on PCV internal condition and site condition (radiation dose, degree of air tightness by the existing safety system) has been obtained as well as that information and experiences on fuel retrieval work can be promptly obtained by starting its fuel retrieval work in a “safe”, “reliable” and “prompt” manner, based on site condition such that fuel debris retrieval work and fuel removal work from SFP can be done in parallel. Small-scale of fuel debris retrieval operation starting at Unit 2 enables to reduce of risk existing in Units 1, 2 and 3.

In Unit 2, in this way, fuel debris will be retrieved by using the arm-type access equipment, and a series of tasks from retrieving, containing, transferring, and storing fuel debris should be continued safely and reliably, then information/experiences required for further implementation should be gained promptly.

The points of recommendations for determining the fuel debris retrieval method of the first implementing unit, which were obtained from the results of these examinations and evaluations, are as follows:

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

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

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

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

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

The "Strategic Recommendation for Determining the Fuel Debris Retrieval methods for the First implementing unit" also discusses the efforts need to be made toward the fuel debris retrieval in the first implementing unit and expanding scale and retrieval in units other than the first implementing unit, which is described later in iii (1).

Progress of ancillary R&D and PCV internal investigation

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

Progress of work environment improvement

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

Progress of site-wide planning

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

↓

Study on concept of fuel debris retrieval

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

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

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

↓

Comprehensive assessment

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

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

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

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

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

↓

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

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

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

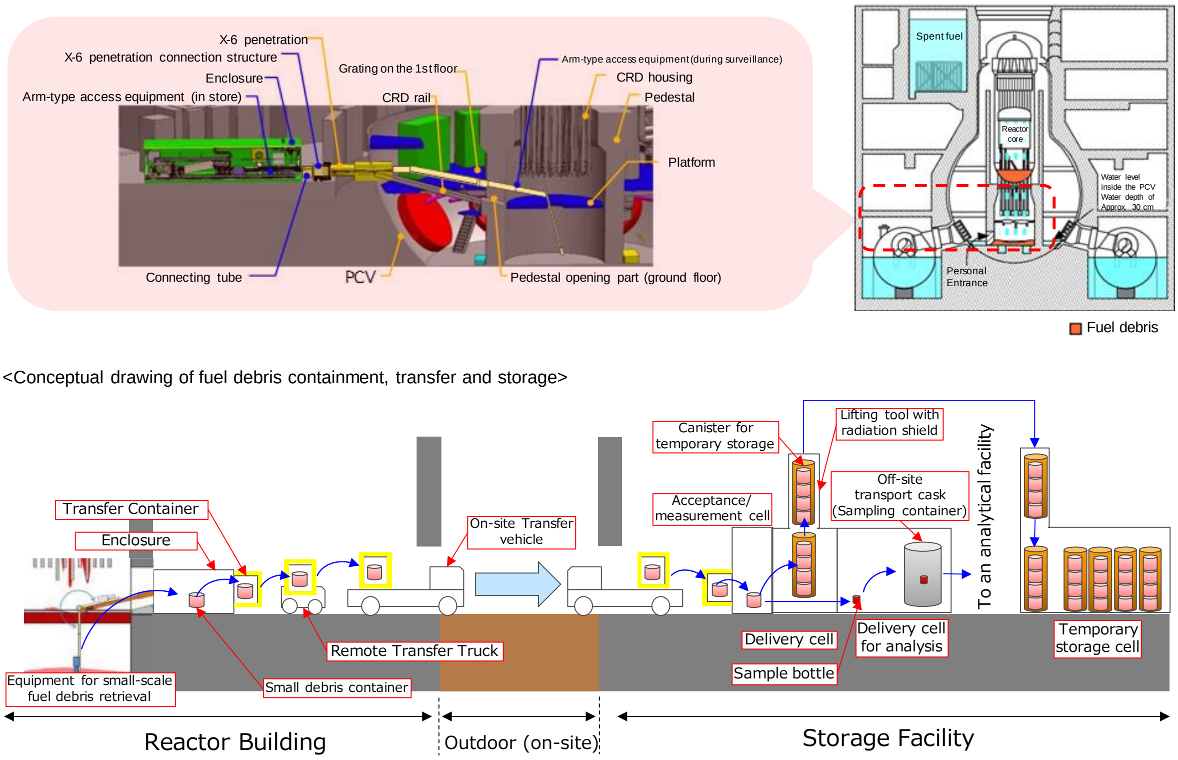
③ Retrieved fuel debris firstly contained in the small container is transferred, contained into the canister and stored in dry condition at the temporary storage facility built within Fukushima Daiichi NPS site.

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

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

Fig.4 Flow of Examinations on "Strategic Recommendation for Determining the Fuel Debris Retrieval Methods for the First implementing Unit"

<Conceptual drawing of fuel debris retrieval>



(TEPCO material edited by NDF)

Fig. 5 Conceptual drawing of fuel debris retrieval, containment, transfer, and storage

(3) Continued internal investigation and accelerated/prioritized R&D

Fuel debris retrieval will proceed according to the step-by-step approach that allows to flexibly coordinate the direction based on the information gradually obtained. Then, it is important to implement internal investigations steadily to understand the initial condition of PCV.

As for understanding about internal investigation of PCV, various information has been gained as a result of internal investigation of PCV that have been conducted so far. However, internal investigation of RPV has not been made and grasping of the internal condition of PCV and RPV is limited as a matter of fact. Thus, research and development (R&D) to implement internal investigation of PCV for collecting more detailed data such as distribution of deposits and fuel debris are underway as well as R&D to implement internal investigation of RPV for obtaining information about the internal condition of RPV.

As internal investigation of PCV, it should be implemented after thoroughly identified what kind of data is necessary. The required data which are distribution (and feature) of deposits and fuel debris inside PCV, information for access route and one for structural condition, are identified from the continuous project in preparing for fuel debris retrieval, which is progressing with step by step approach.

Analyses and investigations on the decommissioning and contaminated water management of Fukushima Daiichi NPS should be implemented within the range of efforts to proceed with decommissioning safely and steadily, since the top priority is to realize decommissioning safely and steadily as early as possible. The necessity to implement these analyses and investigations should be sufficiently considered from the viewpoint of investigating the cause of the accident and improving the safety of nuclear power in the future. After clarifying how the information obtained will contribute to decommissioning, these analyses and investigations should be conducted to the extent that it is reasonably acceptable as a decommissioning project based on the consideration of their significance and the associated burden. Therefore, Analyses and examination on the decommissioning and contaminated water management of Fukushima Daiichi NPS should be intentionally implemented, and their plan should be decided during the engineering process along the basic consideration on intentional implement of analyses and examination on the decommissioning and contaminated water of Fukushima Daiichi NPS.[3]

Acceleration and prioritization for R&D, including the establishment of a containment function on the assumption of the presence of α-nuclides and technology to control the water level in PCV, are encouraged based on the decision of advancing the side access to the bottom of PCV that has been made according to the fuel debris retrieval policy, as well as focusing on the partial submersion method. Preparing for expanding the scale of retrieval, it is important to obtain more information about internal condition of PCV and RPV, to proceed with technological developments to optimize efficiency of retrieval work, to reduce diffusion of radioactive fine particles during retrieval operation, to classify fuel debris and waste, and to analyze and examine the characteristic of fuel debris. In addition, it is also important to proceed with technological development which assume how to respond to the top access method for fuel debris retrieval. In the future, it will be necessary to strengthen R&D management on a project basis by identifying R&D tasks required through engineering studies and implementing them in a timely and appropriate manner.

iii. Technical Issues for promoting sectoral strategies and future plans

(1) Technical issues and plans related to the fuel debris retrieval from the first implementing unit

a. Initiatives toward start of retrieving fuel debris from the first implementing unit

Considerations should be given to the fuel debris retrieval for the first implementing unit in accordance with the recommendations for determining the methods of retrieving fuel debris for the first implementing unit as described in ii (2).

To safely and reliably retrieve fuel debris for the first implementing unit, it is necessary to appropriately provide hold points in the course of engineering activities by TEPCO considering the elements such as validation of safety and actual site applicability at the occasion of mock-up testing

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[3] TEPCO, The basic principles toward the planned analysis and investigation on the decommissioning and contaminated water management of Fukushima Daiichi NPS, Handout 4-1 from The secretariat Meeting of 67th Team meeting on decommissioning and contaminated water treatment, issued on June 27, 2019
http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2019/06/4-1-1.pdf

regarding small-scale retrieval equipment and verification on accessibility at the PCV internal investigation, then to proceed with the retrieval operation while confirming validity.

To make decision on the method of fuel debris retrieval of the first implementing unit, it is also required to pay attentions to the work schedule examination based on the issues through PCV internal investigations and work interference examination based on the considerations on the fuel removal method from SFP as mentioned followings.

- It becomes apparent through PCV internal investigation that there are obstacles in the access route to the fuel debris and improvement of measures to prevent dust diffusion is necessary when removing such obstacles. Accordingly detail planning and examination on work schedule aiming at start of fuel debris retrieval shall be promoted, considering removal method of the obstacles including enhancement of prevention of radioactive airborne material diffusion during obstacles removal work.
- It becomes apparent through PCV internal investigation, research & development and preliminary engineering by TEPCO that the works such as installation of the enclosure require many human works at the site. Accordingly detail planning and examination on work schedule aiming at start of fuel debris retrieval shall be promoted, considering further reduction method of the radiation dose rate at the first floor of R/B(about 5mSv/h) where most human works take place.
- It is observed through the investigation of operating floor of Unit 2 that the radiation dose is reduced so that human works would be available to some limited extent. Several plans are considered on the fuel removal from SFP with method to reduce risk of dust diffusion. Accordingly coordination of work interferences when making parallel works both for fuel removal from SFP and fuel debris retrieval including preparation works shall be well examined based on the progress of engineering on method of fuel removal from SFP.

Toward start of retrieving the fuel debris for the first implement unit, TEPCO announced a plan of the future internal investigations in July, 2018. For Unit 2, it is scheduled to conduct ① deposit contact investigation, ② investigation to grasp the distribution of deposits as well as sampling in small amount of deposits, and ③ sampling in larger amount of deposits. The status and purpose of each investigation and sampling are as follows.

① The deposit contact investigation was implemented in February, 2019. The purpose is to contact the deposits and to check the change of the state before and after contacting. As results, it is confirmed that deposits which are considered as the fuel debris are able to be moved by grasping.

② The investigation to grasp the distribution of deposits as well as sampling in small amount of deposits is scheduled to be implemented in future, and it is appropriate to be conducted before start of retrieving the fuel debris for the first implement unit. The purposes are a) to confirm that the arm type access equipment can go into PCV, and b) to characterize the fuel debris by analysis.

③ The plan of sampling in larger amount of deposits is under consideration now. The purposes are a) to confirm that the fuel debris retrieval can be carried out, and b) to characterize the fuel debris by analysis using larger amount of deposits.

The start of retrieving fuel debris was scheduled to be conducted after confirming a) of ③, this confirmation is evaluated so far to be obtained by the confirmations in ① and ②. In addition, the fuel debris retrieval in small amount is scheduled to start by gripping and sucking, and the data required for assessment of cutting the fuel debris, etc. is evaluated so for to be obtained by sampling in larger amount of fuel debris by using the same equipment as that for fuel debris retrieval in small amount. Thus, the fuel debris retrieval for the first implementing unit is possible to be integrally conducted with ③, and by this procedure it is possible to reduce the total amount of workers' radiation exposure and waste. Therefore, it is appropriate to revise a plan that the fuel debris retrieval for the first implement unit and ③ is scheduled to be integrally carried out.

b. **Initiatives for expanding retrieval scale and retrieval in units other than the first implementing unit**

Retrieval will start from small-scale with no significant changes in the state of the site in using existing safety system as a base, and expand the scale or retrieve fuel debris from units other than the first implementing unit based on new findings including information and experiences acquired from the small-scale retrieval operation. To allow for this, following activities are necessary.

a) Consideration of actual site applicability based on such as conceptual study on safety system
b) Information organization such as radionuclide airborne release fractions for examining necessary and sufficient safety systems
c) Site environment preparation such as radiation dose reduction, water level lowering in PCV and area planning
d) Further understanding of inside condition of PCV and RPV
e) Technologies to make efficient fuel debris retrieval including removing obstacles
f) Technologies to reduce dispersion of radionuclide airborne particles during fuel debris retrieval
g) Consideration on sorting and distinction of fuel debris and radioactive waste
h) Technologies to analyze and estimate fuel debris properties and distributions for understanding

In this regard, improving site work environment, PCV internal investigation and R&D are continued, regarding to the retrieval method in case of expanding the scale or applied to the units other than the first implementing unit. The retrieval method in conjunction with containing, transferring and storage should be determined after proceeding with engineering to examine new safety system, retrieval facilities and the prospect of their actual site applicability, which is based on the information and experiences obtained through fuel debris retrieval for the first implementing unit.

