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

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Nuclear Damage Compensation
and Decommissioning Facilitation Corporation

Table of Contents

Table of Figures

1. Introduction

The overall approach to the decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc. (hereinafter referred to as the “Fukushima Daiichi NPS”) started under the Mid-and-Long-term Roadmap towards the Decommissioning of TEPCO’s Fukushima Daiichi NPS Units 1 to 4, released by the Japanese Government in December 2011.

Urgent issues, such as treating contaminated water and removing fuel from the spent fuel pools, have been given top priority in this effort. However, to complete the decommissioning, mid-and-long-term measures are required such as fuel debris retrieval work, and so it is essential to prepare a mid-and-long-term decommissioning strategy. On August 18, 2014, the former Nuclear Damage Compensation Facilitation Corporation was reorganized into the Nuclear Damage Compensation and Decommissioning Facilitation Corporation (hereinafter referred to as the “NDF”), a new organization responsible for technical studies needed to proceed with the decommissioning properly and steadily from the mid-to-long-term perspective. NDF’s duties include, in addition to those assigned to its forerunner, conducting R&D of decommissioning technologies, and providing advice, guidance and recommendations for ensuring the appropriate and steady implementation of the decommissioning.

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, mid-and-long-term approach like fuel debris retrieval is needed and mid-and-long-term responses are required. When addressing the issues of long and highly difficult with a large uncertainty, approaches to solve issues should be proceed from more systematic and mid-and-long-term perspective, rather than performing project 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 presented 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.

1.1 Structure and system toward appropriate and steady implementation of decommissioning

As the decommissioning project is shifting focus to mid-and-long-term challenges, the structures and systems for the decommissioning are being reinforced to ensure that the decommissioning project continues and that mid-and-long-term issues are properly addressed.

Tokyo Electric Power Company Holdings, Inc. (hereinafter referred to as the “TEPCO”), as the operator of the project, is reinforcing its project management structure with the goal of steady decommissioning by implementing the ongoing activities for sure while responding to mid-and-long-term issues in a strategic manner. To ensure the implementation of the decommissioning financially, a law to partially revise the Nuclear Damage Compensation Facilitation Corporation Act (hereinafter referred to as the “NDF Act”) was established in May 2017 and came into effect in October of the same year. Under the Revised NDF Act, NDF has been assigned the new duty of managing the Reserve Fund for Decommissioning. TEPCO is required to reserve 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). TEPCO will proceed with the decommissioning while withdrawing the reserved funds in accordance with “Withdrawal plan for Reserve Fund” (hereinafter referred to as the “Withdrawal Plan”), which will be prepared jointly by NDF and TEPCO and approved by the competent minister. This ensures that the necessary amount of funds for the appropriate and steady implementation of the decommissioning will be reserved, building a consistent decommissioning structure that works irrespective of TEPCO’s earnings or other factors. In this Reserve Fund system, NDF will play 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 Reserve Fund system.

Specifically, prior to the preparation of the Withdrawal Plan, NDF will present to TEPCO the work targets and major tasks to be included in the Withdrawal Plan by dividing them into major projects in accordance with “The Policy for Preparation of Withdrawal Plan for Reserve Fund for Decommissioning” (hereinafter referred to as the “The Policy for Preparation of Withdrawal Plan”). NDF will also support the appropriate and steady implementation of the decommissioning through activities such as evaluating 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.

The division of roles among the organizations directly involved in the decommissioning of the Fukushima Daiichi NPS, the Japanese government, NDF and TEPCO, as well as organizations specializing in R&D (the International Research Institute for Nuclear Decommissioning (hereinafter referred to as the “IRID”) and the Japan Atomic Energy Agency (hereinafter referred to as the “JAEA”), is shown in Fig.1, which also indicates how the abovementioned systems are implemented.

Among these roles, R&D are discussed in Chapter 5, and dialogue with local residents and communities is described in Chapter 7.

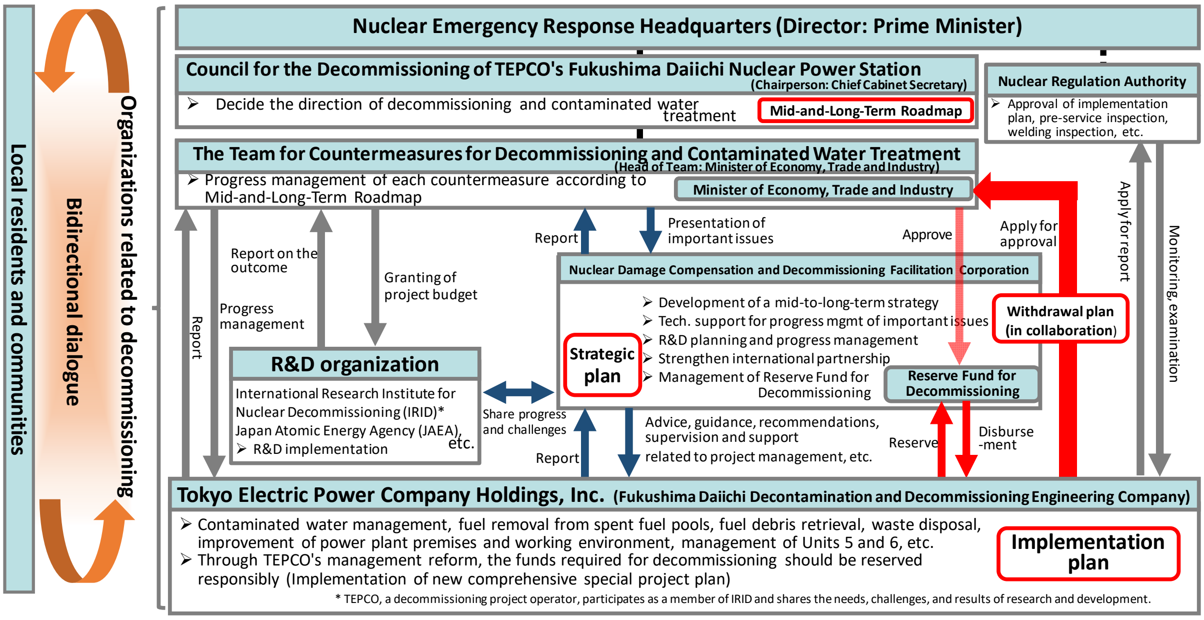


Fig. 1 Division of roles of related organizations in decommissioning of the Fukushima Daiichi NPS

1.2 Strategic Plan

1.2.1 Positioning of the Strategic Plan

NDF has issued a Technical Strategic Plan for Decommissioning of the Fukushima Daiichi NPS of Tokyo Electric Power Company (hereinafter referred to as 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 (Attachment 1).

Since the Strategic Plan 2018, it should include not only the issues focused on fuel debris retrieval and waste management but also measures against contaminated water and fuel removal from the spent fuel pools and should propose future directions from mid-and-long-term perspectives that oversee the overall efforts toward the decommissioning of the Fukushima Daiichi NPS. Any issues that are identified through these studies as requiring current attention will be reflected in the Policy for Preparation of Withdrawal Plan for Reserve Fund for Decommissioning that NDF will present to TEPCO (Fig.2).

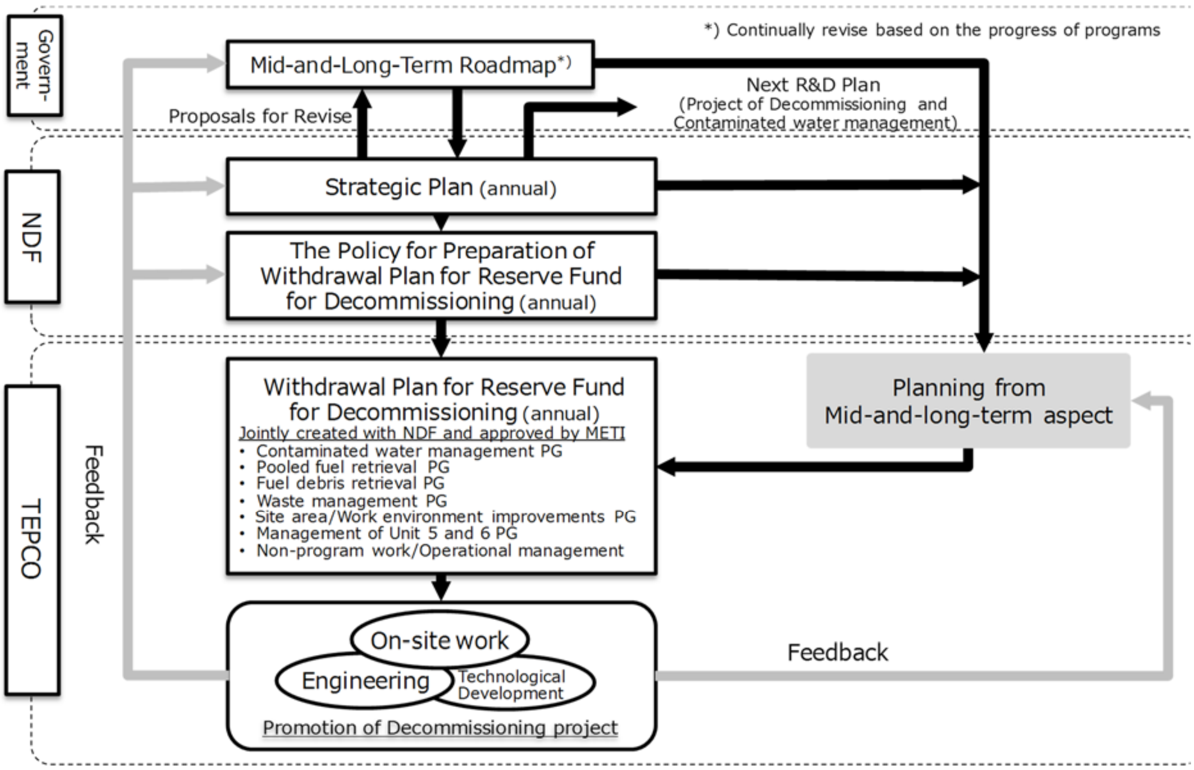


Fig. 2 Positioning of the Strategic Plan based on the system of the Reserve Fund

1.2.2 Overall Structure of Strategic Plan 2019

Strategic Plan 2019 consists of seven chapters.

Chapter 1 (Introduction) states that for the decommissioning of the Fukushima Daiichi NPS, a more proactive, systematic approach will be needed to solve the challenges from mid-and-long-term perspective rather than fulfilling tasks in a reactive manner, in addressing more complex and uncertain challenges over the long term, such as fuel debris retrieval, and it also states the structures and systems including Reserve Fund system.

Chapter 2 (Decommissioning of the Fukushima Daiichi NPS as risk reduction strategies) presents a basic policy for the decommissioning of the Fukushima Daiichi NPS as a strategy to reduce risks, along with risk reduction tools that should be used in carrying out this policy, such as near-term targets, the basic concept of risk reduction, the approach to priority, the concept of securing safety and promotion of cooperation and the stance on responding to a temporary increase in the risk level.

Chapter 3 (Technological strategies toward decommissioning of the Fukushima Daiichi NPS) sets targets in each of the four areas: fuel debris retrieval, waste management, contaminated water management, and fuel removal from the spent fuel pools. Area-specific strategies to achieve the targets are described, along with technological challenges in implementing these strategies, and a plan for future actions to address them.

Section 3.1 (Fuel debris retrieval) of Chapter 3 states the overview of the strategic recommendations to determine the fuel debris retrieval method for the first implementing unit and describes continual implementation of internal investigation as well as accelerated and prioritized technological development, etc. The section also proposes technological issues to be examined on fuel debris retrieval for the first implementing unit.

Section 3.2 (Waste management) presents, in accordance with the basic policies on processing and disposing of solid waste, specific targets to gain a technological vision for waste processing/disposal for around FY 2021, along with a plan for R&D needed to reach these targets.

Section 3.3 (Contaminated water management) proposes, in introducing the approaches being made to complete the treatment of the stagnant water in the buildings by the end of 2020, the direction of efforts toward treatment of contaminated water in the reactor buildings after the start of fuel debris retrieval work.

Section 3.4 (Fuel removal from spent fuel pools) refers to the appropriate and specific operation plan depending on the conditions of each unit, and proposes the directions of the efforts to secure capacity required for proper storage of removed fuel within the site and of the efforts to determine the future treatment and storing methods for fuel in Spent Fuel Pools (SFPs) including evaluation of the long-term integrity of such fuel

Section 3.5 (Other specific measures) states the other approaches including sustaining reactor cold shutdown status, reducing radiation dose/preventing further spread of contamination all over the power station, decommissioning plan for reactor facilities, and specific efforts toward ensuring safety.

Section 3.6 (Comprehensive efforts for the decommissioning project of the Fukushima Daiichi NPS) states the directions of the approaches from the viewpoints of necessities of systematic operation by thinking ahead and necessities to proceed with complex and inter-related operations by ensuring consistency across the operations.

Chapter 4 (Handling Critical enablers for smooth operation of the project) states actions toward improvement of working environment and conditions, enforced management structure for steady mid-and-long-term decommissioning and developing and securing human resources from perspective of the smooth operation of the project, as well as technological study as stated in Chapter 3.

Chapter 5 (R&D initiatives) summarizes the efforts that are expected in government, enterprises and the relevant researching institutions and proposes the directions of further efforts to achieve project-based R&D management that the R&D tasks of which the necessity became clear by engineering considerations should be carried out by the right institutions at the right time and accurately. The chapter also discusses, from the mid-and-long-term point of view, the establishment of a center for basic research and the construction of R&D infrastructure, as well as the importance of fundamental R&D.

Chapter 6 (Enhancement of international cooperation) describes the need to strengthen international cooperation, such as partnerships with institutions involved in decommissioning projects in countries with legacy nuclear sites, in order to gather wisdom and knowledge from around the world, and proposes efforts that should be made in this regard.

Chapter 7 (Local community engagement) notes how these institutions should work together toward that end, to implement continuous decommissioning of the Fukushima Daiichi NPS that spans long period of time, in consideration that we will have seek for decommissioning developed with the restoration in local communities.

2. Decommissioning of the Fukushima Daiichi NPS as risk reduction strategies

2.1 Basic concept of the decommissioning of the Fukushima Daiichi NPS

<Basic concept of the Decommissioning of the Fukushima Daiichi NPS>
To continuously and quickly reduce the radioactive risks caused by the accident that do not exist in the usual 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.

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

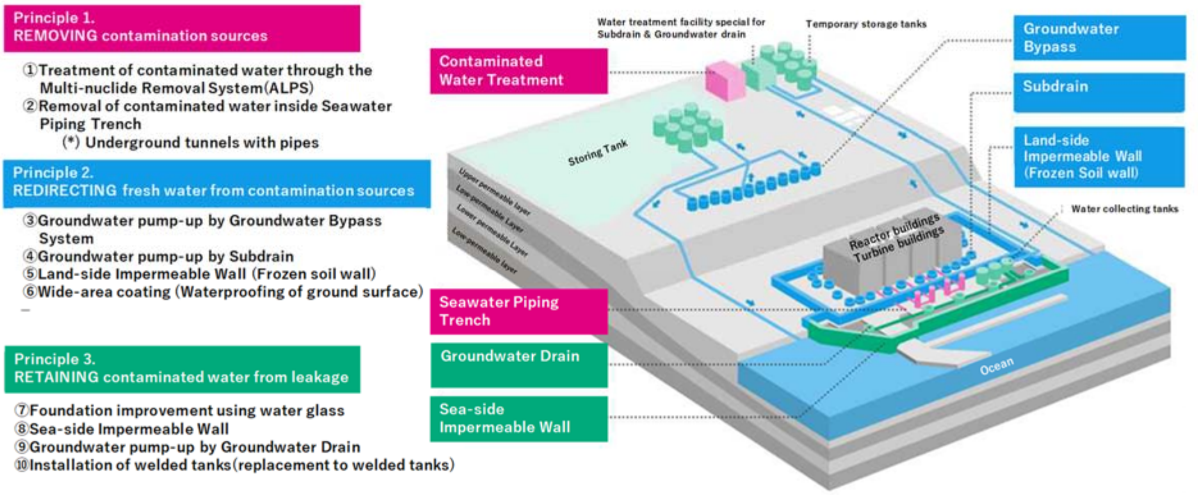
Accordingly, the basic policy for the decommissioning of the Fukushima Daiichi NPS is “to reduce continually and quickly the risks associated with the radioactive materials that resulted from the accident and do not exist in normal nuclear power plants” by taking measures specifically designed for risk reduction. In general, actions that are effective for reducing the risks at nuclear facilities that have suffered an accident are: (i) improving the containment function of the damaged facilities, (ii) changing the properties and form of the confined radioactive material to more stable ones, and (iii) strengthening monitoring and control over the equipment to better prevent or mitigate the occurrence or propagation of abnormalities. To enable these actions comprehensively, (iv) removing radioactive materials from the damaged facilities or insufficient confinement status and placing them in sound storage is also effective.

These diverse risk reduction measures have been continued based on careful preparations aimed at preventing accidents and radiation exposure of workers (refer to Attachment 2).

2.2 Progress status of the decommissioning of the Fukushima Daiichi NPS

(1) Contaminated water management

Contaminated water has been addressed in accordance with the three principles (“Removing” contamination sources, “Redirecting” fresh water from contamination sources, and “Retaining” contaminated water from leakage) (Fig.3).



(Courtesy of TEPCO)

Fig.3 Three principles and measures

As a measure of “Removing” contamination source, radioactive materials are removed from contaminated water with multi-nuclide removal equipment. As a measure of “Redirecting” fresh water from contaminated sources, freezing operation of the land-side impermeable walls was completed in all area by September 2018. With this, reinforcement of the sub-drain system led to the suppression of the groundwater inflow into the buildings, in addition, the sharp decrease in the amount of water transferred from the groundwater-drains to the buildings, resulting in the reduction in contaminated water generated. Because of this kind of preventive and multi-layered measures, total generation amount of contaminated water has been decreased to approximately 170 m^3 per day in FY 2018 from approximately 400 m^3 per day in FY 2016. As a measure of “Retaining” the 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, etc., with the goal[1] of completing the treatment in 2020. At present, the lowest floor of the turbine building at Unit 1 and the middle floor of the lowest floor of the turbine buildings at Units 2 to 4 are exposed. Furthermore, the disconnection of the connecting section between Units 1 and 2 was accomplished by the end of 2018 (the disconnection for Units 3 and 4 was completed in 2017). On the other hand, with regard to the goal of reducing the amount of radioactive materials in the stagnant water in buildings down to 1/10 of the level at the end of FY 2014 by the end of FY 2018, the evaluation became difficult.

[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).

Because high radioactive concentrations were detected in some areas with the progress in the treatment of the stagnant water, though treating of 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.

Decreasing both the amount of the stagnant water and the concentration of the radioactive materials accelerate the reduction of inventory of the radioactive materials in the stagnant water. Moreover, the water treated by the multi-nuclide removal equipment is stably stored and managed in the welded type tanks in order. Comprehensive discussion including social standpoints such as mitigation of the reputational damages have been made in the Government-led subcommittee on the Water Treated by the Multi-nuclide Removal Equipment[2].

(2) Progress of removing fuel from the spent fuel pool

In Unit 1, to remove fuel from SFP at the operating floor, rubble removal on the operating floor has been underway since 2018.

In Unit 2, the contamination status of the operating floor was investigated from November 2018 to February 2019. Based on the outcome, the process toward removing fuel in SFP is being examined. In addition, as the supporting structure of the exhaust stack for Units 1 and 2 was partially broken due to the impact of the earthquake, it was decided to dismantle the upper part of the stack in order to secure seismic safety margin and not to affect the removal operation of fuel in SFP.

Fuel removal from Unit 3 began in April 2019, although it was delayed from the first implementing schedule due to a defect in the fuel handling machine that occurred during the trial operation to start fuel removal.

(3) Fuel debris retrieval

In Unit 1, since it was confirmed that the deposits identified during the surveillance of the Primary Containment Vessel (hereinafter referred to as the “PCV”) in 2017 are present underwater, the PCV internal investigation using a newly developed boat-type access surveillance device with a diving function is scheduled to be performed in FY2019. This surveillance also plans to sample deposits, which are found at the bottom of the PCV, in small amounts.

In Unit 2, remote equipment was used to conduct contact survey on deposits in the PCV in February 2019. As a result, the same surveillance was performed at the bottom of the PCV pedestal and the platform, and it was confirmed that deposits (pebbles, etc.) were movable. In addition, videos, radiation doses, and temperature data were obtained under the condition, which was closer to the deposit than in the surveillance in January 2018.

In Unit 3, as the water level at the bottom of the PCV is as high as approximately 6 m, the study on lowering the water level has been made and the water quality will be checked as the first step.

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[2] Subcommittee on the Water Treated by the Multi-nuclide Removal Equipment
https://www.meti.go.jp/earthquake/nuclear/osensuitaisaku.html#task_force4

(4) Waste management

The operation of the No. 9 solid waste storage building, which stores high radiation dose rubble generated from Units 1 and 2, started in February 2018. Secondary waste generated from contaminated water purification treatment is currently in temporary storage, and large waste storage to store the waste is scheduled to commence operation after this. TEPCO has revised Storage Management Plan to store and manage these solid waste properly in June 2019 based on the review of the predicted generation of solid waste (Attachment 12).

2.3 Basic concept of reducing risk of radioactive materials

2.3.1 Quantitative grasping of risk

The term “risk” may have various meanings depending on the field or scene of use. In general, in the context of appropriate risk management, “risk” can be understood as an expectation value of the negative impact of an event. In other words, the magnitude of a risk (risk level) posed by a subject (risk source) can be expressed as the product of the level of impact and the likelihood of occurrence of the event.

In the Strategic Plan, the method based on the Safety and Environmental Detriment score (SED), which accounts for the public impact developed by Nuclear Decommissioning Authority (NDA) is used to study the reduction of the risk level of radioactive materials.

Risk level expressed by SED is given by the calculation formula below.

Risk Level expressed by SED = Hazard Potential × Safety Management

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

2.3.2 Identification of Risk Source and Risk assessment

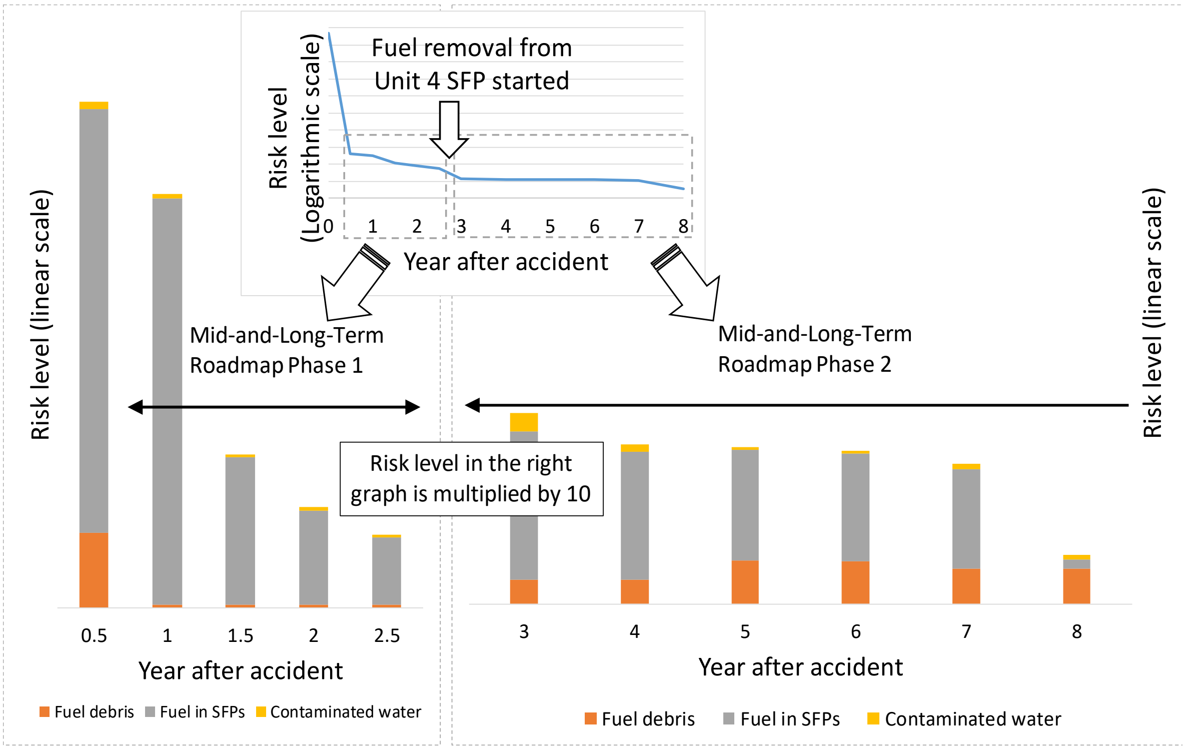
For the development of risk reduction measures, the major risk sources of the Fukushima Daiichi NPS are indicated in Table 1. The sum of these risk sources represents the overall risks for the Fukushima Daiichi NPS, and the overall risk levels are shown in Fig. 4. Continuous efforts have been made to reduce these risks through various measures, including those described in Section 2.2. Moreover, the risk levels of each risk source expressed using Hazard Potential and Safety Management are shown in Fig. 5.

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 SFPs, etc., relatively high risks given a high priority, [2] Fuel debris, etc., risks unlikely to appear immediately though, it may grow in case of dealing with haste, [3] Solid waste, etc. risks unlikely to increase in the future though, 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 Section 3.

As for fuel in SFPs, the testing on SFP cooling shutdown was performed, and it was found that the 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	Rubbles with high radiation dose (30mSv/h and above) stored in the solid waste storage facility
	Soil covered temporary storage, etc.	Rubbles stored in Soil covered temporary storage facility, Temporary storage tent and Outdoor container storage (1~30mSv/h), and felled trees stored in Temporary storage pool
	Outdoor storage, etc.	Rubbles stored in Outdoor seat covered storage (0.1~1mSv/h), Rubbles stored in Outdoor storage (Under 0.1mSv/h), and Felled trees 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



1. The risk level was high due to fuel debris right after the accident; however, it became largely lower because Hazard Potential has been largely decreased by attenuation of radioactive materials inside fuel debris over one year after the accident.

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

Fig. 4 Reduction of risks contained in the Fukushima Daiichi NPS

To date, the Strategic Plan has focused on the risk sources containing a large amount of radioactive materials. On the other hand, when looking at the overall decommissioning process from a long-term perspective, certain measures should be taken for the potential risk sources regardless of the amount of radioactive materials and the waste that have generated before the accident. Thus, survey has been initiated, which expands its scope to identify items requiring consideration in long-term strategies.

Specifically, consideration of issues from a wider vision of entire work will proceed in adding targets including accumulated water on site, underground water tanks, contaminated soil, α sludge, spent control rods; and pool water. (Attachment 4)

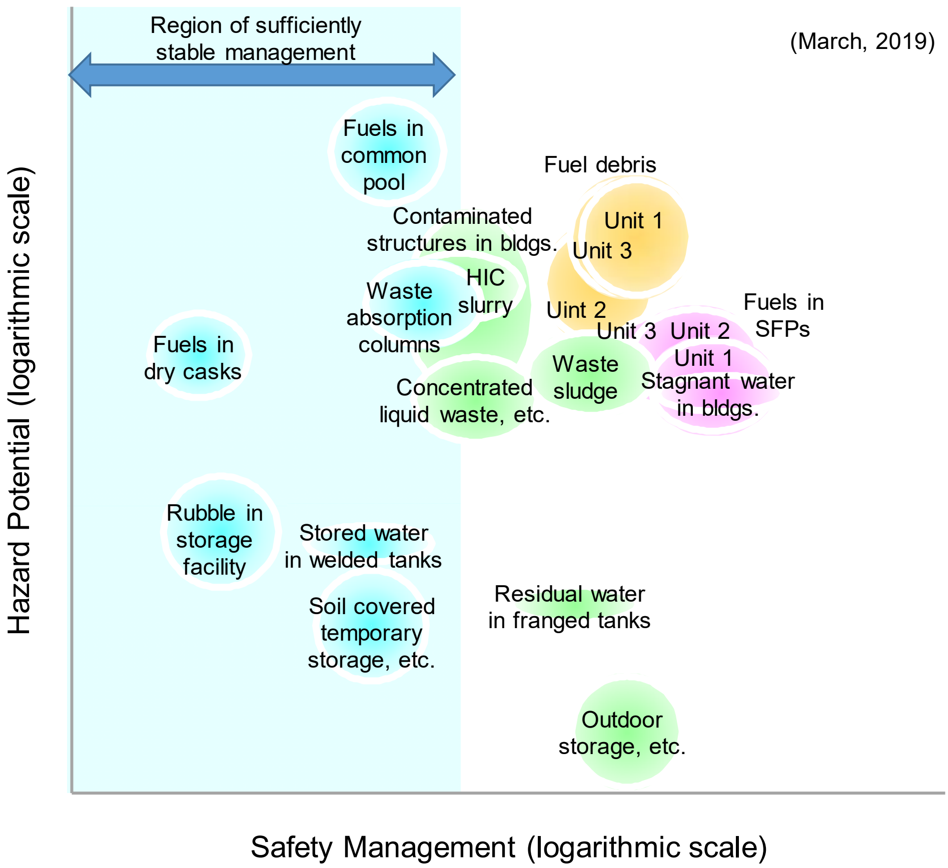


Fig.5 Examples of Risk Levels of Major Risk Sources at the Fukushima Daiichi NPS

2.3.3 Risk Reduction Strategy

2.3.3.1 Interim Targets of the Risk Reduction Strategy

The risk levels of the risk sources shown in Fig. 5 are higher toward the upper right corner. There are two risk reduction strategies which are reduction in Hazard Potential or reduction in Safety Management.

The examples of the former strategy 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 the latter one 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 decommissioning of the Fukushima Daiichi NPS, which is implemented under the basic policy of “reducing continually and quickly the risks associated with the radioactive materials that resulted from the accident and do not exist in normal nuclear power plants” (Section 2.1), should first focus on steadily managing risk sources by keeping them in higher-integrity facilities to lower their Safety Management levels. The interim goal of risk reduction strategies is to bring the risk levels into the “Region of sufficiently stable management” (pale blue area) indicated in Fig. 5.

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

2.3.3.2 Basic approach to risk reduction

The decommissioning of the Fukushima Daiichi NPS is a project with inherent considerable uncertainty. To date, internal status of PCV in the Units 1 to 3 is presumed to some extent by simulation of the accident progression using various measurements, estimation of location of fuel debris by measurement of muon-base, projection of investigation equipment into PCV, radiation dose measurement in the buildings and others. However, since the radioactive environment inside the reactors is still too severe for workers to easily access, the properties of some radioactive materials and the degree of damage to the field equipment and structures left there remain unknown, creating uncertainty.

While it is desirable to eliminate uncertainty by grasping all the above unknowns that are difficult to know, 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 not necessary to take the same steps among the different units, and 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, which are not easy to do, NDF summarizes the following five guiding principles.

(Five guiding principles)

- Safe — Reduction of the risks posed by radioactive materials and ensuring work safety
  (Examples of considerations: confinement of radioactive materials [environmental impact], workers' radiation exposure, risk reduction effects)
- Proven — Highly reliable and flexible technologies
  (Examples of considerations: conformity with the requirements, flexible stance to uncertainty)
- Efficient — Effective utilization of resources (e.g. human, physical, financial and space)
  (Examples of considerations: restricting the generation of waste, cost, securing the work area and space)
- Timely — Awareness of time axis

(Examples of considerations: early start of fuel debris retrieval, duration needed for fuel debris retrieval)

- Field-oriented   Thorough application of the “Three Actuals” (actual field, actual things and actual situation)
  (Examples of considerations: workability [environment, accessibility, operability], serviceability [maintenance, troubleshooting])

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

2.3.3.3 Order of priority

It is necessary to proceed with the project based on this five guiding principles in managing progress of overall project. In particular, the situation at the site is gradually becoming clearer as the decommissioning work progresses. If this basic concept is applied to the actual site, the overall balance should be considered during the decommissioning work at present, while placing emphasis on “safety” and “reliability”, such as controlling radiation exposure and ensuring the safety and reliability of devices and equipment. Moreover, It is important to be aware of position of each project and their mutual relationship in their respective fields In other words, although addressing the highest risks first may seem effective from a near-term perspective, such an approach may not always be optimal when viewed from a long-term perspective that considers various factors, such as the feasibility of the relevant technologies and the time required for preparation.

For instance, although the exhaust stack for Units 1 and 2 located near Unit 2 is contaminated with radioactive materials, mainly cesium that were released by the accident and adhered to its inner surface, its risk associated with radioactive materials is rated as lower than that of fuels in SFP. However, considering fractures and deformation were found at the junctions of the diagonal bracing of the steel tower that supports the exhaust stack, the upper part of the stack is going to be dismantled with remotely controlled equipment as an environmental improvement ahead of fuel removal from SFP.

Thus, in the decommissioning of the Fukushima Daiichi NPS, which aspires to continuous and prompt risk reduction, the traditional approach of proceeding with project tasks by resolving imminent issues one by one would not be effective. Instead, 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 milestones. This idea of pursuing risk reduction optimized for the entire project is discussed in Section 3.6. Taking into account such point of view, TEPCO and NDF have introduced and promoted strengthening of the project management structures. This is discussed in Section 4.2.

2.3.3.4 Concept of securing safety and promotion of cooperation

This is the first attempt in Japan at decommissioning damaged reactors. There are no established or standardized regulations associated with the risk reduction of accident-hit nuclear power facilities. As represented by fuel debris retrieval, the decommissioning of damaged reactors involves reducing existing potential risks, leading to stabilizing the Fukushima Daiichi NPS. The concept of safety is essentially different from the operation at normal nuclear facilities. Considering time variation in the risk level described in Sub-section 2.3.3.1, in other words, it is required to achieve transition to the storage condition under a higher-level of management as early as possible. On the other hand, safety assurance in and outside the premises may be influenced if retrieval starts with insufficient preparations and measures. Furthermore, if excessive protective measures are implemented for associated risks, retrieval may be difficult. Therefore, it is a challenge to realize balanced risk reduction.

Referring to safety efforts from overseas damaged reactors and legacy sites (refer to Chapter 6), when conducting tasks for which no preceding experience exists in the world, principle of securing safety should be established according to the conditions and circumstances of the Fukushima Daiichi NPS. Therefore, appropriate approaches to safety at the Fukushima Daiichi NPS need to be determined in consideration of unprecedented circumstances, such as significant uncertainties in the situation and the difficulty in implementing measures due to high radiation doses at the site.

In light of this situation, with NDF as the main player, TEPCO and system design manufacturers, etc., are collaborating and studying the concept of determining appropriate approaches to safety for the decommissioning work (an approach to ensuring safety). Specifically,

- examination toward establishment of determination criteria and the safety assessment method applicable to the decommissioning work at the Fukushima Daiichi NPS,
- safety assessment by selecting representative accident scenarios for fuel debris retrieval, and consideration of a perspective to determine appropriate approaches to safety based on the results, and others.

NDF should continue to cooperate with other stakeholders, such as TEPCO and the Agency for Natural Resources and Energy, to promote discussions, hold active conversation with the Nuclear Regulation Authority, and reach an agreement on how to determine reasonable approaches to safety for the decommissioning work at the Fukushima Daiichi NPS. For the organizations involved, including regulation authorities, sharing the goal of safe and smooth decommissioning and performing their own roles regarding the reduction of on-site hazards and risks, it is important to make positive efforts while sharing purposes and challenges, and for this safety assurance concept to be effective, it is desirable to promote cooperation among the organizations involved.

As an example, one year after the accident at the United States Three Mile Island Nuclear Power Plant Unit 2 (“TMI-2”), four parties; namely, General Public Utilities (GPU), the Electric Power Research Institute (EPRI), the Nuclear Regulatory Commission (NRC) and the United States

Department of Energy (DOE), signed a cooperation agreement for fuel debris retrieval. Named after the initials of the parties, GEND was a unified team that shared technological challenges beyond the boundaries of the organizations, as various reports[3,4] indicate. At the Sellafield site, U.K., the G6 group was established to carry out decommissioning, with the stakeholders having the common purpose of accelerating the reduction of hazards and risks at the site. G6 included Sellafield Ltd., NDA, the Office for Nuclear Regulation (ONR), the Environment Agency (EA), UK Government Investments (UKGI) and the Department for Business, Energy and Industrial Strategy (BEIS). The group has discussed the order of priority for risk reduction, effective resource use, and how to realize the balance when risks may temporarily grow to reduce the risk in the long run. As an achievement of this commitment, acceleration of the hazard and risk reduction has been observed at the legacy sites in the Sellafield.

2.3.3.5 Addressing temporary increase of risk levels associated with the decommissioning operations

As mentioned in Sub-sections 2.3.3.1 to 2.3.3.3, implementation of the decommissioning work aims at prompt risk reduction from the mid-and-long-term viewpoint. However, the possibility that conducting the work may temporarily change the risk levels and increase the radiation exposure of workers must be carefully considered. This is because carrying out the decommissioning work involves acting on the current situation of the NPS, which is kept in a state with a certain level of stability despite some risks. Such risks may materialize, depending on the way actions are taken. For example, accessing the inside of the reactor to retrieve fuel debris will affect the current confinement status, and special operations and maintenance performed for the retrieval will increase the radiation exposure of workers involved in these activities.

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 (i.e. restricting radiation exposure) of workers should be ensured in accordance with the concept of ALARA[5].

Note that the basic stance of promptly implementing the decommissioning must be firmly maintained because if the work is delayed excessively, existing large risks will remain over the long term and their risk levels may gradually rise as the buildings and facilities deteriorate over time. For this reason, the selection of the method of work, the design and production of equipment and safety

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[3] EPRI, The Cleanup of Three Mile Island Unit 2, a Technical History: 1979 to 1990, EPRI NP-6931 (1990).
[4] NRC, Three Mile Island Accident of 1979 Knowledge Management Digest, Recovery and Cleanup, NUREG/KM-0001, Supplement 1 (2016).
[5] ALALA is the principle of optimization for radiological protection recommended by International Commission on Radiological Protection (ICRP), and is the abbreviation of "as low as reasonably achievable". It is advocated that individual dose, number of the exposed people and likelihood of radiation exposure must be kept as low as reasonable achievable in consideration of economic and social factors. (The 1990 Recommendation by ICRP, Japan Radioisotope Association (issued in 1991),

systems, and the development of work plans for the decommissioning work should many constraints such as consider time, cost and workers' radiation exposure needed for associated preparations and work, while giving priority to limiting the risks involved in the decommissioning work. Based on these considerations, cautious and comprehensive decision-making are required for the early implementation of the decommissioning (See Attachment 5).