Since fuel debris retrieval is carried out in parallel with other works, it is necessary to revise the work plan in accordance with the overall situation of decommissioning activities. Especially in order to realize the regular full-scale fuel debris retrieval safely and smoothly, efficient site space plan with appropriate margin is an important issue by keeping stably available area in the site.

Furthermore, the way of fuel debris retrieval shall be flexibly considered in view of optimization of total decommissioning activities, as example the retrieval at the units other than the first implementing unit can start if prepared well, even though the retrieval of the first implementing unit is still continuing.

(2) Comprehensive understanding of conditions inner PCV by continued internal investigation

The comprehensive analysis and the evaluation results about the access route to fuel debris and the situation of the surrounding structures and the distribution of fuel debris in Units 1 to 3 are shown in Fig.6, that have been derived from actual measured values of plant parameters, etc., which were obtained at the time of accident, severe accident progress analysis, and the knowledge obtained by internal investigations of PCV and examinations, etc.

In Unit 2, for which an internal investigation is relatively advanced, it is scheduled hereafter to conduct the internal investigation to grasp the distribution of structures and deposits in the pedestal and to conduct samplings in small amounts of deposits. In such an internal investigation and sampling, it is necessary to make preparations for the investigation in advance by carefully allowing a certain time for adequate tests of the investigation equipment and training of its remote control, because the equipment which would be bigger than before and would be used for handling of obstacles, etc., will be different from that conducted in the previous investigations. During the internal investigation and sampling, it is not always necessary to obtain information only on the bottom of the PCV, but it is also important to obtain information necessary for the future work, including the characteristic (hardness, adherence situation, and elemental composition, etc.) of deposits adhering on the platform of PCV and the location of internal components.

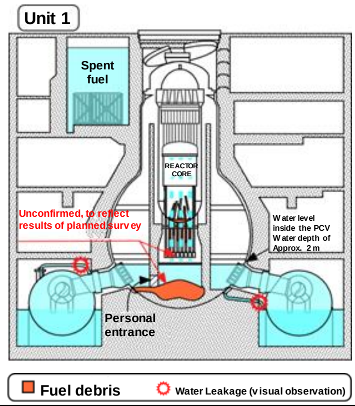
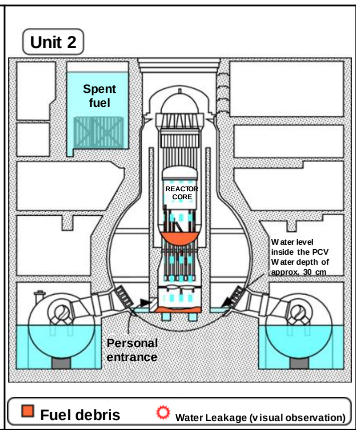
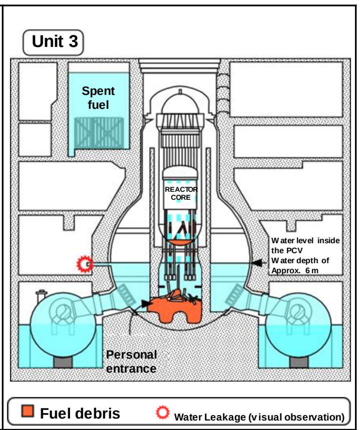
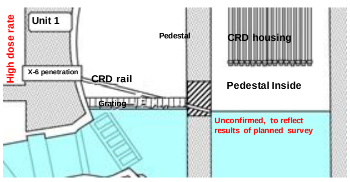
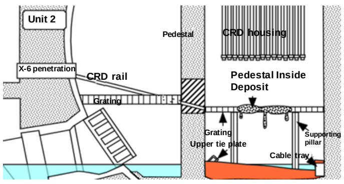
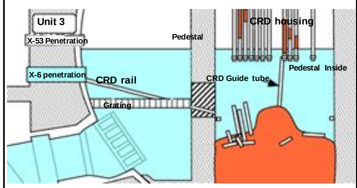
For Unit 1, grasping of the distribution of structures and deposits outside the pedestal and sampling of deposits in small amounts are scheduled for FY 2019. In addition to this, studies to confirm the condition inside the pedestal should also be considered.

For Unit 3, it is necessary to examine the applicability of techniques for internal investigations which were developed and verified through the Government-led R&D program on Decommissioning and Contaminated Water Management, and the necessity of further investigations by use of the submersible ROV which was used in the previous investigation, in parallel with the examination on the lowering of PCV water level.

For Units 1 and 3, considerations should be given to the method of fuel debris retrieval, in addition to these internal investigations.

In the future, prior to implementing further detailed internal investigations, giving due considerations will be required for continuous ensuring safety, including maintaining containment function and prompt recovery during abnormal events as well as measures against radiation exposure and dust control, since maximum opening size of existing penetrations through which equipment have gone into the internal PCV in the previous investigations will be used due to the introduction of larger equipment.

Fuel debris and deposits of Fukushima Daiichi NPS have special aspects that are unparalleled in the world due to the differences of reactor structure and of responding to restoration from the accident. It is necessary to develop analytical/estimation technology to characterize them because of their limited data and higher uncertainty. In particular, it is crucial to demonstrate analytical method for fuel debris by using retrieved samples of fuel debris in order to build analytical technology. In enhancing research facility for analyzing radioactive material, it is important to take into consideration the demonstrated outcome to proceed with characterizing fuel debris according to a location of PCV.

	Unit 1	Unit 2	Unit 3
			
Core Region	· Little fuel debris remains	· Little fuel debris remains (Stub-shaped fuels might exist in peripheral region)	· Little fuel debris remains
RPV Lower Head	· A small amount of fuel debris is present · A small amount of fuel debris is present in the inside and on the outer surface of the CRD housing	· Large amount of fuel debris is present · A small amount of fuel debris is present in the inside and on the outer surface of the CRD housing	· Fuel debris remains on the RPV lower head party · A small amount of fuel debris is present in the inside and on the outer surface of the CRD housing
Bottom of PCV Pedestal inside	· Most of the fuel debris is present	· A certain amount of fuel debris is present on the floor of the pedestal inside	· Amount of fuel debris in Unit 3 is more than that in Unit 2.
Bottom of PCV Pedestal Outside	· Fuel debris may have spread on the pedestal outside through the personal entrance	· The possibility of fuel debris spreading on the pedestal outside through the personal entrance is low.	· Fuel debris may have spread on the pedestal outside through the personal entrance
Radiation dose in operation site ＊1	· Radiation dose rate around penetration X-6 on the first floor of R/B is high (630mSv/h).	· Radiation dose rate on the first floor of R/B had reduced by about 5mSv/h.	· Radiation dose rate on the first floor of R/B is higher than tens of mSv/h.
			
Information on the access route to fuel debris *2	• It is possible to access to the D/W bottom from the upper side. • State around the CRD rail connecting to the pedestal from the X-6 penetration is not observed.	• There is no large obstacle on the CRD rail and around an entrance to the pedestal inside. • It is possible to access to the pedestal inside through an entrance.	• It is possible to access to the pedestal inside through an entrance.
Information of the structure around fuel debris	· There is no large damage on the surface of the pedestal outer wall above the steel grating.	• However a part of fuel assemblies fall, no large damage is observed on CRD housing support. • No large damage is observed on inner wall and structures of the pedestal.	• Some damaged structures and the fall of the CRD housing support were observed in the pedestal inside. • No large damage is observed on inner wall of the pedestal.

*1 Data provided by TEPCO

*2 It is thought that a route to the pedestal inside from the X-6 penetration is important for fuel debris retrieval from a small-scale task by side access method. The content observed by previous internal investigations are mentioned as information to judge whether trouble will be caused by fallen objects on the route, etc. In the access route for the fuel debris retrieval in the PCV, an access route through an equipment hatch is under review in the decommissioning and contaminated water management project.
Due to high dose rate around the X-6 penetration of Unit 1, it may use the same access route as the larger-scale retrieval in the case it is difficult to improve the work environment. Next internal investigation of Unit 1 is scheduled to develop by accessing from X-2 penetration.

(Prepared by Achievement Report 2017 Subsidy for "the Government-led R&D program on Decommissioning and Contaminated Water Management by the supplementary budget (Advancement of comprehensive internal PCV condition analysis)" (June 2018) provided by IRID, The Institute of Applied Energy), etc.

Fig.6 Estimation of fuel debris distribution in Units 1 to 3, access route and the condition of surrounding structures

(3) Technical issues on technical requirements and future plans

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

For ensuring the safety of fuel debris retrieval, it is important to study reasonable protective measures according to the scale of operation while taking actions to reduce the uncertainties of PCVs' internal conditions during the conceptual design phases of retrieval method. In the Strategic Plan, along with organizing the concept of ensuring safety, we are focusing on the key technical requirements for ensuring safety during fuel debris retrieval work as follows.

① Establishing the containment functions (Gas-phase)

As for retrieving of the fuel debris, applicability for the small-scale retrieval starting from gripping or sucking together with existing safety systems has been investigated and confirmed. However, the dispersion of radioactive fine particles (α-dust) containing α-nuclides may occur due to the works such as cutting and drilling fuel debris, and there may be a concern for increasing the concentration of radioactivity in PCVs gas phase. Therefore, a function for containing the gas phase should be established to suppress the radiation dose impact on workers and the public within the allowable value, by minimizing the spread of α-dust from PCV.

In this regard, it is reasonable to expand the scale of the retrieval work while verifying the validity of the containment function built in the subsequent stage by grasping the tendency of dust dispersion at the each stage of scale expansion. For example, during PCV internal investigations or the small-scale retrieval near future, α-dust dispersion can be managed by reducing amount to be retrieved or by careful handling of the fuel debris. At this moment, the dust monitoring system inside and outside PCV should be investigated. And the appropriate measures together with the existing systems that secure the pressure inside PCV equal or less than outside should be investigated as well.

If it is evaluated that the expansion of retrieval work may induce effects on the surrounding environment, further investigation is required for the means to strengthen the containment function by equalization or negative pressurization inside the PCVs as well as constructing a secondary containment function outside the PCVs.

② Establishing the containment functions (Liquid-phase)

To mitigate the dispersion rate of generated α-dust and to minimize the transition to the gas phase, fuel debris retrieval work would be performed, submerging the fuel debris or by pouring water over the fuel debris. Dedicated investigation of applicability for the small-scale retrieval starting from gripping or sucking with existing safety systems has been performed. A large amount of α-particles will flow into cooling water (liquid phase) during crushing for fuel debris or removing of the obstacle. To prevent the cooling water containing α-particles from affecting the environment, it may be of great importance to establish a cooling water circulation/purification system, and a liquid phase containment function.

For this reason, the investigations, that establish technologies of removing soluble nuclides to be leached from fuel debris as well as treatment of solid matter trapped by the filter equipped in the circulating cooling water system, shall be conducted. Also, it is requested to investigate the PCV circulation cooling system which takes the water of the bottom of PCV and injected cooling water into RPV and has an advantage of preventing dispersion of α-particles.

To establish a reasonable containment function in accordance with scale expansion, it is rational to monitor the radioactive concentration of the cooling water and verify the validity of the containment function built in the subsequent stage. For example, if the assumed PCV internal investigations and small-scale retrieval work would be performed using the current water circulation system, it may be possible to suppress the increase in the radioactive concentration of cooling water by reducing the retrieved volume and carefully performing the cutting work, as with the containment function (gas phase). At this time, it is requested to monitor the circulating water system from the viewpoint of investigating the methods to detect the effects induced by the retrieval work on liquid phase, and also requested to investigate necessity of additional facilities and installations for the purpose of reducing the concentration of radioactive materials at the inlet in the existing water treatment systems. Based on the results of monitoring and evaluation of the changes in the condition of the waste solution containing α-nuclides, the scale of fuel debris retrieval will likely be expanded gradually. If an abnormal event such as a large volume of cooling water outflow from a PCV to the torus rooms of a nuclear reactor building occurs, measures should be taken such that the water level in the torus room be maintained lower than the groundwater level to prevent the outflow of cooling water to the surrounding ground. For this reason, it is necessary to establish an appropriate PCV water level and a PCV water level control system.

③ Maintaining the cooling function

The decay heat of the fuel debris has been decreased dramatically since the core melt accidents. However, it may be necessary to keep the cooling function to prevent nuclides from shifting from the liquid phase to the gas phase due to thermal energy during fuel debris retrieval work. At present, the cold shutdown state is maintained with keeping the temperature well below 100 degree centigrade using cooling water. In addition, during fuel debris retrieval work, it may be necessary to keep the temperature below the level at which fuel debris retrieval device can continue to work without any problems for a long period of time.

To maintain the cooling function at each stage of retrieval scale expansion, the consistency with other systems should be checked, such as the concept of water level control within the PCVs for confining the liquid phase, the circulation cooling system and the contaminated water purification system, etc. Based on the data obtained for each stage of retrieval scale expansion, it may be necessary to examine and establish the circulation cooling system in the subsequent stages.