It must also be strongly emphasized that the decommissioning of the Fukushima Daiichi NPS as a risk reduction project should be promoted, not by the understanding among the limited working parties, but by gaining the broad understanding and support by wide range of public including local residents. It is crucial to foster public understanding of the overall risk reduction efforts, including measures to prevent a temporary increase in the risk associated with various decommissioning work; and thus gain understanding of the decommissioning project. It is particularly important to inform local residents, in an easily understandable manner, of issues such as what kind of risk reduction strategy has been established for the decommissioning work, how the safety of the decommissioning work is ensured, and how the overall risks at the NPS have been continuously reduced through the decommissioning work. For this purpose, it is important to implement an easy-to-understand mechanism of monitoring of risks for local residents NDF is considering such a mechanism, and it is important for TEPCO to consider the introduction of a similar structure in the future.

3. Technological strategies toward decommissioning of the Fukushima Daiichi NPS

3.1 Fuel debris retrieval

3.1.1 Sectoral target

For the time being, the objectives of fuel debris retrieval are as follows (For the objects of fuel debris retrieval refer to Attachment 6).

(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 within 2021, necessary approaches will be taken, according to the “Policy on Fuel Debris Retrieval”.

Policy on Fuel Debris Retrieval

① Step-by-step approach

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

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

② Optimization of entire decommissioning work

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

③ Combination of multiple methods

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

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

④ Approach focused on partial submersion method

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

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

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

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

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

3.1.2 Sectoral Strategies

3.1.2.1 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[6] that risk may grow in case of dealing with rush and haste. (refer to Section 2.3). 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. Namely, two types of risk exist in fuel debris. One is a risk from medium-term perspective that adverse effects on the environment can occur due to the development of criticality and cooling problems though its possibility is low as far as it is properly managed in a state with a certain level of stability. The other is a risk from a long-term perspective that environmental pollution can occur resulting from any leaks of included nuclear fuel material due to deterioration of the buildings in future. Therefore, as indicated in (1) of Sectoral target, fuel debris should be retrieved safely after thorough and careful preparations such as safety measures and brought to a 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 the feasibility of the fuel debris retrieval method 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 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 risks associated with its operation, due to the limited information on the internal condition of PCVs 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

[6] Based on the current risk assessment for each unit, there would be a difference in terms of safety management across the units. Unit 1 has no upper reactor building and Unit 3 has a cover for fuel removal instead of an upper reactor building. On the other hand, the reactor building of Unit 2 is in a sound state, and the damage level of the RPV is considered small because most of fuel debris is presumed to remain inside the RPV. Regarding the shape of fuel debris influencing Hazard Potential, there is a possibility of various states such as a state close to fine particles to a solid state, but the specification of the shape has not been done currently. The calculation in Fig. 5 has been estimated from the findings obtained so far. Particularly with respect to Unit 2, much of the fuel debris is presumed to remain in the RPV, and hazard potential becomes relatively low because it is considered to be a stable form due to the low ratio of molten core concrete interaction products compared to Units 1 and 3.

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 implementing 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 the release ratio of radionuclides into the air and water) 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 (safety assessment)
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 actual site applicability, site environmental preparation, investigation inside condition of PCV and necessary R&D shall be conducted continuously.

3.1.2.2 Fuel debris retrieval method for the first implementing unit (Outline of the strategic recommendation for determining the fuel debris retrieval method 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, the fuel debris retrieval for the first implementing unit will start within 2021 by determining the method of containing, transfer and storage (by FY2019) after due consideration of the results of the preliminary engineering work 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 Method for the First Implementing Unit”. (Attachment 7) The recommendation for determining the fuel debris retrieval method for the first implementing unit has been concluded through the examination of overall optimization of the combination of the whole site planning and fuel debris retrieval scenarios of each unit which were established based on the evaluation of the conceptual design of the fuel debris retrieval system and its actual site 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.6.

As a result of the above mentioned examination, selected “fuel debris retrieval work”, which can be defined as a series of operations from containing, transferring and then storing in steady condition, is to start “promptly” from small scale retrieval operation keeping in minimum of risk increase caused by fuel debris retrieval work and to accumulate experience and knowledge “promptly” for expanded-scale of fuel debris retrieval work (expanded-scale retrieval) as well as other units than 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 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 is evaluated possible to retrieve fuel debris “safely”, “reliably” and “promptly”. In addition, fuel debris retrieval by crushing or cutting other than gripping and sucking will be performed without significant modification of existing safety system.

As well, proposed method of containing, transfer and storage of retrieved fuel debris, that retrieved fuel debris firstly contained in the 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.7.

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 sufficient information on PCV internal condition and the site condition (radiation dose, degree of air tightness of the existing safety system) has been obtained as well as that information and experience on fuel debris retrieval work can be promptly obtained by starting its fuel debris retrieval work “safely”, “surely” and “promptly” based on the 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 risks 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 operations from retrieving, containing, transferring, and storing of fuel debris should be continued safely and reliably, and then information/experience 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 in 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, series of operations from fuel debris retrieval to containing, transfer and storage 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 of the retrieved fuel debris applicable for the expanded-scale of 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 Fuel Debris Retrieval for the First implementing Unit” also discusses the efforts to be made toward the fuel debris retrieval in the first implementing unit and expanding retrieval scale and retrieval in units other than the first implementing unit, which is described later in Sub-section 3.1.3.1.

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.

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Study on concept of fuel debris retrieval

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

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

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

↓

Comprehensive assessment

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

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

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

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

⇩

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

↓

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

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

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

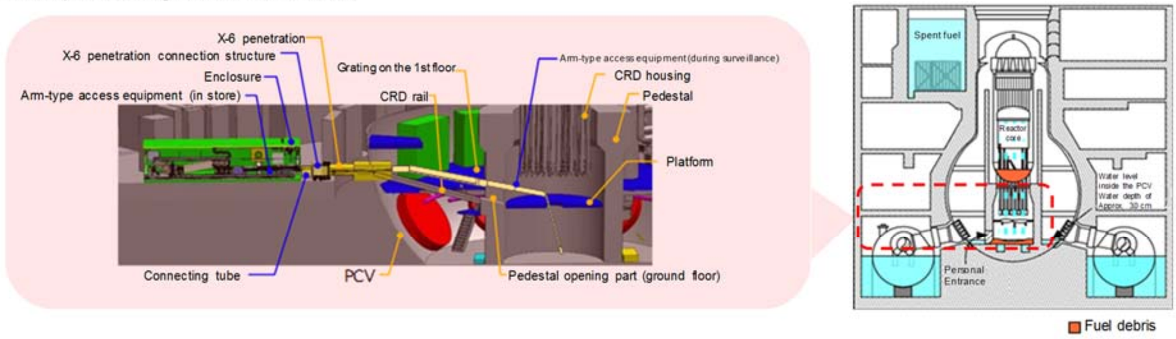
③ Retrieved fuel debris firstly contained in the small container is transferred, contained into the canister and stored in dry condition at the temporary storage facility built within Fukushima Daiichi NPS site.

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

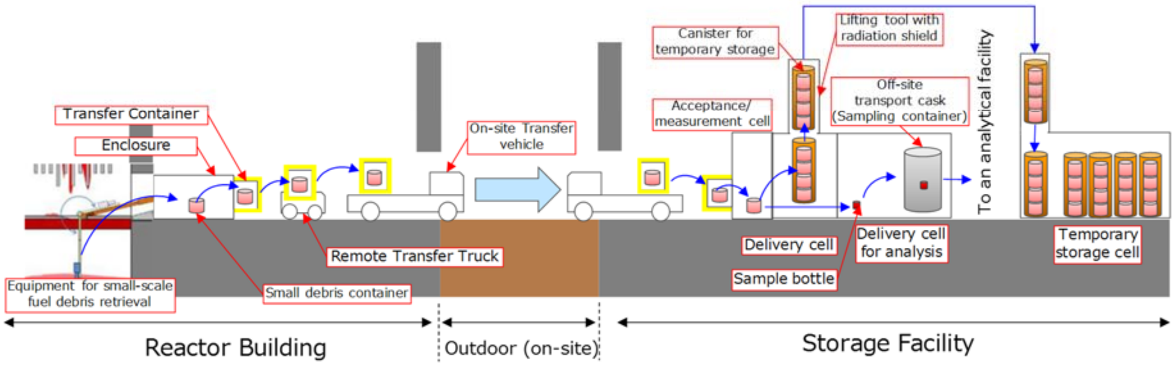
⑤ Retrieval methods including containing, transferring and storing the retrieved fuel debris applicable for the expanded-scale of fuel debris retrieval work phase or other than the first implementing unit need to be established by proceeding with PCV internal investigation, necessary R&D and improvement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

Fig.6 Flow of Examinations on "Strategic Recommendation for Determining the Fuel Debris Retrieval Method for the First implementing unit"

<Conceptual drawing of fuel debris retrieval>



<Conceptual drawing of fuel debris containment, transfer and storage>



(TEPCO material edited by NDF)

Fig. 7 Conceptual drawing of fuel debris retrieval, containment, transfer, and storage

3.1.2.3 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. As described above, it is important to conduct analyses and investigations on decommissioning and contaminated water management at the Fukushima Daiichi NPS in a planned manner. A plan for the analyses and investigations needs to be developed in engineering in accordance with the following "Basic principles toward the planned analysis and investigation on the decommissioning and contaminated water management of Fukushima Daiichi Nuclear Power Station"[7]. (Attachment 8)

Basic principles toward the planned analysis and investigation on the decommissioning and contaminated water management of Fukushima Daiichi Nuclear Power Station

(1) To proceed with the decommissioning of Fukushima Daiichi NPS safely and steadily is of primary importance. With these efforts, it is necessary to achieve "decommissioning as soon as possible". For that sense, the analysis and the investigation on the decommissioning and contaminated water management of Fukushima Daiichi NPS (hereinafter referred to as "Fukushima Daiichi NPS Analysis and Investigation") should be conducted, to the extent that can proceed with the decommissioning in safe and steady.

(2) At the same time, it is also necessary to proceed with the Fukushima Daiichi NPS Analysis and Investigation from the viewpoint of ascertaining the causes of the Fukushima Daiichi NPS accident and improving the nuclear safety for future (hereinafter referred to as "Forensic"). Therefore, due consideration is to be given to the necessity of the Fukushima Daiichi NPS Analysis and Investigation from the viewpoint of Forensic, on the premise of the safe and steady decommissioning of Fukushima Daiichi NPS.

(3) The Fukushima Daiichi NPS Analysis and Investigation is to be planned on the premises of realistic working situations and difficulties of the site, giving the highest priority on the safety for local residents, surrounding environment and workers. In addition, it must be proposed after clarifying the concreteness of technology commensurate with it.

(4) While clarifying what is the information obtained from the Fukushima Daiichi NPS Analysis and Investigation used for and what will it contributes to, it must be conducted in reasonably acceptable range as Fukushima Daiichi NPS decommissioning project, considering its significance and the responsibility associated with it.

(5) Taking into account of Japan's responsibility to the international society, as a country where the Fukushima Daiichi NPS accident occurred, information obtained in the Fukushima Daiichi NPS Analysis and Investigation should be provided in a proactive way. There is a possibility for institutions requesting additional information to bear a reasonable burden.

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,

[7] 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

are encountered 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 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.

3.1.3 Technical issues for developing sectoral strategies and future plans

3.1.3.1 Technical issues and plans related to the fuel debris retrieval from the first implementing unit

3.1.3.1.1 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 fuel debris retrieval methods for the first implementing unit as described in Sub-section 3.1.2.2.

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 regarding small-scale retrieval equipment and verification on accessibility at the PCV internal investigation, then 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 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 gripping.

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 the fuel debris was scheduled to be conducted after confirmation of a) of ③. This confirmation is evaluated so for to be obtained by the confirmation of 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 the fuel debris retrieval in small amount. Thus, the fuel debris retrieval for the first implement 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.

3.1.3.1.2 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 (safety assessment)
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 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 unit 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 the 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.

3.1.3.2 Comprehensive understanding of conditions of PCVs by continued internal investigation, etc.

3.1.3.2.1 Previous internal investigations and inside reactor conditions

The comprehensive analysis and evaluation results about the distribution of fuel debris, the radiation dose at the working area, the access route to fuel debris and the situation of the surrounding structure in Units 1 to 3 are as follows, that have been derived from actual values of plant parameters, etc., which were obtained at the time of accident, severe accident progression analysis, the knowledge obtained by internal investigations of PCV and muon-based detection technology, etc.

(1) Internal condition of Unit 1

It is presumed that most of the fuel debris is at the bottom of the PCV. It is presumed that the fuel debris at the bottom of the PCV has spread to the pedestal inside floor line and has reacted with the concrete to form products of molten core and concrete interaction. There is a possibility that a part of the fuel debris has spread to the outside of the pedestal through the worker access opening.

As the radiation level in working area, it was confirmed that the radiation dose rate around X6 penetration was high i.e. 630mSv/h.

Regarding access routes, it is confirmed that access from the top of the steel grating to the bottom of the PCV outside of the pedestal is possible as per the PCV Internal investigation of 2015.

Regarding the situation of the surrounding structure, no large damage was detected on the outer wall surface of the pedestal on the top of the steel grating by the PCV Internal investigation of 2015. Large damage was not detected to the structure in the PCV Internal investigation of March 2017, neither.

(2) Internal condition of Unit 2

Fuel debris is presumed to be mostly present at the bottom of RPV and from muon measurement, it is evaluated that the fuel is present in RPV. Based on evaluation of core energy it is estimated that an equivalent quantity of non-melting fuel pellet is also present. In the PCV internal investigation of 2018, deposits that appeared to be pebble/rock-like in shape were observed in most of the bottom area of the pedestal. Since a part of the fuel assembly had fallen to the bottom of the pedestal, the deposit observed around it is presumed to be fuel debris. However, large-scale damage and deformation to the concrete wall in the pedestal, melting of cable trays and steel pillars of the CRD handling machine, etc., were not observed, so the fuel debris is considered to be containing a lot of metal components such as internal structural materials. There may have several drop paths of fuel debris because there are other deposits that are accumulated higher than the surroundings. Also, although the worker entrance of the basement floor of the pedestal has been confirmed, it has not been able to observe outflow of fuel debris outside the pedestal. The PCV internal investigation in February 2019 revealed that pebble-like deposits could be moved by gripping, but there was a possibility that deposits like hard rocks existed, which could not be gripped[8].

As the radiation level in working area, it was confirmed that the radiation dose rate on the first floor of reactor building reduced by about 5mSv/h approximately in general.

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[8] TEPCO, Unit 2 Primary Containment Vessel Internal Investigation Results, Handout 3-3, 64th Meeting of Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment, March 28, 2019.
http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2019/03/3-3-3.pdf

Regarding the access route, in the PCV internal investigation of 2018, it was observed from PCV X-6 penetration that access was possible from the worker entrance to the bottom of the pedestal via the CRD rail.

Regarding the condition of the surrounding structure, in the PCV internal investigation of 2017 and 2018, it was observed that part of the steel grating of the pedestal inside the platform had fallen, but no significant damage was found on the pedestal inner wall surface and the existing structures in the pedestal. It was also confirmed that a part of the fuel assembly had fallen to the bottom of the pedestal, but no large damage was observed in CRD housing support within a range of the investigation.

(3) Internal condition of Unit 3

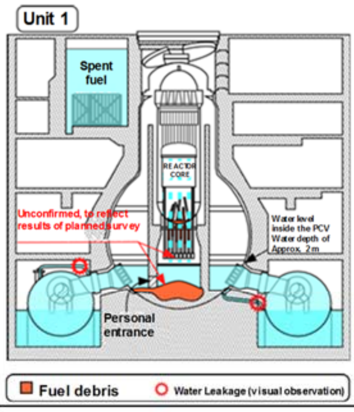
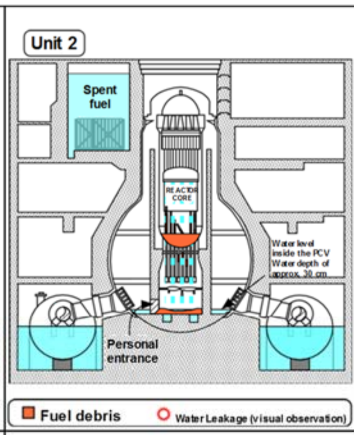
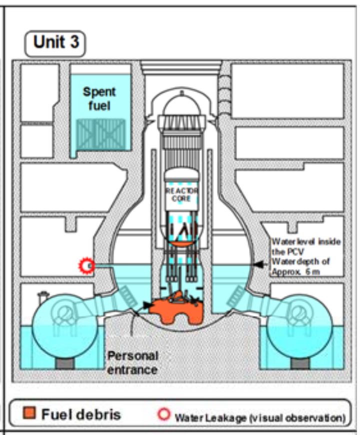
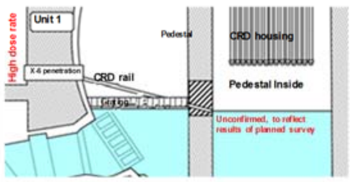
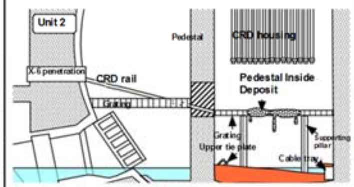
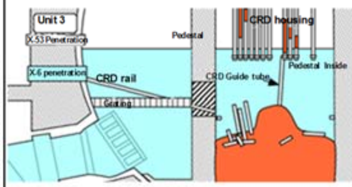
It is presumed that there is more fuel debris at the bottom of the PCV of Unit 3 than that of Unit 2, although some fuel debris may be left at the bottom of the RPV. In the muon measurement, it is also shown that a range of the original core in the RPV does not have any large lump of fuel debris. The evaluation of core energy shows the possibility of a large massive fuel solidifying after melting once existing at the bottom of the RPV. In the PCV internal investigation of July 2017, it was observed that the molten material had solidified in the pedestal. In addition, since the sandy or massive deposits were observed at the bottom of the RPV as well as structures presumed to be the internal structures have been observed, it is presumed that the surrounding deposits may include fuel debris. The worker entrance of the basement floor of the pedestal could not be observed. Since the deposit was observed in the vicinity, the possibility that fuel debris has spread outside the pedestal cannot be ruled out. On the other hand, cooling water was injected into the drywell (“D/W”) at the time of the accident, which may have restricted the spread of the fuel debris.

As the radiation dose in working area, it was confirmed that the radiation dose rate was higher than tens of mSv/h on the first floor of reactor building.

Regarding the access route, it was observed that it is possible to access the bottom of the pedestal via the worker entrance of the pedestal in the PCV internal investigation by the underwater ROV in July 2017.

Regarding the condition of the surrounding structure, in the PCV internal investigation in July 2017, damage to the structures and fallen substances in the pedestal, missing portions and deformation of CRD housing supports were observed. Also, in a range of the investigation, the steel grating was not observed on the platform and it was observed that the steel grating had fallen in the lower part of the pedestal. No large damage was detected on the pedestal inner wall surface.

This information is summarized as in Fig. 8.

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

3.1.3.2.2 Future plan on internal investigations

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 in small amounts are scheduled for FY 2019. In addition to this, investigations 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 underwater 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, and in association with the use of large-scale equipment, giving due considerations will be required for continuously ensuring safety, including prompt recovery of containment functions during abnormal events as well as measures against radiation exposure, dust control and containment functions, in consideration of maximum use of existing penetrations into the internal PCV that have been used in the previous investigations.

In addition, fuel debris and deposits at the Fukushima Daiichi NPS are unique due to differences in the reactor structures and countermeasures to settle the accident, and the data are limited with a high level of uncertainty. Therefore, it is necessary to develop analytical and estimation technologies for characterization. In particular, in order to establish analytical techniques, it needs to demonstrate analytical methods for fuel debris using actual fuel debris samples. For development of radioactive material analysis and research facilities, it is important to take into consideration the demonstrated outcome to proceed with characterizing fuel debris according to a location of PCV.

3.1.3.3 Technical issues and future plans for technical requirements

3.1.3.3.1 Technical issues and future actions for ensuring the safety of fuel debris retrieval work

Generally, when it comes to deal with securing safety at nuclear facilities, it is required to establish the concept of securing safety of nuclear facilities, which clarifies the necessary safety functions and corresponding protective measures based on the scope of typical accident events, in order to avoid unnecessary exposure to radiation or excessive meaningless protective measures. However, in the decommissioning operation of the Fukushima Daiichi NPS, it may be difficult to apply the idea of a stereotyped and standardized concept of securing safety like a normal nuclear power plant. Therefore, it may be necessary to establish the concept of securing safety according to the severe actual circumstances at the site. For this reason, NDF has been working on organizing the idea of securing safety at the site (see Sub-section 2.3.3.4) in order to foster a shared understanding among related organizations including regulatory authorities that share the purpose of promoting safe and smooth decommissioning.

In operations involving unprecedented uncertainty such as the fuel debris retrieval, it may be necessary to incorporate reasonable protective measures at each conceptual design phase for the fuel debris retrieval steps while taking continuous actions to reduce the uncertainties about the internal conditions of PCVs.

As the concept of ensuring safety during the fuel debris retrieval work is being constructed, NDF is focusing on the studies on specifying the technical requirements to ensure safety during fuel debris retrieval work, as shown in Sub-sections 3.1.3.3.2 to 3.1.3.3.7. Specific measures for securing safety not limited to fuel debris retrieval work are described in Sub-section 3.5.4.

3.1.3.3.2 Establishing the containment functions (gas-phase)

Normally, dispersion of radioactive material in operating nuclear power plant is prevented by keeping negative pressure inside of reactor building against the ambient air (active containment function due to by maintaining under negative pressure) and pressure inside PCV is maintained equal to inside of a reactor building (passive containment function). On the other hand, in Fukushima Daiichi NPS, the reactor buildings and PCVs have been partially damaged by the hydrogen explosion and their containment function has been deteriorated. Because of this, establishment of an active containment function due to negative pressure inside PCV during fuel debris retrieval work is being investigated. Moreover, in order to prevent hydrogen explosion due to continuous hydrogen generation by radiolysis of water and in order for the structural members to prevent corrosion caused by the oxygen (inactivation), nitrogen is injected into the PCVs to maintain it inert atmosphere. The dispersion of radioactive material has been preventing by the PCV exhaust gas control system which involves filters to remove radioactive material and involves radioactivity measurement system[9].

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 studied and confirmed. However, the dispersion of radioactive fine particles containing α-nuclides (α-dust) may occur due to the crushing 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 PCVs.

In this regard, the approach for the expansion of the scale of fuel debris retrieval work, while accumulating the tendency of dust dispersion depending on scale expansion and verifying the validity of the containment function built in the subsequent stage is evaluated to be reasonable. 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 PCVs 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 PCVs as well as constructing a secondary containment function outside PCVs.

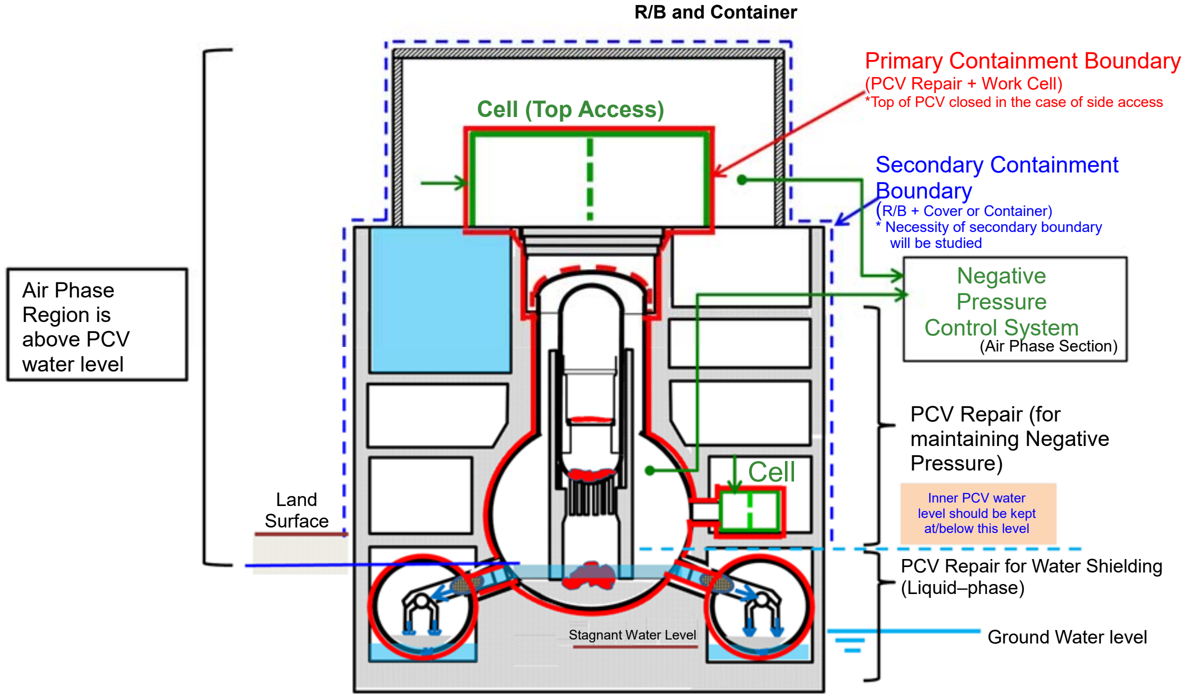


Fig. 9 Example of containment function (gas phase) by pressure control system

[9] While the estimated radiation exposure dose at the site boundary due to the release of airborne waste is 3.0 × 10^{-2} mSv/year, the estimated additional release from Units 1 to 4 reactor buildings is approximately 2.2 × 10^{-4} mSv/year (Estimated value as of March 2019) (See Sub-section 3.5.2.2).

For building this containment function (gas phase), technical issues to be addressed immediately are as follows.

(1) Understanding of dispersion rate of α-dust, etc.

As described above, for the purpose of fuel debris retrieval work, it is necessary to collect concerned data such as α-dust dispersion rate and to establish measures to suppress the transition of α-dust gas phase as much as possible.

In order to collect concerned data such as dispersion rate of α-dust, it is required to establish the plan for dispersion rate measurement during sampling work and small-scale retrieval work. Moreover, in order to proceed with the technology investigation and R&D activities for establishing the fuel debris retrieval method/system under the condition where such actual data cannot be obtained, approximately understanding on the general behavior of α-dust dispersion is required. R&D for verification of general behavior of α-dust dispersion using mock-up debris is currently underway[10].

In order to suppress the transition of α-dust to the gas phase, it is preferable to submerge the fuel debris and to retrieve it in submerged condition as much as possible. However, the water level in the PCV is to be adjusted with other technical requirements such as the containment function of the liquid phase described in the next Sub-section. Therefore, mitigating transition of α-dust to gas phase by supplying water on the fuel debris is under way, because all of the fuel debris cannot be retrieved in submerged condition.

(2) Feasibility of negative pressure control in the PCV

A. Technical feasibility of maintaining negative pressure based on site conditions

In order to maintain negative pressure in the PCV, enough capacity in the gas exhaust system is required according to the PCV damage condition. Although damaged part have not been identified yet, and the exhaust capacity is currently evaluated based on the relationship between actual nitrogen supply volume and actual PCV internal pressure. At this time, it is necessary to maintain sufficient pressure difference to respond to the internal pressure rise of the PCV due to abnormal events such as an internal temperature rise or stoppage of the gas exhaust system. In order to achieve these, repair of the damaged parts of at the upper part of the PCV will be studied as necessary, but there are some difficulties such as remote work or radiation exposure for workers due to work under high radiation dose circumstances.

In this way, it is necessary to ascertain the technical feasibility of maintaining the negative pressure in the PCV according to the site conditions as well as the information through the fuel debris retrieval work.

[10] Refer to (4) Clarify behavior of radioactive airborne particles generated during decommissioning (incl. α-dust treatment) in Attachment 15.

B. Influence of air flow into PCV on negative pressure control

Air flow comes into the PCV when maintaining inside of PCV pressure in negative. Therefore, it is required to collect the data of hydrogen generation by radiolysis of water inside of PCV and to study possibility of hydrogen explosion caused by air (oxygen) into the PCV. It is required to elaborate the countermeasure for maintaining inert atmosphere by increasing nitrogen gas supply, if necessary. Evaluation results on influence of air (oxygen) inflow on corrosion of structural material and its preventive measure are discussed in Sub-section 3.1.3.3.6 for details.

C. Necessity of secondary containment function

As shown in Fig. 9, fuel debris is planned to retrieved and collected into the container which is to be packed into the transport container equipped in the working cell which is connected with PCV. The PCV and this working cell have a primary containment function to prevent of α-dust to the exterior.

In addition to this, in order to respond to the event that radioactive material is dispersed from the containment boundary caused by loss of primary containment function by fail of maintaining negative pressure in the PCV and connected working cell, necessity of the secondary containment function has been investigated. The secondary containment function is established by maintaining negative pressure inside of the Reactor Building and a connected cover or cell which is installed close to the Reactor Building. However, large capacity of gas exhaust system might be required to maintain negative pressure in the secondary containment boundary since the reactor building has a large volume and the its leak tightness may have been deteriorated due to the accident. Therefore, based on the accumulated results of the tendency of dust dispersion obtained hereafter, it is necessary to identify the required functions to establish the secondary containment boundary and to perform the necessary technology development.

D. Control of deterioration of PCV containment function

In order to maintain inside of PCV negative pressure during the fuel debris retrieval work, preparation for maintaining containment function against earthquakes and aging is required. This is discussed in detail in Sub-section 3.1.3.3.6.

(3) Study on exhaust gas management

During PCV inside pressure maintained negative pressure by gas exhaust system, radioactive material derived from fuel debris in exhaust gas shall be managed under the level of radiation dose limit for public by monitoring and controlling released radioactive material condition (concentration and amount). In addition, concentration or amount of the nuclides derived from the fuel debris which releases α or β (ϒ) rays in the exhaust gas needed to be regularly measured so as to evaluate their normal fluctuation range in advance during fuel debris retrieval work. By using such data, it is necessary to develop a system to detect abnormal events such as nuclides leakage in advance and to mitigate the impact of the released nuclides on environment and workers.

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

3.1.3.3.3 Establishing the containment functions (Liquid-phase)

As discussed in the previous Sub-section, to mitigate the dispersion rate of generated α-dust and to minimize the transition to the gas phase, the 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 and confirmed. A large amount of α-particles (radioactive particulates containing α-nuclides) will flow into cooling water (liquid phase) during crushing of fuel debris or removing of the obstacle. To prevent the cooling water containing α-particles from affecting the environment, it may be important 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.

The Mid-and-Long-term Roadmap requests to investigate feasibility of the PCV cooling water circulation line for cooling water taken from PCV and injected to the RPV which is necessary at the time of fuel debris retrieval work. As describes in Sub-section 3.3.2.3, this PCV cooling water circulation and purification line is effective to prevent α-dust dispersion during the fuel debris retrieval work because it has an effect of preventing contamination of stagnant water in the building. At this time, to ensure a more reliable containment function, water sealing methods by repairing the bottom of the PCV pouring the grout materials have been studied. However, based on the results of previous experimental studies, it is becoming clearer that water sealing by repairing the bottom of the PCV is very difficult. Thus, in consideration of the PCV repair technology and the results of the actual scale test[11], it may be important to explore a retrieval method to minimize leakage with the realization of suitable circulation and purification systems of cooling water (Attachment 9).

To establish a reasonable containment function in accordance with scale expansion, it is rational to monitor the radioactive concentration of the cooling water and validate the validity of the containment function built in the subsequent stage. For example, if the PCV internal investigations

[11] IRID, FY 2015 supplementary budget, Subsidies for Government-led R&D program on Decommissioning and Contaminated Water Management, Development of Repair Technology for Leakage Sections in PCV, FY 2016/2017 achievement report, July 2018, http://irid.or.jp/wp-content/uploads/2018/06/20170000_08.pdf
IRID, FY 2015 supplementary budget, Subsidies for Government-led R&D program on Decommissioning and Contaminated Water Management, Full-scale Testing of Technology for Repairing PCV Leakage Points, FY 2017 achievement report (final report), March 2018,
http://irid.or.jp/wp-content/uploads/2018/06/20170000_07.pdf

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 crushing work, together 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 monitoring and the evaluation for the characteristics changes of the liquid waste including α-nuclides, the scale of the 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.

In establishing this containment function (liquid phase), technical issues to be addressed immediately are as follows.

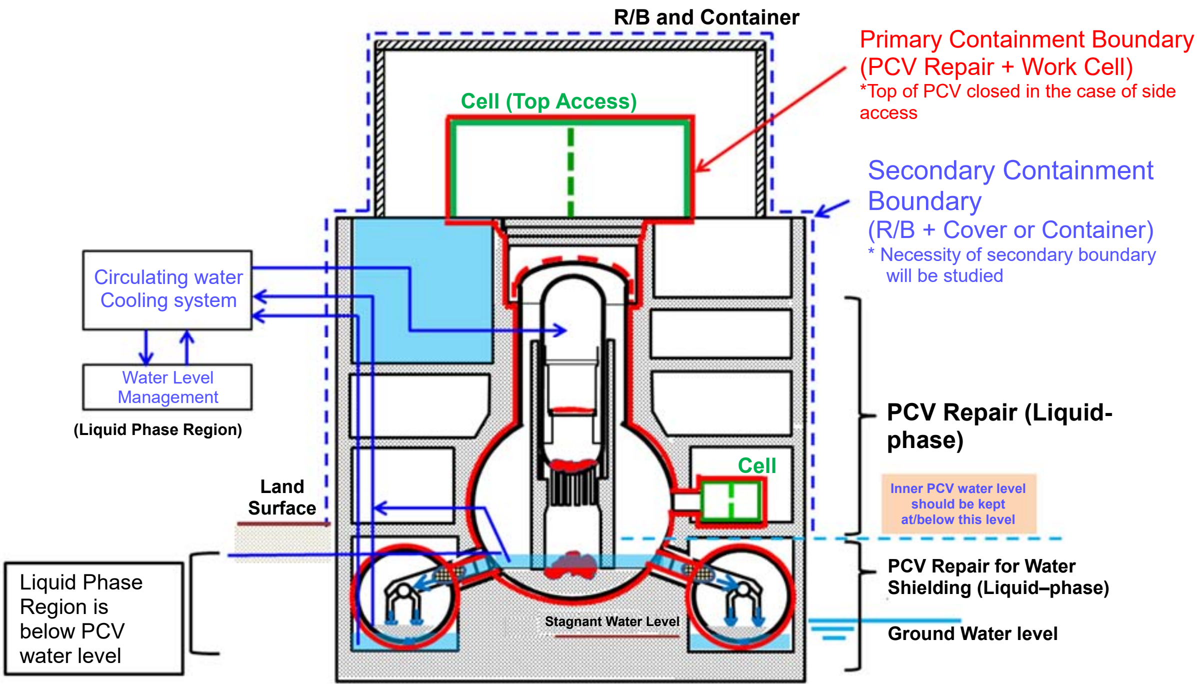


Fig. 10 Example of containment function (liquid phase)

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

It is necessary to plan to investigate the impact of small scale of the fuel debris retrieval work on radioactive concentration in the circulating cooling water.

For suppressing an increase of radioactive concentration in cooling water in the PCV, dust generated by fuel debris cutting is planned to be collected through PCV circulating cooling water system for mitigate dispersion of dust. It is required to validate the performance of the PCV circulating water system according to monitoring and evaluation results even in the small-scale fuel debris retrieval Thereby, it is also required to take necessary actions properly.

(2) Feasibility of PCV water sealing

With the aim of improving the containment function of liquid phase at the bottom of the PCV by suppressing leakage of cooling water into the torus room, various PCV water sealing methods including blockage of the vent tubes, burying of the tip of the down-comers and burying the pipe strainers on the S/C wall by concrete have been studied.

Based on the investigation results through Government-led R&D program on Decommissioning and Contaminated Water Management, it was found not to be able to achieve complete water sealing. Even in the case of practical water sealing work of blockage of the vent tubes, it is necessary to install the PCV circulation cooling system for controlling the water level in the PCV. In addition, due to the low seismic margin of the S/C supports and water leakage paths from the PCV other than from S/C, control of water level in the PCV and torus room has been studied low by cooling water circulation system. In the future, additional study will be carried out, as necessary, to resolve the technical issues identified through the examination on the applicability of current water sealing technologies to each unit which is being performed as a part of the engineering work.

(3) Setting of water level in PCV

Because the seismic margin of the S/C supports is low, water level in the PCV is heavily depends on the applicability/usability of water sealing technologies to each unit.

In the case that flow of cooling water from the Dry Well (D/W) into the S/C can be suppressed by the blockage of the vent tubes, the water in the PCV (D/W) can be maintained at relatively high level. If not, it shall be kept at low level. In such case, evaluation will be needed from the perspective of cooling of fuel debris and radioactive dust dispersion. In addition, the water levels in the PCV, S/C, torus room and groundwater are required to be monitored and controlled as well as location of taking water from the D/W need to be examined.

Attachment 10 shows the water level in the PCV of each unit for the three cases of water sealing work application. First is the cases of blockage of the vent tubes, second is burying of the tip of the down-comers and the pipe strainers on the S/C wall by high-flow concrete and last is no water sealing work.

3.1.3.3.4 Maintaining the cooling functions

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 the fuel debris retrieval work. At present, the cold shutdown state is maintained with keeping the temperature well below 100°C using cooling water. In addition, during the fuel debris retrieval work, it may be necessary to keep the temperature below the level at which the fuel debris retrieval device can continue to work without any problems for a long period of time. Further, it may be required to consider alternative water injection functions including mobile equipment, in preparation for an event the permanent equipment cannot maintain cooling due to a large earthquake, tsunami or other events.