④ Criticality Control

At present, the monitoring of the concentration of rare gas (Xe-135) has shown no sign of criticality. Further, it may be pointed out that the possibility of criticality is low based on the expected state of existence of fuel debris. In addition, even if criticality should occur, its impact would be small because it is estimated that the fuel debris is dispersed over wide area. To keep the subcritical condition more reliably, it is important to store retrieved fuel debris stably in a controlled state, for instance, by storing it into storage cans. To prevent fuel debris from reaching criticality in the process of retrieving fuel debris, it is necessary to investigate what kind of conditions during the work would lead to criticality, in the case the shape of the fuel debris or the water volume changes, and establish an appropriate management method with combined functions of prevention, detection, and termination of criticality.

In the early stage of retrieval, the fuel debris should be retrieved in a way that does not significantly change the shape of fuel debris. Then, the neutron signal level by the situation of the composition and characteristics of fuel debris and the fluctuation of the neutron signal in the vicinity of fuel debris handled during the retrieval work should be checked to evaluate the criticality of the fuel debris, as well as to develop a measures of ensuring prevention of criticality by, for example, combining the oversight and judgement by operators. Also in the process of expanding the retrieval scale, any measures associated with increasing retrieved volume of fuel debris will be considered, such as measurement of subcritical condition before fuel debris retrieval work starting, or taking measures such as placing neutron absorbers.

⑤ Securing structural integrity (earthquake resistance) of the PCVs and reactor buildings

The reactor buildings, PCVs, and reactor pressure vessels (herein after referred to as “RPV”s) experienced the hydrogen explosions when the accident occurred. Further, the radiation exposure to the high-temperature environment and the corrosion due to seawater injection may have affected the integrity of the structures. During the period of fuel debris retrieval work, it is necessary to secure the integrity for the important structures like PCVs and RPVs and to suppress the deterioration of containment functions of PCVs and reactor buildings, considering the effect mentioned above against the possible occurrence of a severe earthquake. In addition, the deterioration of containment function of PCVs and reactor buildings due to corrosion have to be suppressed during the retrieval work. Furthermore, it may be required to prepare for the mitigation measures in advance, evaluating the impact on human beings and the environment induced by the postulated damage to important functions due to a large earthquake.

The previous studies show that the reactor buildings and structural major components of PCV, RPV and pedestal, that supports the RPV of each unit, have relatively large seismic safety margin against a design basis seismic ground motion Ss (600Gal), taking into account the damage caused by the accident, degradation over 40 years by corrosion and increased weight of new facilities required for fuel debris retrieval work. It is necessary to evaluate the seismic safety margin of R/Bs, PCVs and RPVs in more detail and to implement the countermeasures, according to the progress of the further PCV internal investigation and the studies of fuel debris retrieval methods.

⑥ **Reduction of radiation exposure during work**

The main work areas of fuel debris retrieval are high radiation dose areas such as inside the reactor buildings. Also, there comes a need of handling of nuclear fuel materials containing α-nuclides from fuel debris with a large internal dose impact. Accordingly, continued strict control of not only for external exposure but also for internal exposure is essential.

Specifically, it is important to prevent excessive radiation exposure to occupational workers through appropriate radiation protection schemes depending on the working environment and working style. Regarding protection from external radiation exposure, the radiation exposure dose is evaluated considering the radiation sources and the radiation dose rate in the work area. Then, based on the three principles, namely “time, distance, and shielding", it is needed to take measures to keep the radiation exposure dose as low as reasonably achievable. Regarding the protection from internal exposure, measures such as suppressing dispersion of radioactive dust and prevention of contamination expansion are being taken and appropriate protective measures are to be selected depending on the target nuclides, concentration in air and surface contamination density in the work area, to prevent inhalation ingestion and body pollution.

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.

b. Technical issues and future actions for fuel debris retrieval method

① **Securing access route**

For transporting, installing and unloading the equipment and devices used for fuel debris retrieval, and transporting fuel debris and waste, access routes should be established by removing obstacles and reducing the radiation dose to the level at which such tasks can be done by workers. When establishing new openings in the PCV or the like to construct access routes to fuel debris, it should be kept in mind to suppressing the release of radioactive materials from the PCV and RPV and maintaining the integrity of existing structures.

According to the fuel debris retrieval policy based on the partial submersion method that advances the side access to the bottom of the PCV, TEPCO is now conducting the engineering work. Based on the results of the Government-led R&D program on Decommissioning and Contaminated Water Management, an access route from the PCV side opening to the fuel debris is to be constructed. Then, it will be drawn up a plan in which a side wall opening is made on the reactor building and the side wall opening on the PCV is enlarged as required. In addition, toward the future scale expansion, it is also important to develop technologies for removing obstacles and retrieving fuel debris through the top access.

② **Development of devices and equipment**

Equipment and devices for accessing fuel debris and retrieving them safely, reliably, and efficiently should be developed. In order to flexibly respond to the situation on the site, these equipment and devices must meet the specifications of radiation resistance, remote operation and maintainability, high reliability, and relief mechanisms that do not disturb the subsequent work if a trouble occurs.

Accordingly, the development of a retrieval system that can handle various conditions of fuel debris, a fuel debris cutting system, and a dust collecting system, is underway. Furthermore, techniques for installing retrieval equipment is required. The technologies used for remote operation, including installing the work cell for establishing radiation shielding and containment functions (gas phase), boundary connection with existing structures, securing an access route for the top access and removing obstacles required for each of the top access method and side access method, are now under development. The developed equipment and devices will be combined and undergo mock-up tests to verify that the performance mentioned above is demonstrated in a safe and assuring way at the actual site.

③ Establishment of system equipment and working areas

Prior to retrieving fuel debris, it is required to validate that the safety systems can perform in accordance with safety requirements and safety functions, also requested to investigate necessity of additional facilities and installations if required. Then appropriate operation shall be taken. Sufficient spaces for installation, operation, and maintenance, and for installing shields for reducing radiation exposure to operators should be provided, so that the required environmental conditions will be satisfied.

The system equipment includes a negative pressure control system required for establishing a containment function (Gas phase), a circulating water cooling/purification system required for maintaining the containment function (Liquid phase) and cooling function, and a criticality control system required for controlling criticality. Elaboration of measurement systems (pressure, temperature, water level, radiation, etc.), which are essential to monitor the condition inside PCV prior to fuel debris retrieval, is an important technical items to be conducted. An investigation on the specific method of implementing an overall system and equipment integrating these systems should be conducted.

The working area required for installing fuel debris retrieval equipment/related devices and system equipment is now being calculated. Considering the handling of the high radiation dose area in the reactor buildings and interference with other tasks, study of setting up the systems, including outside of the existing buildings, is underway.

c. Technical issues and future actions for safe and stable storage of fuel debris

① Handling of fuel debris (containing, transferring and storing)

Before initiating fuel debris retrieval work, a comprehensive system should be established which consists of a series of steps from containing, transferring to storing of retrieved fuel debris furnished with safety functions such as maintaining subcritical condition, containment function, countermeasures against hydrogen generation, and cooling. The following examinations are in progress accordingly.

- Drawing up of basic specifications of the canister for retrieved debris storage, that is, overall length considering its handling, internal diameter in light of work efficiency and maintaining subcriticality, etc., and planning and implementation of tests to verify the structural integrity of the canister
- Examination of a practical prediction method for hydrogen generation from fuel debris stored in the canister, and consideration on safe transfer condition using the examination results
- Study on drying technology applicable to fuel debris in the canister, and consideration on a drying system using this technology

In the future, specific facilities and systems should be developed from containing to storing of retrieved fuel debris, based on the results of these studies. In addition, further studies should be made on the specific transfer method, the specific type and size of the storage facility, and others, taking into account the amount of fuel debris to be retrieved per day and the filling rate of the canister. In developing specific facilities and systems for handling and storing of retrieved fuel debris, it is also necessary to include responses to safeguards requirements.

It is important to reflect various measurement data collected and accumulated during the small-scale retrieval such as the amount of generated hydrogen, as well as knowledge and experiences on handling fuel debris during the operations from receiving the fuel debris by containers for on-site transfer to storing them at the temporary storage facility, into the design of equipment and facilities for storing fuel debris safely, reliably, and reasonably at expanding scale of retrieval. In addition, it is necessary to specify transfer routes and storage facility locations for expanded-scale retrieval in light of the usage plan of the entire site.

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

② Treatment of radioactive waste during fuel debris retrieval work

During fuel debris retrieval work, a variety of radioactive waste such as replaced or disassembled structures/parts other than retrieved fuel debris are to be generated from inside/outside of the PCV at each phase of its preparation, retrieval and cleaning work. They should be properly classified and put under safe storage conditions.

For the preparation of expanded-scale retrieval work phase, it is important to develop classification criteria toward expanded-scale retrieval in order to appropriately classify such materials as fuel debris or radioactive waste, even if only limited information on the retrieved material is available in advance. For this reason, it is necessary to consider possible methods to classify fuel debris and waste based on knowledge and information that will be obtained in future PCV internal investigations, etc., and to promote survey of component technology and address of technical challenges, which are necessary for realizing such classification.

③ **Safeguard policy for fuel debris**

For Units 1 to 3 of the Fukushima Daiichi NPS, as fuel assemblies treated as items under the material accountancy would no longer maintain their original shape due to melting and the facilities were broken, the same containment/surveillance systems as the level of pre-accident could not be applied. And high radiation would restrict the entry into the areas for inspection and verification activities. Accordingly, pre-accident material accountancy and safeguards has been difficult to be applied and implemented. Therefore, additional safeguards measures are currently applied under this situation to the Units 1 to 3 as an alternative to ensure no undeclared movements of nuclear materials.

On the other hand, as fuel debris retrieval work involves the shipment of nuclear material, new material accountancy and safeguards should be considered. It is necessary to have discussion and share information with IAEA and others in a timely and an appropriate manner in order that newly established material accountancy and safeguards are realistic, so as not to impose excessive burden on the on-site activities, and sufficiently transparent. And such an effort has already started.

Technical issues and future planning described in this article is as shown in Fig. 7.

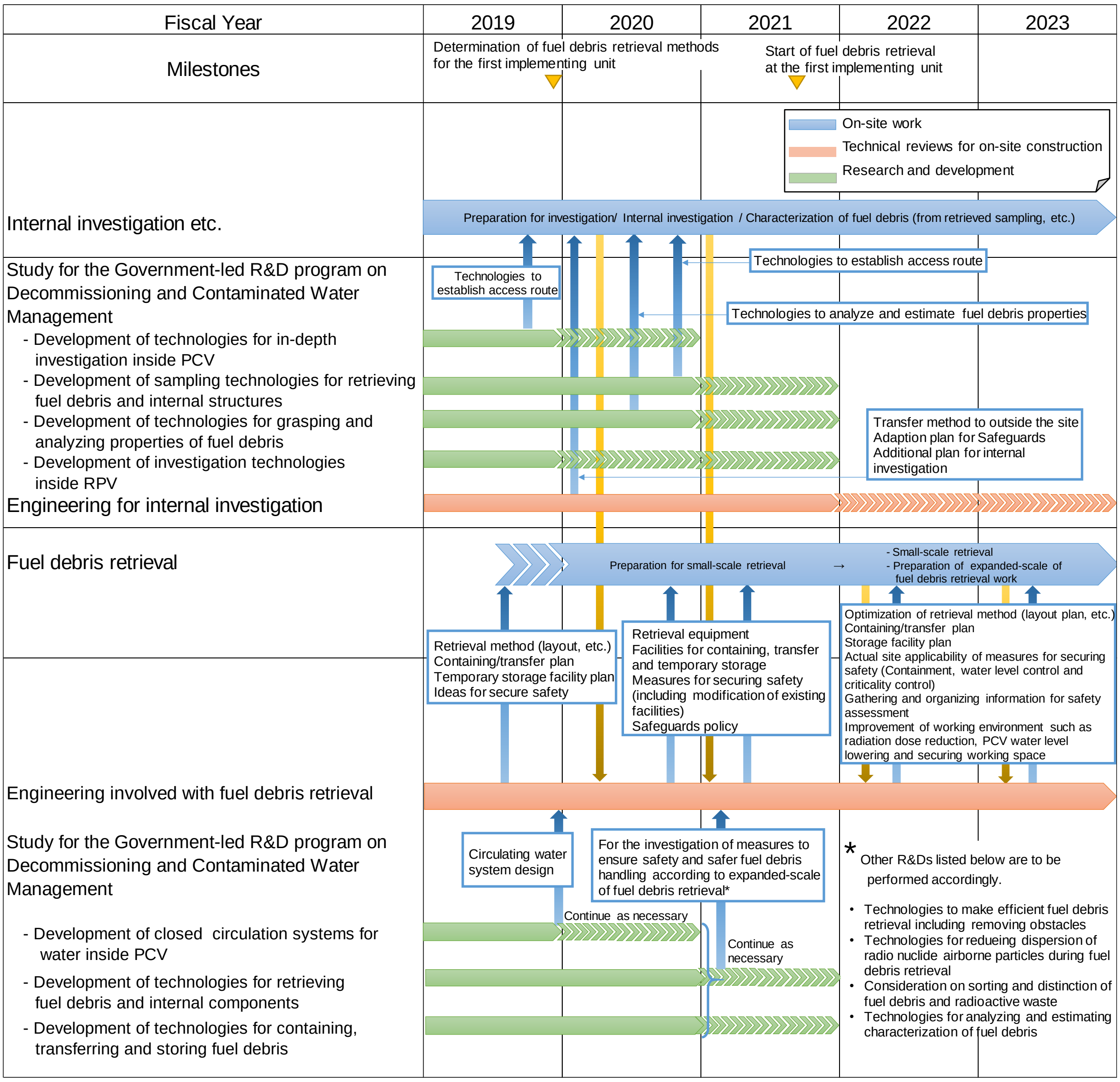


Fig.7 Key technical issues and further planning on fuel debris retrieval（Process chart）

2) Waste management

i. Sectoral target

(1) As the approaches of solid waste storage, the Solid Waste Storage Management Plan (herein after referred to as “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) As the approaches for processing/disposal, countermeasures integrated from characterization to processing/disposal of solid waste are studied from the expert point of view, and the prospects of a processing/disposal method and technology related to its safety should be made clear by around FY2021.