At this time, to maintain the cooling function at each phase of scale expansion, the consistency with other systems should be checked, such as the water level control system within the PCVs for confining the liquid phase and the circulating water cooling and purification systems. Based on the data obtained for each phase of scale expansion, it is necessary to examine and establish the circulation cooling system in the next stage, including consideration of the adequate circulating flow rate required for cooling. However, it should be considered that the injection of cooling water may become redundant in the future due to further decrease in the decay heat, as the fuel debris retrieval progresses.

In maintaining this cooling function, the technical issues to be addressed for the time being are to establish the target temperature inside the PCV to secure fuel debris retrieval work and to investigate countermeasures against the unanticipated abnormal condition as well. An essential countermeasure would be to continue cooling water circulation by early recovery of the cooling water circulation system or by the recovery action by mobile equipment, as well as it is necessary to establish countermeasures and their implementation process/step such as salvage of equipment taking change of condition in the PCV including time margin until reaching the abnormal condition.

Also, monitoring items and their criterion need to be studied and prepared through the engineering work, in order to carefully proceed with fuel debris retrieval work with observing how this work will affect the existing cooling water circulation and purification system as well as its cooling function.

3.1.3.3.5 Criticality Control

At present, the monitoring of the concentration of rare gas (Xe-135), which is a fission product (hereinafter referred to as “FP”), has shown no sign of criticality as the concentration remains at a sufficiently low level with respect to the criticality criterion of 1 Bq/cm^3. In addition, the possibility of re-criticality of the fuel debris at the Fukushima Daiichi NPS is presumed to be low from the engineering viewpoint, because the alternation of molten fuel assemblies is not likely to reach criticality due to the abundance ratio with water and the mixture of impurities, such as internal structures, that can be expected in the course of core meltdown. Furthermore, the fuel debris is presumed to scatter in a wide area outside the core as a result of the accident progression. Even if criticality should occur, its impact would be small because it is estimated that the fuel debris is dispersed over a wide area.

Though the possibility of criticality is low, the shape of fuel debris alters during retrieval. Therefore, it is essential to prevent fuel debris from reaching criticality during retrieval by investigating what conditions would lead to criticality when the shape of fuel debris changes. Establishing an appropriate management method is also required to ensure prompt detection and termination, given unexpected criticality.

In the initial phase of fuel debris retrieval work, fuel debris should be retrieved by limiting the treatment amount based on methods that will not significantly change the fuel debris shape, such as by gripping and sucking, as well as the estimated fluctuation of reactivity. In the process of expanding the retrieval scale and cutting, the retrieved volume of fuel debris will likely be increased, based on the results of measurement of subcriticality before work, or taking measures such as placing neutron absorbers. In addition, through the overall retrieval operations, unless the criticality is unlikely to occur in consideration of the retrieval conditions, it is necessary reliable criticality prevention measures that combine design and evaluation with operator monitoring and judgment, specifically fuel debris retrieval while evaluating it's criticality by checking the amount of neutron signal fluctuation in the vicinity of the fuel debris.

To maintain the subcritical condition more reliably for fuel debris storage after retrieval, it is important to store it stably while controlling the shape and size, such as storing the debris in canisters.

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

(1) Establishment of criticality evaluation method

It is necessary to refine the information on the conditions for reaching re-criticality in fuel debris based on obtained information in each step of expanded-scale fuel debris retrieval. In this regard, an evaluation method has been developed to estimate the conditions for subcriticality and the degree of influence of criticality if it should happen. In conducting these evaluations, a plan should be made so that the information on the critical parameters with high impact on the criticality evaluation can be obtained in the course of internal investigation and retrieval, and to revise the plan through information updates as needed.

(2) Local neutron measurement around retrieval point

As existing neutron detectors, there are various kinds according to the application such as fission chamber, B-10 proportional counter tube, semiconductor detector, etc. It is important to select a neutron detector taking advantage of each feature. The key specifications for the neutron detectors required for criticality monitoring are; (1) ability to survive accumulated radiation dose (Gy) according to the operation period and (2) installability in assumed equipment (size/weight, cable diameter) or installability at a work site (size/weight, cable routing); and (3) required detection efficiency (time, accuracy). Accordingly, it is important to select an optimal detector based on the information on PCV radiation dose rate obtained by internal investigation and the progress of equipment development for each unit.

For the preparation of the actual operations, it is necessary to examine the installation location of neutron detectors and also to set up criteria for stopping retrieval operations and for determining the injection rate of boric acid, which is a neutron absorber, if fluctuations in neutron flux should arise.

The possibility of criticality needs to be examined in places other than retrieval locations. For example, criticality may occur in places where fuel debris cutting particles are accumulated, which cannot be collected in the circulating water cooling system (i.e. outside the PCV bottom pedestal, in piping, water filters, waste water receiving tanks, etc.). Though criticality can be detected by the PCV gas monitor system, countermeasures will be considered in accordance with criticality risk scenarios and evaluations, including the feasibility of approach-to-criticality monitoring.

(3) Feasibility study on the measuring method for the degree of subcriticality

When measuring the degree of subcriticality, in addition to the required specification of (2), it is necessary to select a detecting device with high fidelity and response speed in order to measure a weak neutron signal, capturing a neutron fluctuation in a very short time under a γ-ray environment. From the examination to date, considering the equipment mountability (size/weight/electromagnetic noise) and operation methods (measurement time and duration) by sensitivity are key issues due to the necessity of lead shielding in a high γ-ray environment (assuming 1000 Gy/h) [12]. In the future, it is necessary to consider selection and optimization of the neutron detector, reflecting the constraints introduced by the study results of the project for the fuel debris retrieval method and system. Meanwhile, practical applicability is under review with consideration of the initiatives to ascertain the γ- ray radiation dose rate and neutron count rate in the vicinity of the fuel debris and downsizing the detector for continuous monitoring.

In addition, in order to verify the applicability to fuel debris, where various mixes of compositions and characteristics of the fuel debris are expected, a plan for technical verification has been developed and demonstrated, and then applicability evaluation is needed based on the results.

(4) Feasibility study of neutron absorber

Based on the information obtained in each phase of scale expansion, in preparations for cases where the level of fuel debris criticality is high, the evaluation on the required boron concentration and system feasibility study are in progress for the cases of filling with sodium pentaborate during normal fuel debris retrieval. As a result, environmental impact in the event of leakage and compatibility with concrete as structural materials has been evaluated[13]. While examining the influence on the PCV circulation cooling system and concrete operation to maintain boron concentration, based on the fuel debris composition obtained by the retrieval operation, it is necessary to judge whether the injection of sodium pentaborate would be required during normal retrieval operations.

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[12] IRID, FY 2015 supplementary budget, Subsidies for Government-led R&D program on Decommissioning and Contaminated Water Management (Development of Technology for Criticality Control in Fuel debris Retrieval), Final report, March 2018, http://irid.or.jp/wp-content/uploads/2018/06/20170000_05.pdf

[13] IRID, FY 2017 supplementary budget, Subsidies for Government-led R&D program on Decommissioning and Contaminated Water Management, Advancement of methods and systems to retrieve fuel debris and to remove structures inside reactor (Development of Technology for Criticality Control in Fuel debris Retrieval), Final report, July 2019, http://irid.or.jp/_pdf/20180000_04.pdf

In addition, if criticality should occur, urgent sodium pentaborate injection would be used to achieve subcritical state, but after the suspension, it is necessary to select a method of maintaining subcriticality, which may be the decrease in water level or the maintenance of boron concentration.

Moreover, the development of a non-soluble neutron absorbent that can locally restrain the influence on the PCV circulation cooling system has been performed as well. Until now, fundamental property testing and radiation resistance testing have been conducted to list B_4C metal sintered materials, glass containing B/Gd, Gd_2O_3 particles, water glass, and Gd_2O_3 granulated powder as candidates for non-soluble neutron absorbent. For those candidates, no impact of long-term irradiation on the integrity of canisters during storage of fuel debris, the method of spraying fuel debris for debris fabrication, and the effect after spraying have been verified.[13]

Use of non-soluble absorbents is also under consideration in order to ensure subcriticality can be maintained in the case of low subcriticality during normal condition.

(5) Detection of criticality by PCV gas monitor system installations

Immediate criticality monitoring and sophistication of detectors in the PCV gas monitor is required to detect when approaching criticality and criticality in the vicinity of fuel debris retrieval, and to detect criticality due to the fall of fuel debris and/or accumulation of powder debris in locations other than fuel debris retrieval.

By measuring Kr-87/88 in addition to Xe-135 that has already been measured, it has been found that criticality detection can be accelerated and that the level of subcriticality of the entire PCV can be presumed. However, the applicability to the actual plants is to be examined in the future.[12]

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

The reactor buildings, PCVs, and RPVs experienced the hydrogen explosions when the accident occurred. Further, the 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 the 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 influence mentioned above and the possible occurrence of a severe earthquake. 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

In maintaining the structural integrity and safety functions of the PCVs and the buildings, the technical issues to be addressed for the time being are as follows.

(1) Evaluation of earthquake resistance

A. Evaluation of earthquake resistance based on the impact of accidents and secular changes

In the previous studies, the reactor buildings and major components of PCV, RPV and RPV pedestal of each unit, have been evaluated such that they have relatively large seismic safety margin against a design basis seismic ground motion Ss (600 Gal), taking into account the damage caused by the accident, the degradation over 40 years and increased weight of new facilities required for the fuel debris retrieval work.

In these evaluations[14], while taking into account major damage caused by hydrogen explosions in the reactor buildings of Units 1, 3 and 4, on-site damage investigations such as observation of cracks, have been performed by engineers and/or robots. Particularly, in the reactor building of Unit 4 that was heavily damaged by the hydrogen explosion but with low radiation dose, the investigation of cracks and concrete strength of major structural parts have been done periodically. According to the results of the investigations, it was identified that there has been no development of harmful crack and the concrete strength of major structural parts exceed the design strength as well.[15] However, the periodic investigations of the buildings have to be implemented continuously over the period of the fuel debris retrieval work and a maintenance plan for the buildings shall be prepared to suppress the deterioration, in which remote repairing methods are to be included in case of harmful cracks are found. No openings where size affects the building strength are assumed to be established in small-scale retrieval, which may have no significant impact on seismic resistance of the buildings. However, examinations on local allowable load on the floor and verification of supporting performance are required against the weight of the new systems. During expanded-scale retrieval, a case is assumed where there are openings where the size affects the building strength. Therefore, reassessment of seismic resistance with consideration for impact by increasing seismic force is required in addition to examinations on local allowable load on the floor and verification of supporting performance against the weight of the new systems.

For the evaluation of pedestals, conservative conditions have been set taking into account the influences of exposure to the high-temperature environment, based on the results of accident progress analyses and the information obtained by PCV internal investigation. Since there might be a possibility of erosion by the fuel debris, case studies of seismic margin of pedestals have been performed by analyses with the variation of hypothesized eroded zones of the pedestals, taking into account the material test results of both concrete and rebars on the effects exposed to high-temperature environment.

The S/C supports have relatively small seismic margins and may be greatly affected by the way of lower PCV repair. Therefore, the evaluation has been performed by detailed analytical models.

[14] TEPCO, The seismic safety assessment against a design-basis seismic ground motion Ss of main buildings of Units 1 to 4 of Fukushima Daiichi NPS, February 21, 2013, http://www.nsr.go.jp/data/000050857.pdf

[15] E.g. Periodic Inspection Results for Integrity Verification of the Reactor Building in Unit 4, Fukushima Daiichi Nuclear Power Station, TEPCO (9th), Nuclear Regulation Authority website, measures against the Fukushima Daiichi Accident, July 2014, Interview Appointment/Interview with Regulators, July 24, 2014, http://www.nsr.go.jp/data/000054381.pdf

The results shows that the S/C supports may have a certain level of safety margin against the design basis earthquake ground motion in the case of the water seals at the bent tubes and the strainers or down-comers inside S/C with relatively small berried depth of grout.[16]

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 the fuel debris retrieval methods.

B. Evaluation of the impact induced by postulated damage due to a large earthquake and the preparation of the countermeasures

Preparatory studies of the countermeasures have been done for the postulated damage to major structural components such as a pedestal during a large earthquake. In the studies, countermeasures using mobile equipment are also included such as a countermeasure using mobile pumps for the drainage of the torus room in case major leakage from a PCV occurs due to large cracks induced by the damage to the pedestal. As future investigations improve the understanding of the PCV internal situations, it may be necessary to reevaluate the countermeasures and to reflect the results into the concept of the fuel debris retrieval. In addition, it is considered necessary to determine the seismic design class of new systems and to evaluate their seismic performance based on the current situation (high radiation dose work environment, partial damage to PCV, etc., drastic reduction of decay heat, etc.) after examining appropriate countermeasures.

(2) Countermeasures to suppress the deterioration during the fuel debris retrieval work

As described in Sub-section 3.1.3.3.2, when maintaining negative pressure in the PCV, there may be a concern that the concentration of oxygen rises and corrosion of PCV/RPV structures and required pipes progresses due to inflow of atmospheric air during fuel debris retrieval work. The evaluations of earthquake resistance described in (1) have been performed considering the impact of corrosion progress. It has been evaluated such that they have relatively large seismic margin against the design basis earthquake ground motion Ss (600 Gal) taking into account of thinning by material corrosion for 40 years as described above. On the other hand, in order to maintain the current conditions of PCVs, RPVs and major piping, it may be necessary to suppress the progress of the corrosion during the long period of the fuel debris retrieval work. In the subsidies for Government-led R&D program on the Decommissioning and Contaminated Water Management, countermeasures against further suppression of corrosion, have been studied to select suitable corrosion inhibitors and to investigate the practical application of corrosion control measures, which would be able to get into alignment with the current liquid process system.

The effectiveness of steel corrosion inhibitors for the PCVs, RPVs, piping, etc. have been tested,

[16] IRID, FY 2013 supplementary budget, Subsidies for Government-led R&D program on Decommissioning and Contaminated Water Management, Development of Technology for Integrity Assessment for RPV/PCV and Progress, November 2015, http://irid.or.jp/_pdf/201509to10_09.pdf

taking into account the influence of radiation environment and seawater injection, and corrosion inhibitor options effective for not only overall corrosion but also localized corrosion are extracted[17]. On the other hand, in order to mitigate the influence of the corrosion inhibitors on the existing water cooling circulation and purification system, it has been shown that it is necessary to reduce the corrosion inhibitors concentration considerably before the preliminary stage of the water purification system[17]. Henceforth, to realize a PCV circulation cooling system for the fuel debris retrieval, it may be required to come up with the countermeasures that satisfy both the corrosion control and other required functions such as the water purification, in an integrated manner.

3.1.3.3.7 Reduction of radiation exposure during work

The main work areas of the fuel debris retrieval to be scheduled are high radiation dose areas such as inside the reactor buildings. Also, there comes a need of handling nuclear fuel materials containing α-nuclides with a large internal radiation 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 workers through appropriate radiation protection schemes depending on the working environment (target nuclide, radiation dose equivalent rate, airborne concentration, surface density) and working style (direct operation or remote). 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” (to shorten the exposure time, distance from the radiation source, shield if possible), it is needed to take measures to keep the radiation exposure dose as low as reasonably achievable.

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

- Consider first of all the reduction of exposure to radiation by a combination of remote technologies and decontamination. Then, plan on-site radiation exposure management for site workers by the “time, distance and shielding” approach.
- In the extremely contaminated areas such as inside the PCV and torus rooms, work should be pursued by remotely controlled machines, etc. to avoid engaging personnel inside.
- In the areas inside the R/B buildings other than the above, the best combination of decontamination, shielding, removal of unnecessary objects, remote technologies and reduction of on-site time, with considerations for the balance between the exposure during the decontamination tasks and the exposure during the PCV repair tasks, to minimize the cumulative radiation dose for overall work.

[17] IRID, supplementary budget, Subsidies for Government-led R&D program on Decommissioning and Contaminated Water Management, Development of Technology for Controlling RPV/PCV Corrosion, Report, July 2017,
http://irid.or.jp/wp-content/uploads/2017/06/20160000_10.pdf

- Where remote technologies are employed, additional work will be required, such as the installation of systems, maintenance and technical troubleshooting, which must be taken into consideration in the above evaluation and planning.
- As for the decontamination tasks, the judgment between remote technologies and personnel employment must be made based on factors such as the radiation dose rate in the target areas, type of contamination, space for work, frequency of use, applicability and development situations of remote technologies, schedule and cost, etc.
- A priority must be placed upon areas where work requirements are clearly identified. Considerations must not be pursued if task requirements are unclear, or in a non-specific “betterment-oriented” manner such as to aim for an overall radiation dose reduction.

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, e.g. installing air filter, are to be selected depending on the target nuclides, airborne concentration and surface contamination density in the work area, to prevent inhalation ingestion and body pollution. In addition, it is essential to prepare for countermeasures against internal exposure cases in advance and establish an emergency exposure medical care system including exposure evaluation by bioassay etc.

Meanwhile, for the reduction of radiation exposure in the long-term decommissioning, it is necessary to have an overall perspective and comprehensive, shared measures of exposure reduction. It is important that actual on-site performance and lessons learned from them provide feedback to the planning of subsequent steps to improve the accuracy of the plans, and to prevent recurrence of problems such as delays in work procedures. The above approach must be adopted to develop systems of cross-sectional exposure reduction management and knowhow/technology transfer.

In particular, concerning the reduction of radiation exposure of workers in the reactor building, it is important to set up a dosage reduction plan in consideration of the work and its contamination condition in order to secure the necessary work environment for the operation area. In consideration of the radiation exposure dose limit (50 mSv/year and 100 mSv/5 years) specified by laws and regulations, it is necessary for the target radiation dose rate of the operation area to consider and set the operation methods, working hours and the number of workers by considering them in a single group. Further, it is important to appropriately update the information on dosage reduction technologies in line with the three principles and utilize it on-site.

Since various nuclides are mixed at the Fukushima Daiichi NPS, for radiation exposure management, it is necessary to select nuclide (attention nuclide) for which an appropriately estimation of the radiation exposure dose (internal exposure and external exposure) for each curve font can be rationally conducted. In other words, in the external exposure management, it shall reflect on the radiation dose rate management and the basis for wearing the protection equipment. In the internal exposure management, it shall reflect on the management standard of airborne concentration in the operation environment and the basis for wearing the operator's respiratory - protection equipment etc. In particular, it is necessary to study the measurement management considering the mixture of α-nuclides from both hardware and software sides and to prepare for the application to the fuel debris retrieval work.

In addition, it is required to create a long-term work plan that enables radiation exposure dose reduction for the entire workforce without excessive radiation exposure to individual workers for appropriate exposure control.

3.1.3.4 Technical issues related to fuel debris retrieval methods

3.1.3.4.1 Securing access route

For transporting, installing and unloading the devices and equipment used for fuel debris retrieval work, and transporting fuel debris and waste, an access route should be established by removing obstacles and reducing the radiation dose to the level at which such tasks can be done. When establishing a new opening in the PCV or the like to construct an access route 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 in terms of the containment function in the gas phase described in Sub-section 3.1.3.3.2.

According to the fuel debris retrieval policy based on the partial submersion method that extends the side access to the bottom of the PCV, TEPCO is now conducting the engineering work. Based on the results of R&D of 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, a plan will be drawn up 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 this case, in the side access method, it is a problem that there is a risk of exceeding the load bearing capacity of the reactor building floor at the time of installation of the cells and the like. For this reason, a comparative study of a method of releasing the load to the outside of the building is being conducted, such as suspension bridge system and access tunnel system. In addition to the side access, the technical feasibility of removing obstacles to shorten the work processes is under review as research necessary for constructing access routes including upper access.

In the future, based on the above-mentioned tasks, it is necessary to define the access route clearly to be built at the next stage from the data obtained at each phase of scale expansion.

According to the fuel debris retrieval policy, the optimum retrieval method should be selected depending on where the fuel debris exists for each reactor unit. It is important to proceed with technical development toward the scale expansion.

3.1.3.4.2 Development of devices and equipment

In order to retrieve fuel debris safely, reliably and efficiently, it is necessary to develop fuel debris retrieval devices and equipment that meet the site requirements and have the necessary functions.

To flexibly respond to the situations inside the RPV and the bottom of the PCV where fuel debris is predominantly present, this devices/equipment should necessarily meet specifications of radiation resistance, dust resistance, waterproofness, target temperature described in Sub-section 3.1.3.3.4, remote inspection/maintainability, remote operability, securing visual field, earthquake-resistance, protection mechanism for collision avoidance or automatic stop in case of abnormality, high reliability, appropriate redundancy, a rescue mechanism that does not disturb the subsequent work when trouble occurs, such as efficiency of retrieving fuel debris (payload).

Based on above, devices and equipment for fuel debris retrieval need to be examined. As the functions to be specifically implemented, the development of retrieval system that can handle various fuel debris conditions (fragments, sludge, or fine powder), fuel debris cutting system (laser, boring, or crushing, etc.) and dust collecting system are underway. Though the cutting system has good prospects, development of recovery and dust collecting systems are still in progress. Furthermore, techniques for installing fuel debris retrieval equipment are 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 (Refer to Fig. 11).

These technological developments are currently underway in the Government-led R&D program on Decommissioning and Contaminated Water Management, in the future the developed devices and equipment will be combined and undergo remote mock-up tests to verify that performance is demonstrated safely and reliably for the actual site application.

This remote mock-up test needs to be implemented by a facility simulating the site in order to verify applicability of technically developed remote equipment to the actual environment and operability/maintenance ability of entire remote system under the harsh environmental conditions including uncertainties. It is therefore important to rationally implement according to the purposes, such as utilization of Naraha Remote Technology Development Center of JAEA and Units 5 and/or 6 of Fukushima Daiichi NPS. Therefore, in cooperation with related organizations, NDF is working on organizing and examining how to proceed with the remote mock-up test plan, the way of the test plan review, the scope of the mock-up facility to be maintained, the necessary time, operation management, etc. From the viewpoint of the necessity of full-scale mock-up facilities and systems, which are considered to be particularly important, these are classified into the following categories: “Development mock-up” to verify the basic performance of remote equipment; “Environment mock-up” to confirm the applicability of remote equipment to the on-site environment; and a “Training mock-up” to provide work training for practical application to specify relevant requirements.

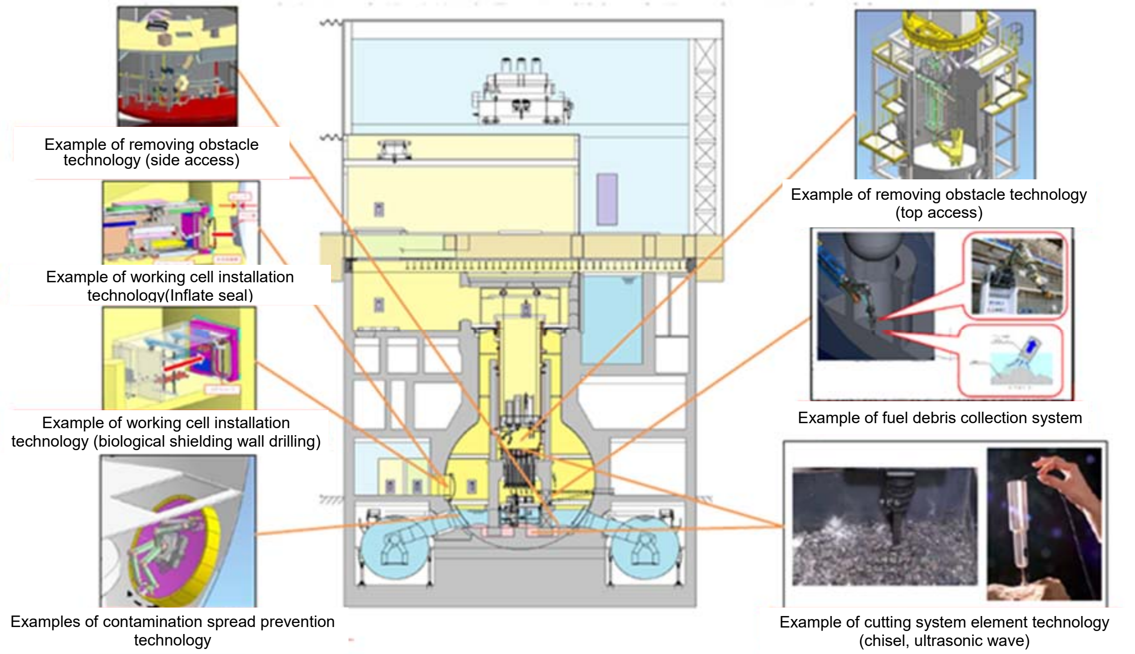

Fig. 11 Fundamental technologies for fuel debris retrieval and internal structures (examples)

3.1.3.4.3 Establishment of system equipment and working areas

When retrieving fuel debris, it is necessary to evaluate the necessity/sufficiency of system equipment (including containers/ working cells/ devices and equipment) to establish safety functions and newly install and operate them appropriately. Also, it should be prepared that sufficient spaces for installation, operation, and maintenance, and for installing shields for reducing radiation exposure to operators, so that the required environmental conditions are satisfied.

The system equipment includes a negative pressure control system required for establishing a containment function of the gas-phase described in Sub-section 3.1.3.3.2, a circulating water cooling/purification system required for maintaining the containment function of the liquid phase described in Sub-section 3.1.3.3.3 and cooling function described in Sub-section 3.1.3.3.4, and a criticality control system required for controlling criticality described in Sub-section3.1.3.3.5. The installation plan for the respective system is being examined.[18] In addition, development of measurement systems (pressure, temperature, water level, radiation, criticality (rare gas concentration, etc.) hydrogen concentration, etc.) to monitor the internal situation, which is essential for retrieving fuel debris, is an important future issue to be addressed. How to implement system installations as the integrated entire system should be specified, which satisfy these system functional requirements.

The working area required for installing the 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,

[18] IRID, FY 2016 supplementary budget, Subsidies for Government-led R&D program on Decommissioning and Contaminated Water Management, Advancement of Retrieval Method and System of Fuel Debris and Internal Structures, FY 2017 report, April 2018, http://irid.or.jp/wp-content/uploads/2018/06/20170000_10.pdf

including outside of the existing buildings, is underway. From now on, in order to carry out fuel debris retrieval work and to implement detailed examination of the layout of the area for installation and operation of the facilities constituting each system, proceed with consideration of the place for temporary placement/treatment of the removed equipment, on-site plot plan for storing the retrieved fuel debris, etc.

3.1.3.5 Technical issues related to safe and stable storage of fuel debris

3.1.3.5.1 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.[19]

- 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 conditions 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 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 the specific facilities and systems for handling and storing 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

[19] RID, FY 2015 supplementary budget, Subsidies for Government-led R&D program on Decommissioning and Contaminated Water Management (Development of Technology for Collection, Transfer and Storage of Fuel Debris), FY 2017 implementation report, June 2018, http://irid.or.jp/wp-content/uploads/2018/06/20170000_03.pdf

fuel debris are investigated and fixed during the third phase after starting fuel debris retrieval work.

3.1.3.5.2 Treatment of radioactive waste during fuel debris retrieval

During fuel debris retrieval work, a variety of radioactive waste such as replaced or disassembled structures or 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 stored under safe conditions.

It is practically difficult to accumulate and organize necessary and sufficient information such as distribution and characteristics of the fuel debris and the radioactive waste in the PCV prior to its actual retrieval work which are essential for investigating classification standard and storing method, even though it is continued in operation with collecting and organizing such information. Also, since the essence of the fuel debris is considered to be the existence of nuclear fuel material in it, it is desirable that the retrieved material is classified into fuel debris or radioactive waste based on the concentration of nuclear fuel material in it. However, it is currently considered as highly-difficult technical challenges to accurately measure or estimate the concentration of nuclear fuel material in the retrieved material itself or in it collected into the canister.

As a practical issue during retrieval, therefore, 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 issues, which are necessary for realizing such classification.

3.1.3.5.3 Study on Safeguards Measures

Nuclear facilities in Japan need to fulfill obligations concluded with the International Atomic Energy Agency (hereinafter referred to as the “IAEA”) of comprehensive safeguards agreement and its additional protocol, and are expected to show that nuclear materials are utilized for peaceful purpose only as declared by implementing material accountancy as a part of the domestic safeguards system, and by accepting containment/surveillance of nuclear materials, and inspection and complementary access by IAEA. In the Fukushima Daiichi NPS, as above, it had been confirmed via the IAEA safeguards activities that the nuclear material had been used as declared. After the nuclear accident, however, the basic information of the facilities and the situation for utilization and storage of the nuclear materials, provided in advance for the implementation of the safeguards, greatly changed. In a sound nuclear power plant, the nuclear material is clearly accounted for in each material balance area (MBA) as an item one by one with a fuel assembly of a certain defined shape as one unit for material accountancy. However, large amount of fuel assemblies would no longer maintain their shape due to melting in Units 1 to 3 of the Fukushima Daiichi NPS. Implementation of pre-accident material accountancy and safeguards is deemed difficult since the damaged facilities would not allow the same containment/surveillance systems at strategic points as the level of pre-accident, or high radiation would restrict access into the areas for inspection and prevent verification activities. Additional safeguards activities are currently applied under this situation to the Units 1 to 3 as an alternative measure to ensure no undeclared movements of the nuclear materials.

Given that further fuel debris sampling and retrieval operations intrinsically move nuclear materials from the inside of the PCVs to the outside of the PCVs in Units 1 to 3 of the Fukushima Daiichi NPS, corresponding new material accountancy and safeguards will be required. However, fuel debris is highly likely to contain structural materials other than nuclear materials, and the confirmation of the composition and quantitative evaluation of contained nuclear materials are believed quite hard to technically achieve. Accordingly, material accountancy and safeguards to be applied to the Units 1 to 3 of the Fukushima Daiichi NPS would pose an essential question on how realistic solution could be found to replace the pre-accident scheme.

In response to those issues, discussion in regard to the safeguards in Fukushima Daiichi NPS continues and discussion in regard to material accountancy newly applied to small-scale sampling of fuel debris have commenced in Fukushima Task Force Meeting organized between IAEA and NRA. Japan has been providing necessary updated information to stakeholders, including the IAEA from the early stage, aiming at the smooth application of safeguards and proper material accountancy. These efforts are consistent with the idea of the IAEA's "Safeguards by Design (considerations to be paid to the safeguards from the design phase)". Moving ahead, realistic and transparent material accountancy and safeguards that do not impose excessive burden on the on-site operations must be proposed proactively by Japan to reach an agreement among the stakeholders, including the IAEA.

3.1.3.6 Summary of key Technical issues

The main technical subjects and plans described in this section are summarized as shown in Fig. 12.

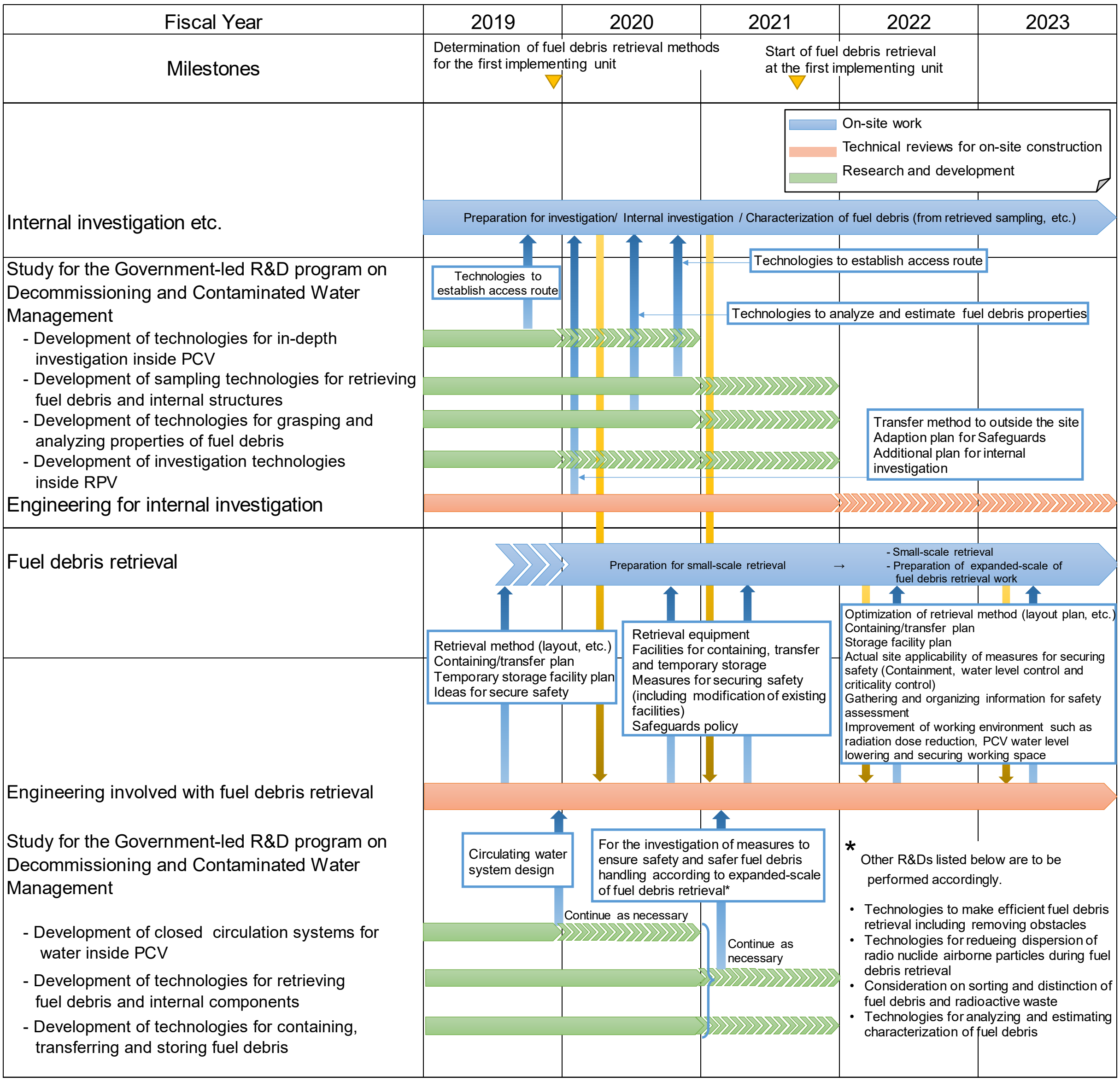

Fig. 12 Technical issues and further plan on fuel debris retrieval (Process chart)

3.2 Waste management

3.2.1 Sectoral target

Near-future targets in waste management are as follows:

(1) As the approaches of solid waste storage, the Solid Waste Storage Management Plan ("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.

3.2.2 Sectoral strategies

3.2.2.1 The concept of risk reduction in waste management

Waste management is a long-term effort that needs to attain the prospect of implementing final disposal, while reducing risks in every stages. For the terms regard to radioactive waste management, the definitions of terms provided by the IAEA is shown in Attachment 11.

The solid waste, such as concentrated waste water, waste sludge, slurry in the high integrity container (HIC), rubbles, etc., and contaminated building structures, is unlikely to increase in risk in the future; however, it is still a source of risks which should make its countermeasures properly in the decommissioning process. (refer to Section 2.3) Compared with other major risk sources, they are 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. Solid waste is, however, highly diverse of characteristics, including waste contaminated by radioactive materials adhering to the surface, waste in the form of sludge, and waste with high radiation dose that generates hydrogen. For this, risk reduction measures are to be implemented systematically by continuously conducting research on risk reduction for safer management, by seeing throughout disposal and by ensuring safety as a precondition.

3.2.2.2 The basic policies on solid waste

The Strategic Plan 2017 explains the properties of solid waste estimates based on the accident conditions, post-accident decommissioning efforts, and the results of the characterization of waste so far. Based on these findings, the plan proposes a policy of solid waste management, along with strategic recommendations that include specific tasks to be performed at present (i.e. statement for the preparation of the basic concept for the processing/disposal of solid waste).

The Mid-and-Long-term Roadmap revised in September 2017 summarizes the basic policies on solid waste, based on the content of the strategic recommendations.

The basic policies on solid waste

[1] Thorough containment and isolation
Solid waste management should be implemented thoroughly, with containment and isolation of radioactive materials to prevent their dispersion/leakage and human access to them, in order not cause harmful radiation exposure.

[2] Reduction of solid waste volume
The amount of solid waste generated by decommissioning is reduced as much as possible in order to ease the burden of solid waste management.

[3] Promotion of characterization
To proceed with study on processing/disposal method of solid waste, characterization of solid waste such as nuclide composition and radioactive concentration is needed. In addition to the fact that solid waste of the Fukushima Daiichi NPS is large in volume, and have varied nuclide compositions, it is necessary to address an increase in the number of analysis samples and proceed with their characterization properly.

[4] Thorough storage
To dispose of solid waste, it is essential to understand the volumes and characteristics of the solid waste, and to establish specifications of disposal facilities and technical requirements for waste packages (technical requirements for disposal). However, the volumes and characteristics of solid waste will become clear step by step, with the future clarification of progress and plan of decommissioning. Therefore, the solid waste generated should be stored safely and reasonably according to characteristics of solid waste. Storage capacity should be secured to ensure that the waste can be stored within the site of the Fukushima Daiichi NPS.

[5] Establishment of selection system of preceding processing methods in consideration of disposal
In order to safely store solid waste, the system for selecting the method of processing for stabilization and immobilization (preceding processing) will be established, and selecting the method of the preceding processing, before the technical requirements of disposal are established.

[6] Promotion of effective R&D with a bird’s-eye-view of overall solid waste management
To efficiently proceed with R&D concerning solid waste management, close cooperation should be realized between R&D fields such as waste characterization, processing/disposal. Issues and discussions on R&D should be shared between parties, and necessary planning made with a bird’s-eye-view of overall solid waste management, should be progressed collectively.

[7] Efficient implementation of R&D projects from the perspective of overall solid waste management
In order to continue safe and steady solid waste management, the continuous operational framework system including development of adequate facilities and human resources, which are concerned with solid waste management, must be undertaken.