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

① Thorough containment and isolation
Containment and isolation shall be thoroughly carried out so that people will not access to radioactive materials to avoid significant radiation exposure.

② Reduction of solid waste volume
The amount of solid waste generated during decommissioning shall be reduced to the extent possible.

③ Promotion of characterization
To promote studies on processing and disposal of solid waste, an appropriate characterization shall be performed in response to the increase in the number of samples for analysis.

④ Thorough storage
Adequate storage capacity shall be secured for solid waste generated, so that they can be stored safely and reasonably according to their characteristics within the site of the Fukushima Daiichi NPS.

⑤ Establishment of selection system of preceding processing methods in consideration of disposal
Before the technical requirements for disposal are determined, a method of selecting a processing (preceding processing) for stabilization and immobilization shall be established to select a preceding processing method.

⑥ Promotion of effective R&D with a bird’s-eye-view of overall solid waste management
Issues on R&D shall be identified through collaboration among the fields of characterization, treatment and disposal, with a bird’s-eye-view on the overall solid waste management.

⑦ Efficient implementation of R&D projects from the perspective of overall solid waste management
For ongoing safe and steady solid waste management, a continuous operational framework including development of adequate facilities and human resources shall be established.

⑧ Measures to reduce radiation exposure of workers
Thorough radiation exposure control, health control, and safety management in accordance with relevant laws and regulations shall be established.

ii. Sectoral Strategies

(1) The concept of risk reduction in waste management and basic policies on solid waste

The solid waste stored on the sites, such as “rubble, etc.”, is unlikely to increase in risk in the future, but it is still a source of risk which should make its countermeasures properly in the decommissioning process. It is in a state where the risk level is generally lower than other major risk sources, and it is considered that a constant risk level can be continuously maintained by appropriate maintenance and management in the future.

The challenge on solid waste generated by decommissioning of the Fukushima Daiichi NPS is the existence of a large volume of waste with various characteristics. For this reason, in addition to improving the analytical capability for characterization, a flexible and reasonable waste stream (an integrated flow of measures from characterization to processing/disposal) shall be developed. Specifically, the relevant organizations should proceed with their efforts based on each role in line with the basic policies of solid waste management that was compiled in the Mid-and-Long-term Roadmap, and NDF takes the initiative and proceeds with the technical study on the integrated countermeasures from the characterization to processing/disposal of solid waste according to the following policies.

(2) Storage

The fundamentals of managing solid waste are to confine not to scatter or leak. Also, it should be kept isolated in a properly storage place, and managed appropriately by monitoring and so on. It is important to instill the concept of the waste hierarchy, and raise awareness on reducing the volume of solid waste to be generated. 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. Since the estimated amount of generation fluctuates depending on the progress of the decommissioning work in the future, it is necessary to revise the volume estimation once a year and update the Storage Management Plan as appropriate.

The secondary waste generated by water treatment, which has high fluidity, should be stored and managed in a more stable and reasonable way, by reducing risk levels through a certain processing. In general, it is ideal to conduct waste processing based on the technical requirements of disposal once it is established, if the processing is conducted prior to disposal. However, there may be cases where processing for stabilization and immobilization are required although the technical requirements for disposal are not determined (i.e. preceding processing). Therefore, study will be continued on how to select the preceding processing method with disposal in mind.

(3) Study on the processing/disposal policy

The Mid-and-Long-term Roadmap specifies that the prospects of a processing/disposal method and technology related to its safety should be made clear by around FY2021. The overall picture of solid waste becomes clear step by step according to the progress of the effort. Keeping it in mind that it will still remain in a stage of accumulating necessary information on its characteristics around FY 2021, the concrete targets for technical perspective are listed as follows:

- Establish safe and rational 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 method reflecting features of the disposal concept, with considering examples of foreign countries.
- Clarify radiological analysis and evaluation method for characterization.
- Clarify processing technology that could be expected to introduce actual equipment for stabilization and immobilization considering disposal for several important waste streams such as secondary waste generated by water treatment.
- Establish method of rationally selecting processing technology to stabilize and immobilize waste based on the above methodology although the technical requirements for disposal are not determined (i.e. preceding processing).
- Have prospect of setting processing/disposal measure for solid waste of which the processing technology considering disposal is not clarified, using a series of method to be developed by around FY2021.
- Clarify issues and measures concerning storage of solid waste until it is conditioned

It is described in the Mid-and-Long-term Roadmap that in accord with these efforts, specifications and production methods of the waste packages associated with decommissioning work should be determined in the third phase. Then, a processing system should be installed in the Fukushima Daiichi NPS. After establishing the prospects of disposal, production of waste packages should be started, and then carried out.

iii. Technical issues and plans for promoting sectoral strategies

(1) Promotion of characterization and enhancement of analysis systems and technical capabilities

It is essential to analyze and understand a wide variety of radioactive waste generated in the decommissioning process in order to consider reasonable storage and processing/disposal methods. To carry out such analysis work, there are important issues, such as developing facilities as hardware, development of human resources for analysis, and inheriting and enhancing technical capability on analysis. Therefore, for the time being, it is important to systematically promote the development of Radioactive Material Analysis and Research Facility and the development of human resources for analysis. Through these efforts, technology, facilities and systems must be established, and the necessary analytical work for decommissioning must be carried out continuously and in a timely and appropriate manner.

Under the circumstance that the Laboratory-1 of the Radioactive Material Analysis and Research Facility is scheduled to commence operation at the end of FY 2020; it is important, for the time being, to improve the accuracy of models to obtain evaluation data based on the limited number of radiological analysis data. Analysis for characterization has been studied, but in the future, clarification of analytical accuracy and review of the nuclides to be analyzed in accordance with the objectives of storage and processing/disposal will be carried out, and simplification and acceleration of radiological analysis methods will be studied to establish an efficient analytical technique.

In addition, by the government-led R&D program on Decommissioning and Contaminated Water management, the sampling and analysis of rubble, contaminated water, secondary waste generated by water treatment, etc. are carried out, and the correlation of nuclide composition of each analysis object is gradually clarified, and R&D for characterization are being carried out.

(2) Further safety improvement in storage

As temporary risk reduction measures concerning secondary waste generated by water treatment, processes to be dehydrated for stabilization and extracted/removed the waste will be implemented to transfer from temporary storage facilities to storage facilities on a hill.

On the technologies for stabilization, immobilization and conditioning of the secondary waste generated by water treatment, while addressing challenges for introducing actual equipment, gathering and evaluation of data on technical requirements should be made. Processing technology expected to be applicable for actual processing should be identified, and specification of waste package should be determined, from the point of view whether it may contributes to establish selection method for preceding processing method.

Regarding the methods of storing high radiation dose solid waste generated during fuel debris retrieval, study should proceed on the items such as the way of sorting fuel debris/waste, the type of waste, the evaluation of waste volume, and the flow of handling waste, and narrow down candidate methods for storage. For storage and management, it is necessary to study measures against hydrogen generation, and reasonable methods, such as application of vented containers should be examined.

For other solid waste, study should proceed on generation of hydrogen during storage, together with the timing and content for the case of requiring further measures to secure safety, and reflects to the Storage Management Plan as needed.

(3) Development of processing/disposal concept and safety evaluation method

In order to select candidate technology as a preceding processing methods, it is necessary to conduct safety assessment with the specifications of the waste package that is developed by respective candidate technologies, as a target. For that reason, selecting reasonable and feasible candidate technologies and developing safety assessment methods will be made by the end of FY 2021.

Solid waste from the Fukushima Daiichi NPS is characterized by a large amount of waste with a wide variety of properties. Therefore, it is necessary to consider solidification performance, detoxification performance, control of hydrogen generation, processing speed, volume reduction performance, etc. when selecting processing technologies, based on the R&D status of each technology. From this viewpoint, the R&D of low-temperature processing technology (cement solidification, etc.) and high-temperature processing technology (vitrification, etc.) are currently being carried out as concrete processing technologies in the Government-led R&D program on Decommissioning and Contaminated Water Management.

Furthermore, in establishing the concept of disposal, it is necessary to consider issues such as enlarging the capacity of disposal facilities, the acceptability of various types of waste, and uncertain risks, due to the fact that the waste from the Fukushima Daiichi NPS is large in quantity, has various properties, and is characterized by large uncertainties. From this point of view, the approach will be studied for the case using preceding overseas examples as reference.

(4) Other

As solid waste to be generated with fuel debris retrieval in future, structures such as core internals and outside of reactors to be dismantled and removed, and secondary waste such as filters generated during fuel debris retrieval related works are expected. It is necessary to proceed to study on the storage method for the solid waste along with the study on the method of fuel debris retrieval.

Technical issues and further plans described in this article is as shown in Fig. 8.

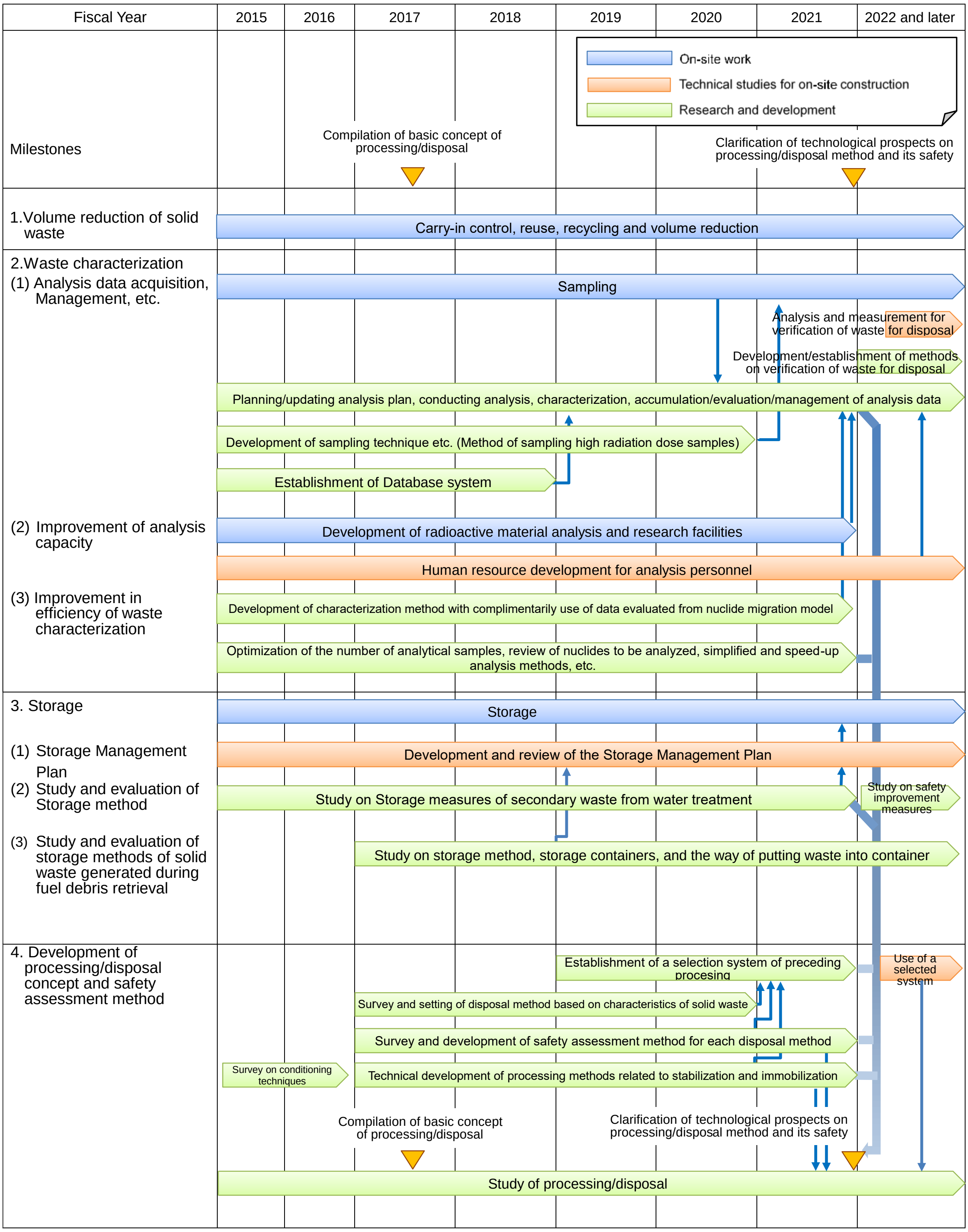


Fig.8 Key technical issues and further plans on waste management (Process chart)

3) Contaminated water management

i. Sectoral target

(1) Under the three basic principles concerning contaminated water issues ("Removing" contamination sources, "Redirecting" fresh water from contamination sources, and "Retaining" contaminated water from leakage), the reinforcement and optimum operation of the water level control system should be continued. The multilayered measures should be implemented to complete the processing the stagnant water in the buildings by 2020.
(2) Considering the total decommissioning process including the full-scale fuel debris retrieval beginning in near future, the long term strategy should be examined for the measures of the contaminated water.

ii. Sectoral strategies

(1) Concept of risk reduction in contaminated water management

Measures have been taken based on the three principles on the issue of contaminated water ("Removing" contamination sources, "Redirecting" fresh water from contamination sources, and "Retaining" contaminated water from leakage).