[8] Measures to reduce radiation exposure of workers
To steadily proceed with solid waste management, it is important to ensure the safety and health of workers. Therefore, radiation exposure control, safety management and healthcare programs should be implemented thoroughly based on the relevant laws/regulations.

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 compared to the waste generated from the decommissioning of normal nuclear power plants. While the characteristics of the solid waste are known to some extent so far, it is necessary to improve capabilities of radiological analysis (i.e. efficiency and capacity) to further clarify such characteristics, to foresee the final disposal and to develop a flexible and reasonable waste stream (integrated measures from characterization to processing/disposal of the waste).

Specifically, the relevant organizations should proceed with their efforts based on each role in line with the basic policies, and NDF takes the initiative on proceeding with the technical study on the integrated countermeasures, from the characterization to processing/disposal of solid waste, according to the following policies.

3.2.2.3 Storage

3.2.2.3.1 Storage at present

The fundamentals of managing solid waste are to confine not to scatter or leak, by placing it into container or immobilizing, and so on, as need. Also, it should be kept isolated in a properly storage place, and managed appropriately by monitoring and so on.

From the view point of minimizing the volume of solid waste to be generated and to be disposed of in order to lower environmental impact, "Waste hierarchy" (1.Waste Prevention, 2.Waste Minimization, 3.Re-use of Materials, 4. Recycling, 5.Disposal, in the order of preferred approach) is shared as a priority of measures to be taken in the U.S. and the UK. It has succeeded in suppressing the final volume of disposal by implementing waste management according to this concept. For practically developing Waste Hierarchy, it has been pointed out that the department in charge of waste management should be involved in it from the stage of developing construction work plan for decommissioning.

In the Fukushima Daiichi NPS, such efforts are being made in line with the "Waste Hierarchy" shown in Fig. 13. It is important to instill the concept of the waste hierarchy, and raise awareness on reducing the volume of solid waste to be generated.

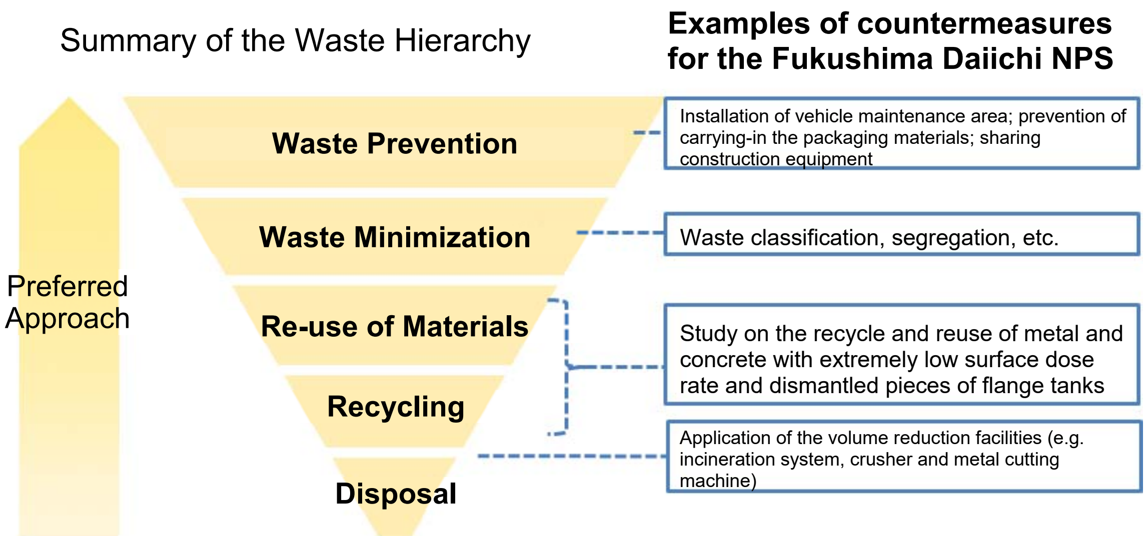

Fig. 13 Summary of Waste Hierarchy at the NDA, UK[20] and Countermeasures at the Fukushima Daiichi NPS

[20] Edited Figure 7. Summary of the Waste Hierarchy p. 60, NDA, Nuclear Decommissioning Authority Strategy Effective from April 2016 (2016)

Among the solid waste that has been generated by March, 2019, rubble, etc. have been classified into rubble, felled trees, used protective clothing and so on, and about 460,000 m^3 of waste is stored in temporary storage areas according to the surface radiation dose rates. Among the secondary waste generated by water treatment, about 4,300 used vessels, which have undergone additional measures such as adding shields and increasing water tightness, are stored in used adsorption column storage facilities. Table2 shows the status of storage of the solid waste.

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.

The Storage Management Plan states that the volume of rubbles, etc. should be reduced as far as possible, and will be carried to store in the solid waste storage building around FY 2028, excluding reusable rubble. Regarding secondary waste generated by water treatment, large, heavy waste such as used vessel is planned to be stored in a building that will be built to accommodate large waste. These measures will consolidate waste storage areas and supersede many of the currently scattered temporary storage areas (Attachment 12).

In the Storage Management Plan, however, the future generation of some items is left uncalculated. It will be reflected to the estimated amount of generation when the decommissioning plan is taking shape and the possibility of activity such as dismantlement become known in the next 10 years. Since the estimated amount of generation fluctuates depending on the progress of the decommissioning work and plans in the future, it is necessary to revise the estimated amount once a year and update the Storage Management Plan as appropriate, as TEPCO expresses to do.

Table 2 Solid Waste Storage Management Status

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

(as of Mar 29, 2019)

Rubble

Surface radiation dose rate (mSv/h)	Storage method	Stored volume (m^3) / Storage capacity (m^3) (Percentage)
≤0.1	Outdoor storage	195,300 / 252,700 (77%)
0.1~1	Outdoor sheet covered storage	37,900 / 71,000 (53%)
1~30	Soil-covered temporary storage facility, Temporary storage tent, Outdoor container storage	18,500 / 31,700 (58%)
>30	Containers (in Solid waste storage building)	15,100 / 45,600 (33%)
Total	----	266,800 / 401,000 (67%)

Felled trees

Classification	Storage method	Stored volume (m^3) / Storage capacity (m^3) (Percentage)
Root	Outdoor storage	96,800 / 134,000 (72%)
Branch/leaves	Temporary storage pool	37,300 / 41,600 (90%)
Total	----	134,100 / 175,600 (76%)

Used protective clothing, etc.

Storage method	Stored volume (m^3) / Storage capacity (m^3) (Percentage)
Container	56,000 / 68,300 (82%)

(b) Management status of secondary waste generated by water treatment

Used vessels (as of Apr 4, 2019)

Storage place	Type of Used Vessels	Stored Number	Stored Number/Capacity (Percentage)
Outdoor Temporary Storage area of used Vessels	Cesium adsorption apparatus	775	4,332 / 6,372 (68%)
	2nd Cesium adsorption apparatus	216	
	HICs from Multi-nuclide Removal Equipment	1,590	
	HICs from improved Multi -nuclide Removal Equipment	1,460	
	Used vessel from high-performance Multi-nuclide Removal Equipment	74	
	Used column from multi-nuclide Removal Equipment	11	
	Used vessels and filters from mobile-type strontium system	206	

Waste sludge

Storage place	Store volume (m^3)	Stored volume (m^3) / Storage capacity (m^3) (Percentage)
Sludge storage facility (Indoor)	597	597 / 700 (85%)

Concentrated waste liquid

Storage Method	Store volume (m^3)	Stored volume (m^3) / Storage capacity (m^3) (Percentage)
Concentrated waste liquid storage tanks (Outdoor)	9,364	9,330 / 10,300 (91%)

3.2.2.3.2 Further safety improvement in storage

The secondary waste generated by water treatment, which has high fluidity (such as slurry generated from multi-nuclide removal equipment and waste sludge generated from the decontamination system) poses a relatively large risk in the storage because of the fluidity, and it should be stored in a more stable and reasonable way after risk reduced by performing 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.

The possibility that the specifications of solid waste conducted preceding processing are incompatible with the technical requirements for disposal should be minimized. Therefore, safety assessment should be conducted for each specification of processed solid waste, using scenarios, models, data and so on, for multiple disposal methods which are rational and feasible to implement, and also suitable for features of the waste without specifying disposal facility's place, scale and so on. The selection of preceding processing method should be studied based on the result.

3.2.2.4 Study on the processing/disposal measures

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, including waste which does not need preceding processing. 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 FY2021, 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 the 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 methods 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 after the start of fuel debris retrieval. 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.

3.2.3 Technical issues and plans for promoting sectoral strategies

3.2.3.1 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 study processing/disposal methods. In order to carry out such analysis work, there are important issues, such as arranging facilities as hardware, developing human resources for analysis, and inheriting and enhancing technical capability on analysis. Therefore, for the time being, it is important to systematically promote the establishment of the Radioactive Material Analysis and Research Facility and the development of human resources for analysis. Through these efforts, it is desirable that technology, facilities, and systems be established, and that the necessary analytical work for decommissioning 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 to improve the accuracy of models to obtain evaluation data based on the limited number of radiological analysis data. The study will be advanced on the method of reflecting dispersion of radiological analysis data to inventory evaluation using analytical method, and concept of setting and revising radioactive inventory based on comprehensive evaluation of radiological analysis data and analytical value.

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, as well as processing/disposal, will be carried out, and simplification and acceleration of radiological analysis methods will be studied to develop an efficient analytical technique. While reducing radiation exposure by introducing remote sampling methods, high radiation dose sampling will be conducted.

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

Through these efforts, it will be a challenge to build an environment where system, facilities/equipment, and technologies for highly accurate characterization of solid waste will be established by the end of FY 2020, and necessary radiological analysis data will be acquired for some solid waste.

3.2.3.2 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. Specifically, adsorption vessels and the like are temporarily stored in the used adsorption vessel storage facility after taking measures according to the type and, in the future, the plan is to store them in a large waste storage. The waste sludge is temporarily stored in the waste sludge storage facility, and the plan is to remove it from the storage tank to be transferred to a hill for storage in FY 2020.

On the technologies for stabilization, immobilization and conditioning of the secondary waste generated by water treatment, challenges for introducing the actual equipment should be dealt with, and gathering and evaluation of data on technical requirements should proceed by means of engineering scale test equipment, etc., processing technology expected to be applicable for the actual processing should be identified, and specification of waste packages should be determined from the point of view of whether it may contribute to establishing a selection method for preceding processing methods.

Regarding the methods of storing high radiation dose solid waste generated as a result of 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, it is necessary to study measures against hydrogen generation, and reasonable storage, such as application of vented containers, needs to proceed for study.

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

3.2.3.3 Development of processing/disposal concept and safety assessment method

In order to select candidate technologies for preceding processing methods, it is necessary to conduct safety assessment with the specifications of the waste package associated with decommissioning work that is developed by the respective candidate technologies, as a target. The selection of reasonable and feasible candidate technologies and the development of suitable safety assessment methods corresponding to it will proceed until 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, and AAM solidification) and high-temperature processing technology (vitrification, and molten solidification) are being carried out as concrete processing technologies in the government-led R&D program on decommissioning and contaminated water management.[21]

In addition, study on domestic and international waste acceptance criteria, disposal concepts and safety assessment methods, etc., are conducted. Then, the study of disposal concepts based on the characteristics of solid waste of the Fukushima Daiichi NPS is promoted. Subsequently, multiple disposal methods are to be presented, and suitable safety assessment methods will be developed. Furthermore, it is necessary to proceed with studies considering issues such as increasing 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, having various properties, and showing characteristics of having large uncertainties. From this point of view, the approach will be studied for the case using the preceding overseas examples as reference.

3.2.3.4 Other

As solid waste to be generated with the retrieval of fuel debris in future, structures such as core internals and the outside of reactors to be dismantled and removed and secondary waste such as filters generated during fuel debris retrieval related works are expected. It should be noted that this kind of waste may contain α-nuclides derived from fuel debris, it is necessary to proceed with study

[21] IRID, FY 2016 supplementary budget “Subsidies for the Government-led R&D program on Decommissioning and Contaminated Water Management” R&D for Treatment and Disposal of Solid Waste, FY 2017 report, February 2019 http://irid.or.jp/wp-content/uploads/2018/06/2017000_14.pdf

on the storage methods for this type of solid waste, along with study on the method of fuel debris retrieval.

As a long-term challenge, TEPCO is scheduled to develop the decommissioning plan in the third term after the start of fuel debris retrieval, as later described in Sub-section 3.5.3. At that time, measures against the waste generated from such as dismantling buildings should be established based on the progress and prospect of decommissioning work, the conditions of reactor and other buildings, and the latest status of R&D, etc.

Further, as measures for promoting efficient decommissioning, the characterization using quick measurement (in situ analysis and on-site analysis) by means of spectroscopic methods should be examined in addition to radiochemical analysis, and necessary R&D in this regard is expected to be promoted.

3.2.3.5 Summary of key Technical issues

In regard to the technical issues described in this Section, studies will be carried out on the efforts to respective issues with close cooperation between them as shown in Fig. 14, with having bird's-eye view of overall management of solid waste

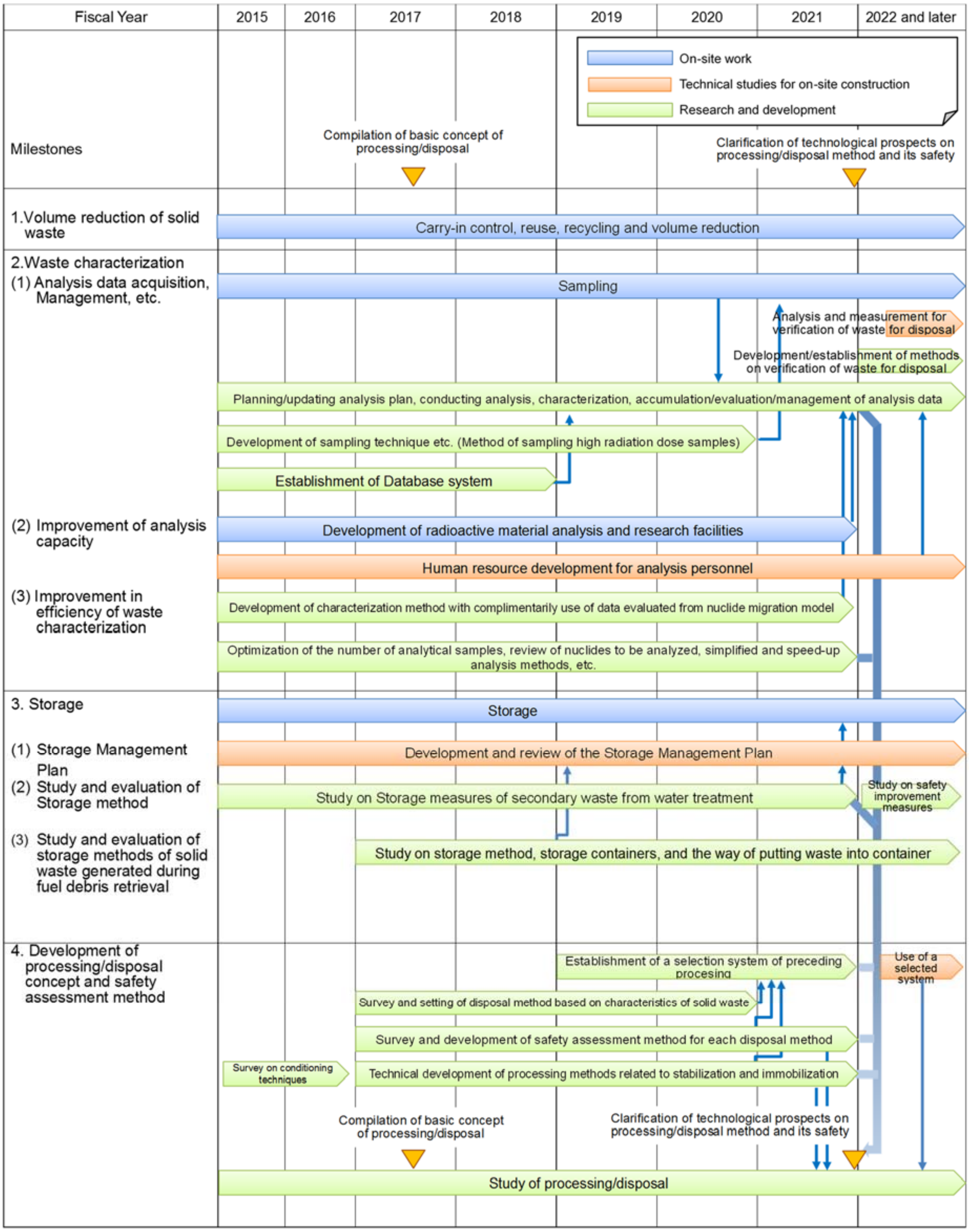

Fig. 14 Key technical issues and further plans on waste management (Process chart)

3.3 Contaminated water management

3.3.1 Sectoral target

The near term objectives of measures against contaminated water are as follows.

(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),[22] 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.[1]

(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.

3.3.2 Sectoral strategies

3.3.2.1 Concept of risk reduction in contaminated water management

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

From the viewpoint of measures to reduce the risk due to the radioactive material, safety measures for the stagnant water in the building are required as soon as possible. Since the stagnant water is generated from groundwater/rainwater mixed with the cooling water contacted with the fuel debris, it contains a considerable amount of the dissolved radioactive materials. The storage conditions of the stagnant water are not inherently and include uncertainties. Thus the Safety Management of the stagnant water in the buildings is relatively high (refer to Section 2.3). The stagnant water is recovered and treated with cesium adsorption apparatus (KURION and SARRY), etc., and the radioactive materials are transferred to the water treatment secondary waste such as adsorption vessels with lower Safety Management.

As measures against risk reduction so far, disconnection of the penetrations between Units 1 and 2 was carried out due to lowering of the water level of residual water in the buildings, and the strontium-treated water inside the flange tank was treated for purification by multi-nuclide removal equipment and was transferred to more reliable welded tanks (this was completed in November 2018). The risk will be reduced on a continuous basis in the future.