The stagnant water in the buildings is the liquid containing a considerable amount of dissolved radioactive materials and its hazard potential is relatively high. Thus the stagnant water is required to be dealt with as soon as possible.

The radioactive materials contained in stagnant water have been treated with cesium adsorption apparatus and transferred to the secondary waste such as adsorption vessel.

(2) Steady execution of contaminated water management indicated in the Mid-and-Long-term Roadmap

From a situation requiring urgent countermeasures immediately after the accident, it is thought that it has shifted to a certain stable state where it is possible to forecast a mid-to-long-term plan to some extent by preventive and multilayered countermeasures based on the three principles on the issue of contaminated water. The milestones shown in the Mid-and-Long-term Roadmap are as follows: (1) reduction of the contaminated water generation to about 150 m^3/day (by 2020), (2) storing all the water treated by nuclides removal equipment in the welded type tanks (FY 2018), (3) by lowering the level of stagnant water in the buildings, separation of the penetrations between Units 1 and 2 and between Units 3 and 4, respectively (by 2018), (4) reduction of the radioactive materials in the stagnant water in the buildings up to approximately one tenth of the amount at the end of FY 2014 (FY 2018), and (5) completion of the treatment of stagnant water in the buildings (by of 2020).

As of July 2019, (2) and (3) of these have been completed. The amount of radioactive material has been treated more than planned, on the other hand, due to the progress in the processing of stagnant water, a high radioactivity concentration was detected in some areas, making it difficult to evaluate (4). However, efforts will be made to complete the treatment of stagnant water in buildings by the end of 2020. It is expected that the specific measures outlined in the Mid-and-Long-term Roadmap will continue to be steadily implemented to achieve the milestones.

(3) Study on contaminated water management based on the relation with fuel debris retrieval work

Because full-scale decommissioning work including fuel debris retrieval will start after a while, it is necessary to discuss the optimal control of contaminated water and groundwater together at each stage of the decommissioning process.

According to the target process of the Mid-and-Long-term Roadmap, it is considered that the processing of stagnant water in the buildings other than the reactor buildings of Units 1 to 3 will be completed by 2020. By that time, a circulation system in which the stagnant water is recovered in the reactor buildings (instead of turbine buildings) and purified to be used as a coolant should be established. In addition, examinations should be made on the lowering of the stagnant water level in the reactor building and the lowering of the water level in the suppression chamber. Furthermore, the PCV circulation cooling system is being studied in accordance with the expansion of the scale of fuel debris retrieval work.

From the viewpoint to secure a multiple boundary, the water sealing method by repairing the bottom of PCVs have also been studied. It has been revealed, however, that complete water sealing through the repair work of the bottom of PCVs is very difficult, hence the circulation system should be prepared for the inflow of α-particles from inside of the PCVs to the stagnant water in the reactor building. It is also necessary to consider setting an appropriate difference in the water level between the stagnant water in the reactor building and groundwater, in case cooling water leaks from a PCV into the reactor building.

As the fuel debris retrieval proceeds, when water injection for cooling the fuel debris is no longer necessary, it can be expected that there is no water inflow into the reactor building. In such a case, it is important to build a system that can stably control the groundwater level for a long period, such as by combining passive equipment with fewer machine troubles than other to dynamic equipment.

iii. Technical issues for plans for promoting sectoral strategies

(1) Steady execution of contaminated water management stated in the Mid-and-Long-term Roadmap

By steadily continuing preventive and multilayered measures based on the three principles on the issue of contaminated water, consideration should be made toward the completion of treatment of the stagnant water in buildings, while suppressing further generation of contaminated water and preventing leakage.

(2) Study on contaminated water management based on the relation with fuel debris retrieval work

With regard to the PCV circulation cooling system during fuel debris retrieval work, since fuel debris-derived materials containing α-particles may be mixed into the water treatment system, it is necessary to proceed with the examination of the entire system, including enhancement of the monitoring to confirm the concentration of radioactive materials at the inlet of the water treatment system and the installation of equipment to reduce the concentration of radioactive materials.

In addition, for the PCV circulation cooling system which is to be established depending on the expansion of the scale of fuel debris retrieval, it is necessary to set the conditions for receiving a part of purified water at existing equipment as a destination of water constantly flowing into the reactor building, in parallel with examining the PCV circulation cooling system.

In order to maintain the effectiveness of contaminated water management for the future, further enhancement is needed on monitoring system (e.g. observation point, observation frequency or data management, and so forth) for water level of groundwater and radioactive materials for the purpose of steadily managing the groundwater surrounding the buildings as well as implementing regular inspections and updates of facilities for sure. Moreover, necessary contaminated water management should be considered based on the association with risks from large-scale natural disasters including tsunami or heavy rain and further decommissioning operations.

Technical issues and further plans described in this article is as shown in Fig. 9.

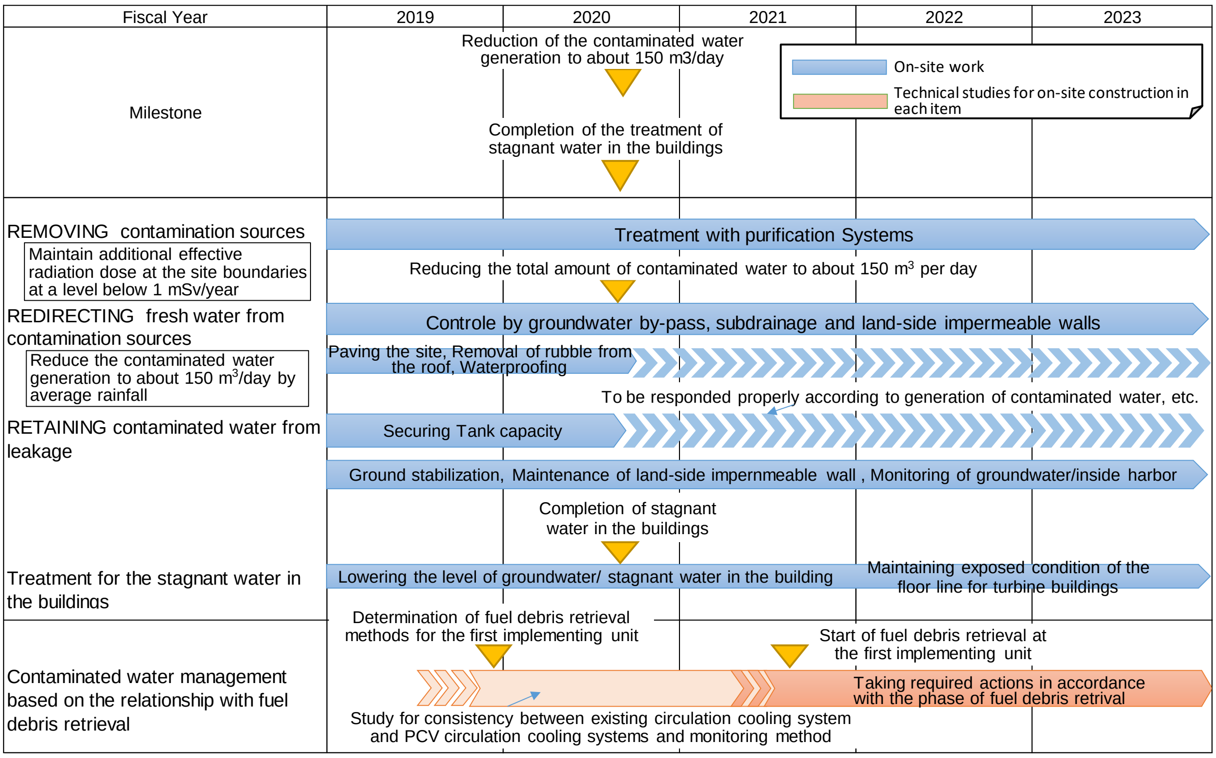


Fig.9 Key technical issues and further planning on contaminated water management (Process chart)

4) Fuel removal from spent fuel pools

i. Sectoral target

(1) Risk assessment and management for the progress of the work will be carried out properly, and measures for safety and security including the prevention of scattering of radioactive materials will be taken thoroughly. For Units 1 and 2, the removal of fuel in SFP will start by 2023. For Unit 3, the removal is scheduled to be completed in FY2020.
(2) By transferring the fuel stored in the common spent fuel storage pool to the dry cask temporary custody facility, the fuel in the spent fuel pools of Units 1 to 4 is to be stored in the common spent fuel storage pool appropriately.
(3) Based on the assessment of the long-term integrity and investigation for future treatment of the removed fuel, the storage and future treatment methods of them will be fixed around 2020.

ii. Sectoral strategies

(1) Risk reduction concept and concrete plan for removing fuel in SFP

The fuel stored in SFP of the reactor buildings of Units 1 to 3, some of which were partially damaged by the hydrogen explosion, is to be transferred to the common spent fuel storage pool that needs lower safety management, as shown in Fig. 3 of Chapter 2, in accordance with an appropriate and concrete work plan developed depending on the situation of each unit, as soon as possible. Especially, return of the local residence and reconstruction approaches began after the first evacuation instruction has released in the locating municipalities of Fukushima Daiichi NPS in April 2019. Considering these circumstances, careful approaches focusing on safety more are necessary against dust dispersion, and the like. For example, in Unit 1, since there is rubble on the operating floor, and there are operational risks such as a rubble falling into the spent fuel pool during the rubble removal work or impact on surrounding area and workers resulting from dust scattering. While giving due considerations to those, it is necessary to carefully prepare for the removal of fuel in SFP.

Work schedule for Units 1 to 3 was specified in the Mid-and-Long-term Roadmap, and TEPCO has been proceeding with their tasks to meet this schedule.

In Unit 1, roof slab, steel frame building materials for the upper part of the buildings, and fuel handling machines were scattered around the operating floor. The removal work of this rubble started in 2018 and has been continuing, and the removal of fuel from the SFP is scheduled to start in FY 2023.

In Unit 2, in order to install the fuel removal facility, a method to access the operating floor is being considered, and removal is scheduled to start around FY 2023 based on the radiation dose survey conducted on the operating floor in FY2018.

In Unit 3, removal of fuel in SFP began in April 2019 and to be addressed with top priority given to safety assurance while aiming to finish in FY2020, although there were some delays due to a number of malfunctions that occurred during the test runs of the fuel handling equipment.

The fuel in SFP of Units 5 and 6 reactor buildings are being stored under stable conditions same as a normal nuclear power plant. The Mid-and-Long-term Roadmap states that the spent fuel of Units 5 and 6 should be properly stored in each spent fuel pool for the time being and then, the removal should be carried out so as not to affect the operations of Units 1 to 3.

(2) Storage plan for removed fuel

Adequate storage capacity for the removed fuel in SFP of each should be reserved both in the common spent fuel storage pool and in dry cask temporary custody facility. For this reason, it is necessary to expand storage capacity of the dry cask temporary custody facility systematically.

(3) Decision of future treatment and storage methods

The fuel in SFP includes many kind of spent fuel such as flawless spent fuel, damaged one before the accident, and that may be damaged by the fallen rubbles into the spent fuel pool. There was also a history of seawater injection into the spent fuel pools of Units 2, 3 and 4 when the accident occurred. Although these effects are expected to be small, it is necessary to identify whether there are technical requirements that may impede the same treatment as ordinary spent fuel.

In the future, considering the status of fuel removed from Unit 3, assessment of the long-term integrity and investigation for future treatment of the removed fuel will be carried out and, future treatment and storage methods will be decided around FY 2020.

iii. Technical issues and future plans for promoting sectoral

(1) Removal of fuel in SFP

<Unit 1>

In Unit 1, the roof of the building collapsed due to hydrogen explosion accumulated on the operating floor as rubbles and the fuel handling machine (FHM) and the overhead crane were deformed and damaged and covered over the spent fuel pool. When removing this rubble, it is important to take measures to prevent rubbles, FHM or overhead crane from falling into the spent fuel pool, and it is necessary to carefully conduct the required work over a certain period of time, including the protection of the spent fuel pool and the support of overhead cranes. In addition, with the progress of the rubble removal work, it is considered that the status of the site, such as the distribution of rubble, will be revealed. Therefore, it is necessary to make steady progress in the work step by step based on the onsite information.

In addition, from the viewpoint of effects on the surrounding environment, removal of rubble on the operating floor and manipulation of the well plugs need to be carried out with measures such as the prevention of radioactive dust dispersion and radiation dose monitoring, due to possible effect of sky-shine radiation caused by a gap of well plugs.

<Unit 2>

In Unit 2, so far both plans have been studied, which are to share containers for fuel removal from SFP with containers for fuel debris retrieval and to install a cover for fuel removal from SFP respectively for the purpose of dismantling the upper part of the operating floor in the reactor building. In addition to this, another plan has also been studied, which includes a method to reduce risk of radioactive dust dispersion during dismantlement of the buildings and to access from the south side of the reactor building without dismantling the upper part of the operating floor as much as possible from viewpoints of advancing construction in a safer and more secure manner.

In regard to determination of removal plan for fuel in SFP, it is necessary to comprehensively study radioactive dust dispersion control, securing safety for surrounding environment and workers' radiation exposure, rainwater control and feasibility with other works to be performed in parallel.

<Unit 3>

In Unit 3, there was a malfunction with the fuel removal device, the start of the removal was significantly delayed from the original plan. Of fuel in SFP, and twenty-eight new fuel were removed from the pool in April 2019, completing the transfer to the common spent fuel storage pool. It is necessary to continue working steadily toward completing the removal of the remaining fuel in SFP in FY2020.

(2) Proper storage of removed fuel

For systematic transportation of fuel in SFP possessed by the entire site to the common spent fuel storage pool, a fuel transportation plan needs to be developed, taking the fuel stored in Units 5 and 6 into account as well, and dry cask temporary custody facility needs to be added accordingly.

(3) Decision of future treatment/storage method

R&D on the long-term integrity of the fuel in SFP which has contacted with seawater or fallen rubble has indicated that removed fuel can be stored safely under the environment of common spent fuel storage pool for a long period. Also, it was confirmed that the effect of seawater and scratches by fallen rubble on the fuel is limited for integrity of stored fuel in the dry cask. Furthermore, another R&D showed a perspective that the impact of seawater and scratches by fallen rubble on the fuel is very limited on the treatment of the fuel removed from SFP.

In the future, it is necessary to check the fuel removed from Unit 3 and determine whether or not it needs to be considered for long-term storage.

Technical issues and future plans described in this article is summarized in Fig. 10.

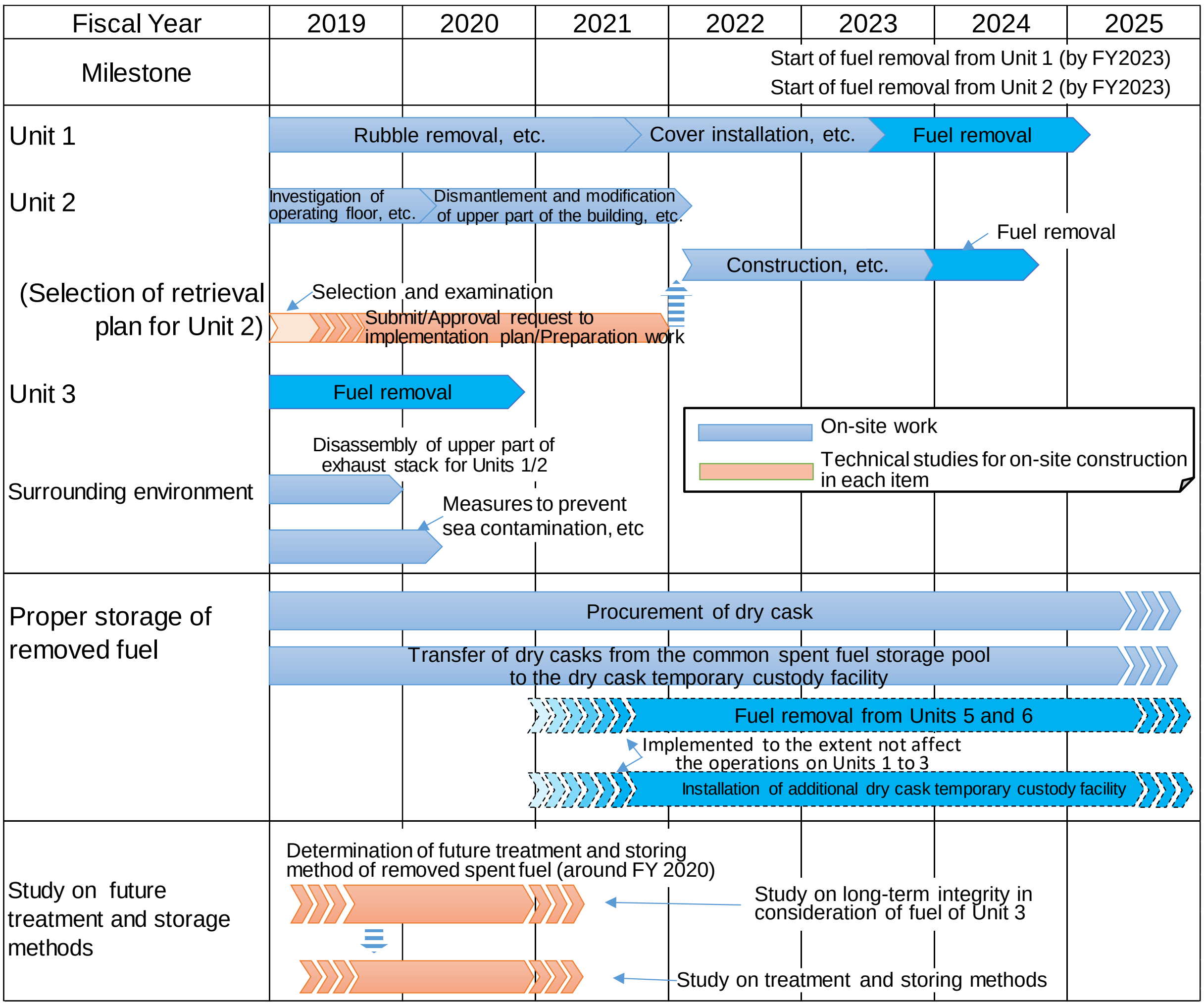


Fig.10 Technical issues and further plan on removing fuel from spent fuel pool (Process chart)

5) Other specific measures

i. Sustaining of reactor cold shutdown status

As for the plant conditions of Units 1 to 3, it is judged that a stable state of cold shutdown is maintained based on the internal plant data on PCVs, such as radiation dose, temperature, hydrogen concentration, pressure, radioactive substance concentration, etc. To maintain the stable state in the future, it should be continued to monitor parameters in PCVs and seal nitrogen to reduce a risk of a hydrogen explosion, while maintaining and improving reliability through maintenance and management. In light of the fact that the decay heat of fuel debris is thought to have decreased significantly, a flow rate reduction test for fuel debris cooling at Unit 2 was conducted in April 2019, and a temporary shutdown test for cooling was conducted in May. With this, the actual condition of the cooling condition of fuel debris is grasped, and improvements such as the optimization of the emergency response procedures are expected to be made.

ii. Radiation dose reduction and contamination expansion prevention all over the power station

(1) Prevention of sea contamination expansion

The concentration of radioactive materials in the port is below the concentration limit defined in the notification because of the removal of highly concentrated contaminated water in the trench, installation of the sea-side impermeable wall, covering of the seabed soil, etc. Measures to reduce the concentration of radioactive materials in the drainage channels that flow into the port, including measures to manage rainwater flowing in from the rooftops of buildings and paving around the buildings, should be continued.

Regarding contamination of the soil in the vicinity of the harbor, assessing the impact on the ocean from a long-term perspective and future environmental restoration, R&D should be conducted such as to clarify the near-surface nuclide migration mechanism and refine the analytical models.

(2) Management of gas and liquid waste

Monitoring of gas and liquid waste should be continued and its emission should be closely controlled to ensure that the concentration limits defined in the Notification is strictly observed. With this view, proper countermeasures should be taken as their concentrations are made as low as possible based on a reasonable methods.

(3) Radiation dose reduction through site decontamination

In March 2014, TEPCO formulated “Implementation Policy of Radiation Dose Reduction on the Site of the Fukushima Daiichi NPS" and set target radiation dose rates in stages for each area in the sites to reduce the radiation dose. As a result of these efforts, the target radiation dose equivalent rate of 5 μSv/h was achieved at the end of FY 2015 in the area where lots of workers work, except for the zones surrounding Units 1 to 4 and the waste storage area. The areas where working in general work clothes is permitted have currently increased to approx.96% of the entire site. The average radiation dose equivalent rate should be maintained below 5 μSv/h, and the target radiation dose equivalent rate should be gradually lowered to bring it as close as possible to the state before the accident.

(4) Reduction of environmental impact

Regarding the evaluation of the radiation dose at the site boundary including additional emissions from the entire site, the value to less than 1 mSv/year is continued to maintain after the goal to reduce the value to less than 1 mSv/year has been achieved at the end of 2015 in the result of the efforts stated in the previous clauses and purification of highly contaminated water.

(5) Comprehensive risk review

TEPCO conducted a comprehensive inspection of risk sources that may affect the outside of the site and announced it in April 2015. In addition, for the radiation sources requiring additional measures, specific measures were discussed while taking priorities into consideration. They were reviewed as appropriate reflecting environmental changes, and have been explained and announced at places such as the local adjustment meeting for decommissioning and contaminated water management.

Also, the Nuclear Regulation Authority created a target map for reducing the mid-term risk of the Fukushima Daiichi NPS in February 2015. This target map for reducing the mid-term risk of Fukushima Daiichi NPS, which has been updated from time to time, is characterized by a risk reduction work process of about three years, while focusing on the presentation of residual risk. In regard to this, TEPCO reported the current approach, issues and responding status according to the further schedule in May 2018.

It is important to continue to reduce and comprehensively grasp the risk sources like this, while taking the positioning and priority in the entire decommissioning project into consideration for implementing each measure.

iii. Plan for decommissioning measures for nuclear reactor facilities

In the Mid-and-Long-term Roadmap, TEPCO should formulate a decommissioning plan of the Fukushima Daiichi NPS in phase 3 after commencing fuel debris retrieval work, after starting debris retrieval operations. NDF should provide multifaceted and expert advice and guidance based on the progress and forecast of the decommissioning, the situation of the reactor buildings, and the trends of R&D with wisdom and knowledge from around the world.

Based on the need to take prompt and efficient measures for reducing risks of the whole facility in Fukushima Daiichi NPS, NRA is examining a review to regulate entire Fukushima Daiichi NPS integrally mainly with the implementation plan, in order to put more effective regulation to decommissioning work into practice. Therefore, the provisions of “Plan for decommissioning measures” are not to apply to Fukushima Daiichi NPS.

iv. Concrete efforts toward securing safety

(1) Efforts to ensure work safety

For the work plans that require workers to intervene in a high radiation dose environment, it is important to evaluate the environment according to input resources from the viewpoint of "justification and optimization", aiming to ensure the safety of the working environment as well as suppressing personal radiation dose. Particularly when the work is “for the first time,” “changed,” or “for the first time in a long time,” it is essential to fully implement work training using a mockup in order to develop, implement and verify effective work procedures and test methods.

Moreover, it is necessary to formulate a detailed work plan for each work step, to take preventive measures concerning troubles that may occur, and to consider ways to cope with unexpected situations.

In line with the Mid-and-Long-term Roadmap, it is stated that measures for industrial accident prevention will be taken and reviewed continuously, medical preparedness will be planned in anticipation of industrial accidents, and measures will be taken to reduce occupational risk of radiation exposure as much as possible. It is important to ensure a perfect system of work safety by continuing these efforts.

(2) Efforts for facility safety

In the Fukushima Daiichi NPS where there are various kinds of work and safety facilities, special attention to the safety of facilities is also essential. For this reason, measures are implemented to maintain and improve equipment reliability based on the maintenance plan for every piece of equipment. Particularly, for equipment vital to securing safety for cooling fuel debris, it is important to continue thorough measures that will be taken to prevent their important function from stopping, not just from the standpoint of equipment but from management and operation standpoints as well.

In the last fiscal year, there was a malfunction with the fuel removal device when fuel was removed from Unit 3 SFP. As a result, the start of the removal was significantly delayed from the original plan. This malfunction was directly caused by insufficient quality control of products procured from overseas. Therefore, TEPCO is taking measures to strengthen quality control to prevent recurrence.

While this response is of course necessary, we believe that this case should not be viewed as merely a matter of quality control, but rather as an indication of the existence of an organizational problem, i.e., a lack of broad technical response skills necessary to promote the project. Considering that more difficult work such as fuel debris retrieval is expected in the future, this case should be utilized in order to strengthen technical response skills as a decommissioning organization in the future.

(3) Security enhancement

A great quantity of nuclear fuel material is stored in the Fukushima Daiichi NPS. Accordingly, it requires particular attention to be paid for its security same as a normal nuclear plant, measures to confirm the reliability of each individual, enhance nuclear security training, prevent unauthorized intrusion into the sites, etc. are being implemented. Continuing with these efforts, it is necessary to implement appropriate measures for operation to allow accepting the visits of inspectors.

6) Comprehensive efforts for the decommissioning project of the Fukushima Daiichi NPS

In the decommissioning project of the Fukushima Daiichi NPS in the future, more complex and greatly uncertain challenges, such as fuel debris retrieval, must be coped with over a long term. For this reason, it is necessary to make efforts to solve problems in a systematic manner while looking ahead and ensuring a lead time for making sufficient preparations.

Decommissioning of the Fukushima Daiichi NPS is a complex and multi-layered large-scale project, various efforts are carried out concurrently and in parallel and in a mutually related manner. In particular, when fuel debris retrieval is started in the future, the relevance of the work in various fields such as the treatment of cooling water used for cooling debris, the installation of debris storage facilities, and the sharing of space with various other works will be strengthened. To proceed with the overall decommissioning project in a stable manner over the mid- to long-term, it is important to optimize the allocation of limited resources (people, goods, money, time, and space) while ensuring the consistency and feasibility of these many related efforts as a whole.

From the viewpoint of the necessity of the systematic work with a forward-looking perspective and the necessity of coordinating the complicatedly related work as a whole, in order to proceed with the decommissioning project steadily and efficiently in the future, it is necessary to formulate a consistent long-term plan for entire decommissioning from the current state to the short-, mid-to-long-term, so that various efforts can be managed comprehensively in accordance with this plan.

Even if a long-term plan is drawn up, it is virtually impossible to develop a plan into the future with high accuracy at this point because there are still significant uncertainties in the status of decommissioning and the work to be required in the distant future. Therefore, as a long-term plan, it is considered to be practical to optimize the work plan for the time being within the long-term range as long as possible where the work can be embodied to a certain extent, from the viewpoint of showing the path of decommissioning inside and outside, though there are restrictions in terms of how much detail the embodiment can be made.

As to the decommissioning of the Fukushima Daiichi NPS, we do not have any previous experience, and it is a project that needs to be carried out in a severe environment and with limited information, while accumulating experiences and results. To safely and stably proceed with a decommissioning project, it is important to draw up a plan based on the information currently obtained and assumptions, to incorporate new information and various knowledge gained as work progresses in a timely manner, and to review the plan flexibly according to the situation that becomes clear. It should also be noted that over-adherence to a plan after it has been developed may reduce the scope for selecting an optimum or a safest approach under the situation, thereby impeding the progress of safe and steady work.

For such a concrete use of the long-term plan, it is more important to set judgment points in advance at an appropriate time so that new knowledge can be obtained, evaluate the progress of work at that time and knowledge, consider how to proceed thereafter, and flexibly revise and operate the long-term plan based on that.

4 Handling critical enablers for smooth operation of the project

1) Actions toward improvement of working environment and conditions

The working environment of the Fukushima Daiichi NPS has now been steadily improved. A good working environment is the basis for ensuring safe and steady progress of the decommissioning project of the NPS, which will be carried out over the long term. For example, TEPCO is improving the working environment infrastructure by consolidating and removing existing rest stations and setting up alternative rest stations, etc. Moreover, a variety of measures are taken such as management for safety and sanitation, preventing heatstroke, radiation exposure management and radiation dose reduction measures in the site.

It is necessary, in the future, to make appropriate and ongoing efforts to improve the working environment and working conditions.

2) Enforced management structure for steady mid-and-long-term decommissioning

Since the Fukushima Daiichi D&D Engineering Company was established, TEPCO has put in place a project framework for decommissioning. However, there is a challenge that responsibility and authority are not apparent; for example, line operation management and project operation coexist in actual management. To clarify the responsibilities and the authority for project toward FY2020 and to support overall optimization of project management, TEPCO has established a Program Management Office (PMO) made efforts to strengthen project management. NDF has also established a Program Supervision and Support Office to supervise and support TEPCO's efforts. In addition, it is necessary to strengthen the management mechanism for the long-term decommissioning project, deepen the technical understanding of the individual works actually carried out in the project, and make this mechanism function effectively under the appropriate work management.

3) Developing and securing human resources

i. Developing and securing operators and engineers

The decommissioning project of the Fukushima Daiichi NPS requires completely different skills from the technologies related to the construction and operation of NPSs that TEPCO has accumulated to date as well. Accordingly, a draft technology map has been developed to grasp the overview of necessary technologies and decommissioning personnel, and this map is expected to be utilized for developing and securing human resources in the future. In addition, NDF is preparing to provide opportunities for engineers and others working at the Fukushima Daiichi NPS to learn common technologies required for decommissioning work.

In handling a complex large-scale project like the decommissioning of the Fukushima Daiichi NPS that involves many related factors , it requires specialized personnel with the ability to manage projects from a comprehensive perspective, including the consideration of the relationship between the projects based on the overview of the entire decommissioning process.

ii. Fostering the next generation to play roles the decommissioning of the Fukushima Daiichi NPS in the future

To continue decommissioning of the Fukushima Daiichi NPS as well as research and development activities for a long period of time in a sustainable manner, it is essential to train and secure future researchers and engineers. For this purpose, it is important for industrial-academic-governmental institutions relating to nuclear power, as a whole, to steadily promote making efforts.

Specifically, the industry and educational institutions should cooperatively continue the activities to enhance students' understanding of the nuclear power industry and show the attractiveness of the industry. They should also convey to students that the decommissioning of the Fukushima Daiichi NPS is an extreme technological challenge unprecedented in the world, as well as building and showing a variety of career paths for researchers and engineers to take part.

In addition, the stable development of researchers and engineers is of paramount importance. From this perspective as well, the Ministry of Education, Culture, Sports, Science and Technology (MEXT)’s the Center of World Intelligence Project for Nuclear S&T and Human Resource Development (hereinafter referred to as “the World Intelligence Project”) has started in 2015. It develops framework of common core nuclear research program designed to foster young people at universities and colleges especially since FY 2018. It is also essential, in the future, to encourage and enhance the measures aiming to secure human resources among universities and colleges.

Furthermore, in long-term and large-scale projects such as the Fukushima Daiichi NPS decommissioning, it is essential to develop core personnel for research and development who can perform scientific and engineering investigations from an academic perspective and personnel with a panoramic perspective (system integrators) who can integrate individual technology seeds into a system with practical functionality. This activity is being implemented by Essential R&D themes described later in Chapter 5.

5 R&D Initiatives

1) Basic policy for R&D

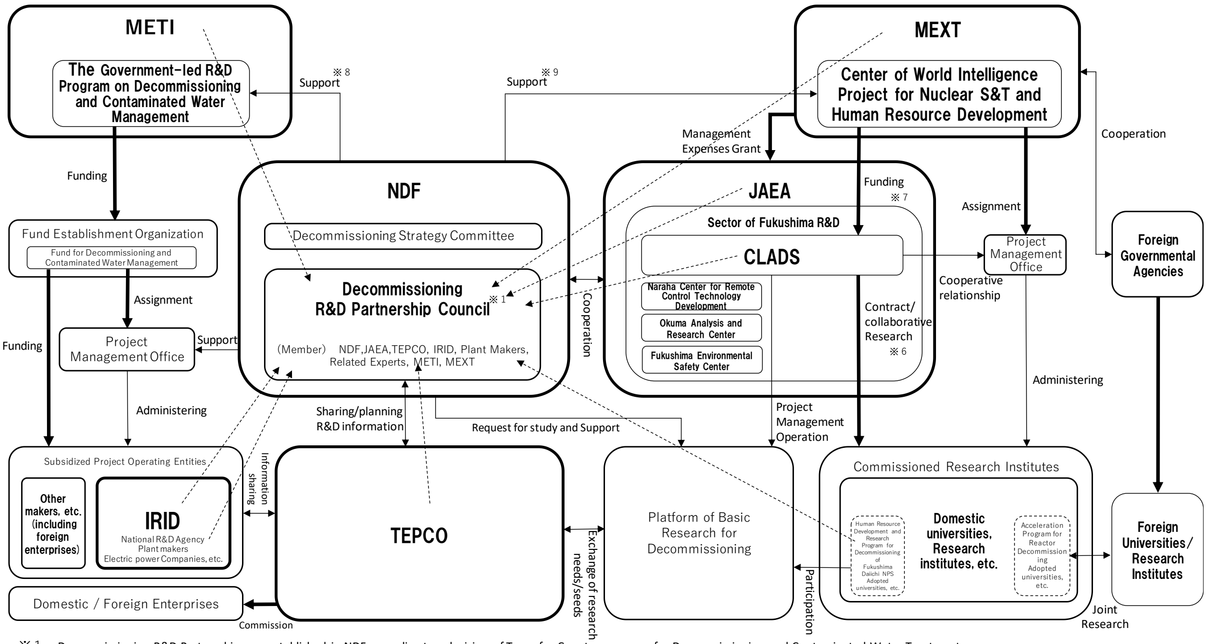
i. Basic policy

NDF has developed an R&D duties implementation policy based on the NDF Act, and has been managing a wide range of R&D to support the steady implementation of initiatives technically according to the Mid-and-Long-term Roadmap.

As detailed processes towards the decommissioning will be clarified, the roles of each R&D player should be more clarified. In doing so, it is necessary for the government and business operators to appropriately divide their roles and steadily promote the application of research and development outcomes to the work front. As the progress of engineering is expected to lead to the extraction of R&D tasks for on-site application, TEPCO is required to make efforts to put more weights on their own technological development that are directly linked to applicability on site for materializing decommissioning work.

ii. Entire perspective of R&D

Various problems exist in the decommissioning of the Fukushima Daiichi NPS, and R&D activities for solving these problems are being conducted by a variety of industrial-academic-governmental institutions engaged with the Fukushima Daiichi NPS decommissioning R&D project through the areas of basic/fundamental research, applied research, and development/utilization Fig.11. To organically link these activities and efficiently solve the on-site problems through R&D, NDF regularly holds meetings of “the Decommissioning R&D Partnership Council” according to the decisions made by the Team for Countermeasures for Decommissioning and Contaminated Water Management.



※1 Decommissioning R&D Partnership was established in NDF according to a decision of Team for Countermeasures for Decommissioning and Contaminated Water Treatment.
※2 Bold solid arrows mean supplies of R&D and management expenses (except for facilities expense).Light solid arrow means cooperation. Dotted line arrow means participation in Decommissioning R&D Partnership Council.
※3 Some institutions including JAEA are at the multiple positions.
※4 Each institution has their own cooperation with foreign institution based on MOU, etc.
※5 R&D activities by other institutions including Central Research Institute of Electric Power Industry are abbreviated.
※6 Among the promotion projects of nuclear energy science technology/human resource development that require collective know-how, the adopted projects up to 2017 were entrusted by MEXT to the trustee, which are not shown in this figure.
※7 Subsidies for the promotion projects of nuclear energy science technology/human resource development that require collective know-how are delivered to JAEA, but expressed as being delivered to CLADS for the sake of clarity here.
※8 For Decommissioning and Contaminated water treatment subsidy project, NDF drafts the next R&D plan and METI determines it based on the policies on Roadmap and the Strategic Plan and R&D progress.
※9 NDF participates in the steering committee of human resource development promotion project of Nuclear Science Technology that gathers wisdom and intelligence, as a constituent.

Fig.11 Whole picture of R&D structure of the decommissioning of Fukushima Daiichi NPS (As of FY 2019)

2) R&D of decommissioning required for on-site work/engineering

i. Promotion of effective research and development

There are two types of R&D activities towards practical use for successfully implementing the decommissioning of the Fukushima Daiichi NPS: the engineering activities including technological development implemented by TEPCO and the Government-led R&D program on Decommissioning and Contaminated Water Management carried out by selected subsidiary companies. In particular, management of R&D is required to be carried out in a project-base manner in the future. In other words, R&D tasks that have been deemed necessary through engineering studies should be carried out in a timely and accurate manner by appropriate implementing institutions, and the results should be provided to the work front timely and accurately. To this end, TEPCO and NDF should organize the details of R&D currently in progress, and R&D tasks required in the future under the project management system in relation to the engineering schedule, that is, clarifying when the problem must be solved and which project needs it.

In this regard, the implementation of R&D tasks, including implementing the tasks in the Government-led R&D Program, should be considered in line with the basic concept of an appropriate division of roles between the government and TEPCO according to the details of the tasks. Specifically, R&D activities that require government support are deemed highly difficult, and in this regard, TEPCO is required to carry out R&D tasks that have many engineering elements.

Based on this concept, TEPCO is required to: (1) position necessary R&D tasks in the engineering schedule, including the Government-led R&D Program; (2) actively commit to the management of overall processes in this Government-led R&D Program, mainly in the stage leading to engineering by TEPCO; and (3) extract R&D tasks from engineering studies and steadily advance research and development.

ii. Future approach to research and development

As a result of the research and development conducted through the Government-led R&D Program, there has been certain accomplishments such as the situation of the inside of PCVs have been clarified by degrees, by implementing elemental technology development and developing research devices. As mentioned above, as the concrete process for full-blown decommissioning has become clearer, the research and development directly related to the on-site application to realize decommissioning work will be required in the future. For this purpose, TEPCO, while performing actual work on site, shall plan out and manage R&D, based on their own operations and measures for securing safety, as well as the overall picture of decommissioning. Accordingly, TEPCO needs to make efforts to put more weights on the research and development directly related to on-site application to effectively conduct, while establishing a system as own planning and management of research and development. As mentioned above, regarding R&D activities including fundamental ones, the governmental support should be provided, which require an approach on a mid- to long-term basis with high degree of technical difficulty and thus, are difficult for TEPCO to implement and the government should support.

3) Enhancement of basic study and R&D infrastructure for the success of the decommissioning project

i. Essential R&D Themes and its strategic promotion derived from the needs

While universities and public research institutes in charge of basic research are expected to maintain and develop human resources, knowledge, and infrastructure that can promptly respond to technical issues requiring science and engineering knowledge when they arise in the future, it is also important for them to share their awareness for the issues that the decommissioning sites are facing.

To facilitate the Fukushima Daiichi NPS decommissioning project in a safe, steady and effective manner, it is essential to plan out mid- and long-term R&D strategies including scientific and technological studies based on understandings of the principles and the theories. For this purpose, NDF has built a task force on research collaboration and specified the 6 Essential R&D Themes that should be preferentially and strategically targeted based on the discussions at the Decommissioning R&D Partnership Council.

ii. Building R&D infrastructure based on mid-and-long-term vision

To make the decommissioning work proceed steadily in terms of technology, it is essential to work on developing R&D infrastructure and accumulating technological knowledge, developing generic technologies and collecting basic data, including the Essential R&D Themes, building up research centers, facilities and equipment, and human resource development.

The building for international research collaboration of JAEA/CLADS has opened in April 2017 in Tomioka-machi, Fukushima prefecture. According to a proposition by NDF, the Center of World Intelligence Project for Nuclear S&T and Human Resource Development by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) is implemented under the structure centered on JAEA/CLADS from the newly adopted issues since FY2018.

It is also important to develop research infrastructure of hardware. JAEA put the Naraha Remote Technology Development Center (Naraha-machi, Fukushima Prefecture) in service in April 2016, Fukushima Prefectural Centre for Environmental Creation where Fukushima Prefecture, JAEA, and the National Institute for Environmental Studies have their offices (Miharu-machi, Fukushima Prefecture) opened in July 2016, and JAEA opened the facility management building of the Okuma Analysis and Research Center (radioactive material analysis and research facility) (Okuma-machi, Fukushima Prefecture) in march 2018. R&D infrastructures aiming at the mid-and-long-term vision are being set up mainly in Fukushima Prefecture.

6 Enhancement of international cooperation

1) Significance of international cooperation

In recent years, nuclear reactors and nuclear fuel cycle facilities, constructed in the development age of nuclear power, are coming to the end of operating life and these decommissioning have already been progressing in the world. There are three major nuclear reactors caused severe accidents: Windscale Unit 1 in UK, Three Mile Island Unit 2 in the US, Chernobyl Unit 4 in Ukraine. These facilities have taken stabilization and safety measures for a long time. Furthermore, there is significant uncertainty in the management of various radioactive substances in past nuclear facilities called “legacy sites” where are located in the UK, US and France etc. In these sites, there are implemented decommissioning and environmental remediation for a long time. These countries have continued to be challenging to issues such as technological difficulties called “unknown unknowns” (don’t know what is unknown), project management over several decades, and securing of large amount of funds.

As a risk reduction strategy, it is important to learn the lessons of decommission experience from accident reactors and legacy sites in the world and to utilize it into the actual decommissioning as well as good use of excellent technologies and personnel resources that have been cultivated in each countries, in order to make steady progress on decommissioning of the Fukushima Daiichi NPS that engineering challenges are addressed. In addition, it is also important to engage in mutually beneficial decommissioning with open to international societies, while giving back to the knowledge and the like obtained from Fukushima Daiichi accident and decommissioning actively and strategically through international cooperative activities on decommissioning, to maintain and develop continuous understanding and interest or cooperation of international communities on decommissioning.

In regards to the international cooperation, it is important to utilize a multilateral cooperation framework through the international institutions such as IAEA, Organization for Economic Co-operation and Development/Nuclear Energy Agency (hereinafter referred to as “OECD/NEA”), in addition to proceed with bilateral cooperation in harmony with the circumstance in each country. These international institutions have a role of contribution to designing the international standard, share the knowledge and experience among nations, and form the international common perceptions for decommissioning. To proceed with the decommissioning of the Fukushima Daiichi NPS in an open manner on the international basis, it is important to participate in the activities of these institutions. At the same time, Japan participates in the discussion for design the international standard, based on the experience of the Fukushima Daiichi decommissioning, it leads to share the experience with memberships of the institutions. It is also expected to fulfill the responsibility to the international society.

2) Facilitation of international cooperation activities

i. Enhancement of partnership with overseas decommissioning agency

As the decommissioning of the Fukushima Daiichi NPS is delivered over a long period of time, it is necessary to establish a long-term and continuous partnership with overseas decommissioning agencies.

Especially, the decommissioning of legacy sites will serve, as a model for approach preceding to the Fukushima Daiichi NPS decommissioning, in many knowledge in accordance with technology and management. Decommissioning for legacy sites is promoted by decommissioning institutions that is established officially by each country because it requires the expertise, concept and new technologies, etc. that differ from the operation/maintenance for nuclear reactor or nuclear fuel cycle facility. Therefore, it is important for NDF to establish and reinforce a long-term partnership with these institutions such as Nuclear Decommissioning Authority (NDA), Commissariat a l'energie atomique (CEA), United States Department of Energy, Office of Environmental Management (DOE/EM) under government-level framework. TEPCO should establish a long-term partnership with overseas decommissioning operators, and these should be broad cooperation-based.

ii. Integrating and utilizing wisdom and knowledge from around the world

In regard to decommissioning of the Fukushima Daiichi NPS, wisdom and knowledge from around the world that our country should obtain are implemented with a variety of approaches such as system/policy, providing strategy, project plan/operation, ensuring security, regional communications, and so forth, not only in technical aspect but operational aspect. On the other hand, there are tendencies to support decommissioning of the Fukushima Daiichi NPS by international society, and several kinds of supports have been given by overseas governmental institutions and experts including DAROD project led by IAEA and collaboration projects promoted by OECD/NEA.

Decommissioning is implemented by many companies and decommissioning operators under the contract in both domestically and internationally. The decommissioning market is expanding worldwide. In order to use the excellent technologies and human resources in the world effectively, it is essential to update the latest status.

iii. Dissemination to global society

It is essential to promote decommissioning in an open manner to international society for prevention of reputational damages as stated in the Chapter 7 and it should strengthen to distribute easily understandable information, for helping accurate comprehension from international society.

For this reason, NDF takes dissemination of information about the situation of the Fukushima Daiichi NPS decommissioning globally through holding side events of IAEA General Meeting and giving speeches at key international meeting. Furthermore, NDF holds the International Forum on the Decommissioning of the Fukushima Daiichi NPS in order to report information about the situation of the Fukushima Daiichi NPS decommissioning to the world and to take effort to communicate with local communities.

iv. Taking part in international collaborative activities

Eight years have passed since the Fukushima Daiichi accident occurred, there is some movement to apply knowledge acquired from the accident to other issues in abroad.

Decommissioning as a risk reduction strategy is an issue with the highest priority for our country, it is important to continue to maintain high overseas interest in the Fukushima Daiichi NPS accident from the viewpoint of gathering knowledge from the world for advancing decommissioning. In addition, it is also significant to give knowledge acquired through decommissioning back to collaborative organizations in the world appropriately. Consequently, NDF proactively participates in international collaborative activities hosted by OECD/NEA and others and provides information about the Fukushima Daiichi NPS accident to respond to such new interest from the world in a positive manner. It should be continued in cooperation with relevant organizations.

3) Close cooperation with relevant domestic organizations

As stated in Chapter 2, concerning international cooperation, it is promoted that relevant domestic organizations build and strengthen partnership with foreign organizations in accordance with the role of each organization. It should be shared the knowledge and human connections obtained through these activities to ensure consistency of international cooperative activities in Japan and implement effective international cooperation. Therefore, the relationship of relevant domestic organizations should be further enhanced.

7 Local community engagement

1) Approaches for local community engagement

In order to implement decommissioning of the Fukushima Daiichi NPS steadily that spans long periods of time, it must to be seeking for decommissioning developed with the restoration in local communities under the recognition of “Decommissioning and the reconstruction of Fukushima as an indispensable pair”.

On that account, understanding and cooperation of the region are essential as it is the first priority to proceed with efforts toward decommissioning in a safe and steady manner, accurate information concerning decommissioning should be disseminated at the right time and appropriately. In addition, it is important to respond to their voices by communicating carefully through dialogues to listen to the voice of anxieties or questions from the local communities and various standpoints sincerely.

Moreover, we believe that decommissioning can be trusted by the community and co-exist with the regions, while effectively utilizing the local resources and developing decommissioning or a variety of its relevant activities along with the restoration of the region.

2) Actual effort for better communication

As decommissioning operation proceeds, it is necessary to put into practice information providing or interactive communication in a further well thought-out manner, under proper collaboration of the relevant organizations including government, NDF and TEPCO.

For instance, NDF hosts International Forum on the Decommissioning of the Fukushima Daiichi NPS annually and vigorous dialogue about decommissioning with the local citizens and the future generations who are to face to decommissioning. NDF continues vigorously to promote interactive communication activities like these and to take all of the local voice sincerely. TEPCO promotes to accept observers into the Fukushima Daiichi NPS, as well as opened “TEPCO Decommissioning Archive Center” in November 2018.

3) Measures to reputational damages

There is a possibility that a reputational damage may be caused by being anxious even if the risk does not become obvious. When delays in responding to reputational damages or troubles on decommissioning work occur, it may produce a vicious cycle such as downgrading evaluation from society for addressing decommissioning then it causes the further delay of decommissioning approaches. In order to prevent from a vicious cycle like this, it is the extremely important to promptly reduce existing risks as top priority while making efforts for proper safety management. Besides, it is crucial to establish trust relationship by communicating regularly with local residents, as disseminating information on decommissioning should be made at the right time and accurately.

4) Decommissioning that moves forward together with the recovery of the community

Under the recognition of “Decommissioning and the reconstruction of Fukushima as an indispensable pair”, it is important to address to develop local human resources that will engage decommissioning and to integrate its relevant industries in conjunction with “Fukushima Innovation

Coast Framework”, to recover the industry in Hamadori region of Fukushima prefecture where was lost by The Great East Japan Earthquake and nuclear disaster.

For proceeding with decommissioning along with the local reconstruction, it needs to increase contact with the region, for instance, TEPCO procures materials and services associated with decommissioning from the local vendors and employs the local workers. On the other hand, it is required to balance decommissioning in a safe and steady manner with priority given to the region in light of the demand to safely promote prompt decommissioning as soon as possible. In order to realize the efforts like these, it is strongly expected that the Fukushima Revitalization Headquarter and Fukushima Daiichi Decontamination and Decommissioning Engineering Company address various issues by working together in TEPCO, while the relevant organizations including the government, NDF and the local government will coordinate each other. Moreover, an environment should be improved, of which enables many of the local companies to participate in decommissioning work through using of resources and knowhow that related organizations obtained and technological and business supports.