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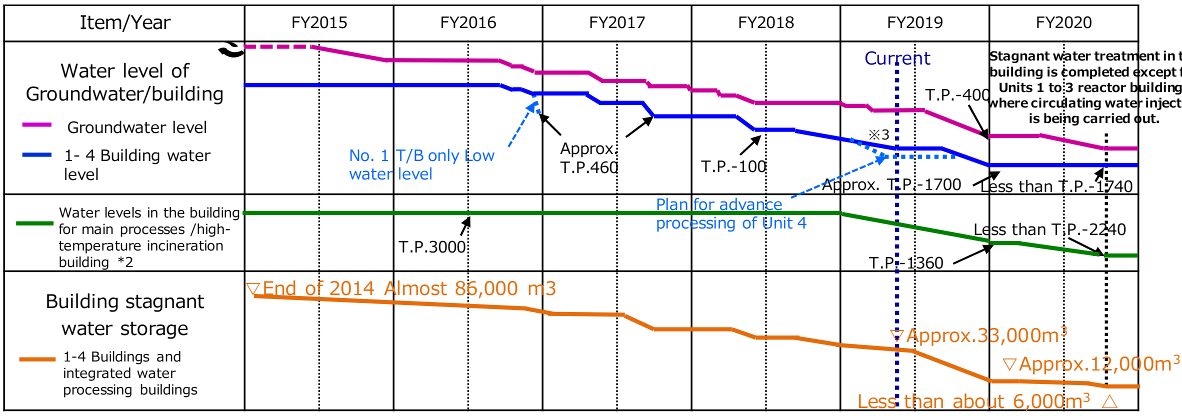
[22] Nuclear Emergency Response Headquarters “Tokyo Electric Power Company, Incorporated Basic Policy on Contaminated Water Problems at the Fukushima Daiichi Nuclear Power Station,” September 3, 2013, Nuclear Emergency Response Headquarters “Tokyo Electric Power Company, Incorporated Additional measures for the problem decommissioning and of decommissioning and contaminated water at the Fukushima Daiichi NPS” December 20, 2013

3.3.2.2 Steady execution of contaminated water management indicated in the Mid-and-Long-term Roadmap

Since the Fukushima Daiichi NPS is located in an area with abundant groundwater, the groundwater flows into the reactor buildings and mixes with the cooling water injected to the fuel debris. This is the main cause of generation of the contaminated water in the site. Treating the contaminated water and the ground water was urgent issue. Currently, as a result of the preventive and multilayered measures based on the three principles on contaminated water, the site situation has shifted from that requiring urgent measures immediately after the accident to certain stable situation that can examine a mid-and-long-term plan. Those measures are; pumping up high-concentration contaminated water in the underground tunnel (trench), blockage of the trench, purification by multi-nuclide removal equipment (ALPS), paving (facing) of the site to prevent the rainwater infiltration to reduce the amount of groundwater, pumping up of the groundwater bypass system and the groundwater in wells (sub drains) near the reactor buildings, installation of a land-side impermeable wall to reduce the groundwater inflow into the area of the reactor buildings, installation of the sea-side impermeable wall for suppressing the outflow of groundwater into the ocean, and soil improvement with the water glass in the seawall area of the ocean-side of the buildings.

The milestones (major goals schedule) mentioned 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 for purification by multi-nuclide removal equipment in the welded type tanks (FY 2018), (3) by lowering the level of stagnant water in the buildings, separation of the communication sections 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 2020). As of September 2019, (2) and (3) have been completed. On the other hand, as to (4), although the quantity of radioactive nuclide that has been processed is higher than planned, with the progress in the processing of stagnant water, a high radioactivity concentration was detected in the Unit 3 reactor building, etc., making it difficult to perform assessment. However, efforts will be made to complete the treatment of stagnant water in the 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.



*1 Selection of vacuum pump and so on will be considered depending on the situation at the site.
*2 Water level in the building for main processes is displayed as the representative. In addition, there is a temporary fluctuation due to rainfall because it is used for temporary storage during heavy rain.
*3 As for subdrains, while maintaining the specified water level difference from the south-east triangle corner of the Unit 3 R/B, which has the highest water level, reducing the water level in the building is scheduled while assessing the groundwater inflow.
In case the inflow increases with the expansion of water level difference, the reducing of the water level in the building will be suspended.

（Source : TEPCO）

Fig.15 Status of the stagnant water in the buildings[23]

3.3.2.3 Study on contaminated water management based on the relationship with fuel debris retrieval

As mentioned above, the contaminated water management at the Fukushima Daiichi NPS, although out of a state where urgent countermeasures are required and it still needs further efforts, it seems that it has shifted to a certain stable condition where the mid-and-long-term plan can be examined. Because the full-scale decommissioning work including the fuel debris retrieval will start after a while, it is necessary to discuss the optimal control of the contaminated water and the groundwater together at each stage of the decommissioning process. Furthermore, it should examine a future images of the contaminated water management considering the inherent measures and the issues to be addressed with a long-term perspective until the completion of the fuel debris retrieval.

At present, as for the stagnant water in the reactor building, a circulating water cooling and purification system is adopted in which the cooling water injected into the RPV flows into the PCV, the leaked water from the PCV stays in the torus room on basement floor of the reactor building, and this stagnant water is recovered and purified by cesium adsorption apparatus, etc., before being reused as cooling water. At this time, by controlling the water level of the stagnant water in the reactor buildings lower than that of the groundwater around the buildings to let the groundwater flow into the building (in-leak), containment function in the buildings can be secured by preventing outflow of the radioactive materials to the outside of the building. (Attachment 9).

As described in the preceding Sub-section, according to the target process of the Mid-and-Long-term Roadmap, it is considered that the processing of the stagnant water in the buildings other than the reactor buildings of Unit 1 to 3 will be completed by 2020. By that time, the circulation water cooling and purifying system needs to be modified to the system that the stagnant water is recovered in the reactor buildings (instead of turbine buildings) and purified to use as the cooling

[23] TEPCO, “Progress on the stagnant water in the buildings” Handout 4 of 73rd Meeting of the Study group on monitoring and assessment of specified nuclear facilities, July 22nd , 2019 http://www.nsr.go.jp/data/000277899.pdf

water. It is shifting to such circulation cooling system at the present. It is necessary to consider the possibility of using a circulating cooling system even for small scale debris retrieval. In addition, it is important to proceed with the lowering of the stagnant water level in the reactor building and the examination of the lowering of the water level in the suppression chamber.

In addition, studies are under way on the feasibility of a PCV circulation cooling system by taking water from the PCV when the scale of fuel debris retrieval is expanded, and also on the water seal by repairing the lower part of the PCV, etc., from the viewpoint of ensuring the multiple boundaries. However, it became clear that a complete water seal through repairing the bottom of PCVs is very difficult. Based on this, in preparation for the inflow of α-particles from inside of PCVs to the stagnant water in the reactor buildings, the response on the PCV circulation cooling system is needed. Even if the water shielding is applicable, it is necessary to consider the setting of a sufficient difference in water levels between stagnant water in the reactor building and the groundwater, in case of cooling water leaks from the PCV into the reactor building.

The details of the containment function of this liquid phase have been described in Sub-section 3.1.3.3.3. In addition to this, requirements from both sides of the fuel debris retrieval work and the contaminated water management should be clarified and coordinate them in case of items to be reconciled such as the increase of the radioactive materials concentration arose as the fuel debris retrieval work proceeds.

Also, as the fuel debris retrieval proceeds, when the water injection for cooling the fuel debris will be no longer necessary, it can be expected that there is no water inflow into the reactor buildings. In such a case, it is important to plan to develop a system that can stably control the groundwater level for a long period by studying the combination of the dynamic equipment such as pumps, and the passive equipment with lower potential for machine trouble.

3.3.3 Technical issues for promoting sectoral strategies and future plans

3.3.3.1 Steady execution of contaminated water management in the Mid-and-Long-term Roadmap

Since there are penetrations between the buildings of each unit, the water levels of the stagnant water in the buildings are almost the same in all buildings. In order to prevent the stagnant water in the building from leaking to the outside, it is necessary to make the water level lower than the groundwater level (keep the water level difference). Stable management of groundwater around the buildings has been made by strengthening the function of sub-drains and completing the land-side impermeable wall, etc.

By proceeding with these preventive and multilayered measures, the amount of contaminated water has been reduced to approx. 170 m^3 per day in FY 2018 from approx. 470 m^3 per day in FY 2014[24] (Fig. 16). Also, the amount of the groundwater pumped-up from sub-drains and the groundwater drains in the seawall area have been reduced as well.[25]

In this way, the condition of contaminated water is being controlled. From now on, further measures based on the three basic policies should be taken to complete the treatment of the stagnant water while addressing the measures for contaminated water directed by the Government-led Committee on Contaminated Water Management, and focusing on the problems that have not been clarified yet.

(1) Reduction of occurrence of stagnant water in buildings, including countermeasures against rainwater inflow

Reduction of the generation of the contaminated water to 150 m^3/day or less in 2020, which is indicated as a milestone in the Mid-and-Long-term Roadmap, and 170 m^3 per day of the contaminated water is generated based on the result of FY 2018.

In the future, further effort to reduce the generation of the contaminated water should be continued by implementing the multilayered countermeasures such as stagnant water treatment in the buildings, lowering the sub-drain water level, measures against inflow of rainwater into the buildings. Further measures continuously need to be taken in the future, such as the suppression of the inflow of groundwater and rainwater through the repair of the building roof and the water seal of the connecting trench, and the suppression of rainwater infiltration into the soil through facings on the T.P. 6 m and T.P. 8.5 m panels. Further, as to the facing on the inside the land-side impermeable wall, while coordinating with other works, the measure needs to be carried out from the area where it is possible to work on. As for the inflow[26] of groundwater into the site banker

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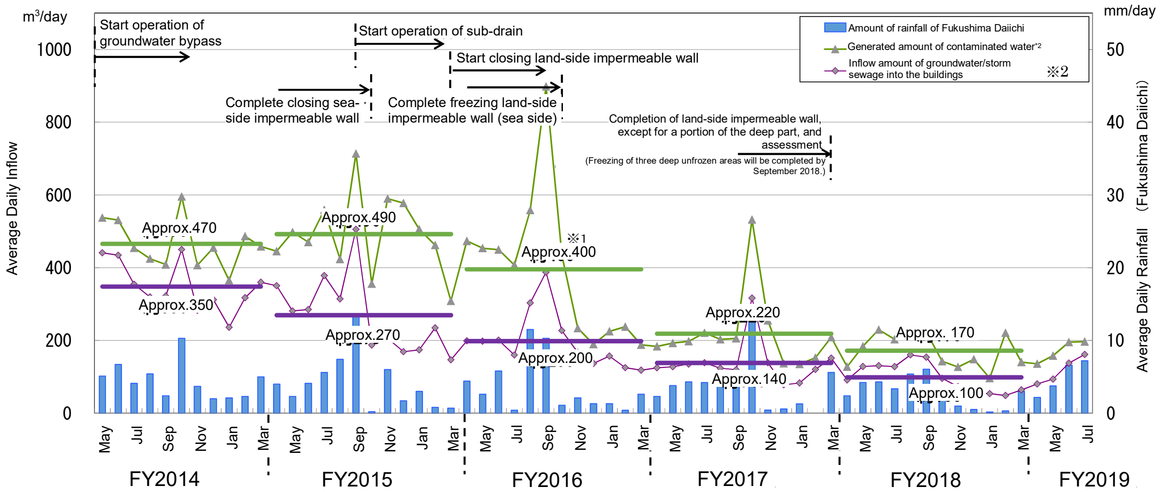
[24] Average from May 2014 to March 2015.
[25] "Evaluation of Frozen Soil Wall and further Contaminated Water Management", Government-led Committee on Contaminated Water Treatment, issued on March 7, 2018
http://www.meti.go.jp/earthquake/nuclear/osensuitaisaku/committtee/osensuisyori/2018/pdf/020_s04_00.pdf
[26] This is because the amount increased from approx. 5 m^3/day to approx. 40 m^3/day since mid-November 2018.
https://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2019/08/3-1-2.pdf

building outside the land-side impermeable wall, water blockage has completed at the inflow points confirmed in 2018, it should be suppressed continuously.



*1 : The values are different from the announced one in the 20th Government-led Committee on Contaminated Water Treatmentheld on August 25th, 2017 due to the review of the calculating method of the generated amount of contaminated water on March 1, 2018. The detail of the review is indicated in the handouts of the 50th and 51st meetings of Secretariat of the Team for Countermeasures for Decommissbning and Contaminated Water Treatment

*2 : The daily average amount per month is calculated from the amount per day from previous Thursday through Wednesday added up based on the data measured at 7:00 every Thursday.

(Courtesy of TEPCO[27])

Fig. 16 Transitions in the generated amount of contaminated water and the inflow amount of groundwater/rainwater, etc., into the buildings

(2) Work associated with the lowering of the water level in the building due to the progress of treatment of stagnant water in the building

As progress is made in the treatment of stagnant water in buildings, high concentrations of radiation are being found. When continuing to work on the treatment of stagnant water in the building, the inventory water level needs to be reduced. On the other hand, when there is a large change in the concentration of radiation, the stable operation of the cesium adsorption apparatus may be hindered, it needs to be treated on a continuous basis while observing the concentration of radiation in stagnant water in buildings. Further, in the area where oil content is observed on the surface of the stagnant water, it is necessary to collect the oil content before exposing the floor surface so that declines in performance of the contaminated water treatment equipment can be prevented, and this will be carried out adequately.

After radiation exposure of the floor surface, there is also a concern that dust may be generated because of drying of sludge on the floor, and it is necessary to monitor the work of closing openings, the status of generation and scattering of dust, and the total α concentration in sludge. In particular, there will be work such as installing pumps to the floor drain sump to expose the lowest floor surface and transferring and processing the remaining water in the isolated area. Accordingly, after exposing the floor surface of the intermediate part on the lowest floor, in order to suppress the radiation exposure dose of workers, the radiation dose needs to be reduced.

27 Handout 2 of "Overview of Decommissioning and Contaminated Water Treatment", the 69th meeting of Secretariat of the Team for countermeasures for Decommissioning and Contaminated Water Treatment, August 29, 2019
http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2019/08/2-1.pdf

(3) Enhanced contaminated water management installations

It is essential to appropriately maintain and reinforce the established water level management system and the purification equipment, including the land-side impermeable wall and sub-drain.

As for subdrains, there was a case in which the issue of influence to the operation due to rising tritium concentration in some of the subdrains. Considering these issues, measures need to be taken, such as groundwater quality surveys and soil improvement as required, while continuing appropriate management and operation.

The land-side impermeable wall is sequentially shifting to maintenance operation that allows to stop circulation of coolant according to the soil temperature, it has completed in all the area in February 2019. From the planning stage, the material is designed to maintain its functions through maintenance and replacement in consideration of the long-term operation of the frozen soil wall. However, to continue the operation for a long time, in addition to daily and regular inspections, it is important to renew the system appropriately and to consider a systematic replacement and construction plan.

3.3.3.2 Study on contaminated water management based on the relationship with fuel debris retrieval

As described in Sub-section 3.3.2.3, there are matters to be adjusted between retrieval of fuel debris and contaminated water management. As problems to be solved, there are concerns that deposit at the bottom of the PCV reduces the visibility of the water when retrieving fuel debris and increases the processing load of the purification equipment (especially, removing solid particles).

In the case of small-scale retrieval, it is assumed that the existing purification system such as cesium adsorption apparatus will be used, however, fuel debris-derived materials containing α-particles may be mixed. Therefore, it is necessary to examine the entire system, such as checking status of α-nuclides concentration in the existing purification system, and the impact of α particulate on the system, enhancing monitoring to check the concentration of radioactive materials at the inlet of the water treatment system, and the installation of systems to reduce the concentration of radioactive materials.

When expanding the scale of fuel debris retrieval, establishment of a PCV circulation cooling system will be examined but, at this time, the material derived from fuel debris that contains α-particles will be mixed. Therefore, it is necessary to properly remove α-particles in the PCV circulation cooling system. Since the groundwater flows into the buildings continuously, a part of the water treated by the PCV circulation system will be sent to the existing circulating water cooling and purification system in order to maintain the water balance. There is a possibility that the water will be treated with equipment such as multi-nuclide removal equipment. Therefore, it is necessary to monitor the α-nuclides concentration of the stagnant water in the reactor buildings and to set the conditions for receiving a part of water treated by the PCV circulation cooling system in the existing circulation water cooling and purification system in parallel with considering the system.

In addition, to maintain the effectiveness of contaminated water management in the future, it is necessary to conduct regular inspections and renewals of facilities, and to further expand the monitoring system for groundwater level and radioactive materials (observation points, observation frequency, data management, etc.) to control the groundwater around the buildings in a stable manner. It is also necessary to consider necessary contaminated water management while taking into account the risk of large-scale natural disasters such as tsunamis and torrential rains, and the relationship with future decommissioning work.

3.3.3.3 Summary of key Technical issues

The main technical subjects and plans described in this section are summarized as shown in Fig.17.

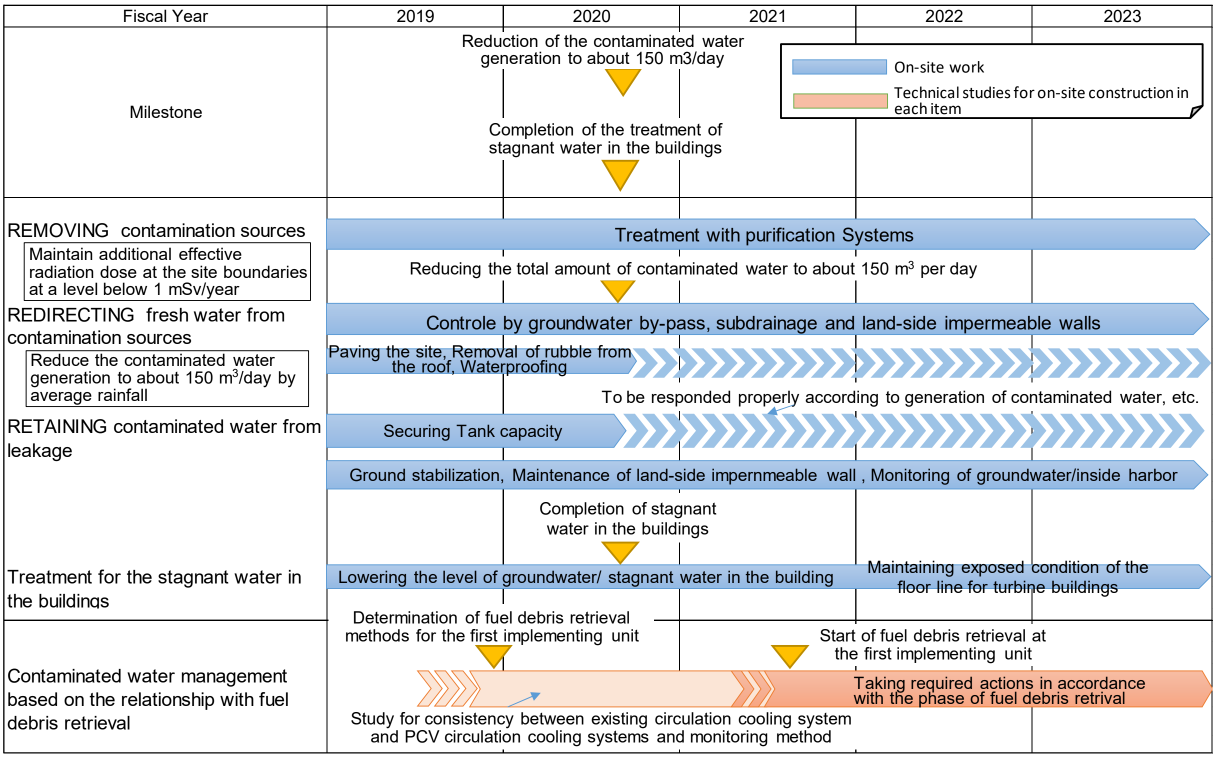


Fig.17 Technical issues and further plans on contaminated water management (Process Chart)

3.4 Fuel removal from spent fuel pools

3.4.1 Sectoral target

The immediate objectives of fuel removal from the spent fuel pool are as follows.

(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 from the SFPs will start by 2023. For Unit 3, the removal is scheduled to be completed within FY 2020.

(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.

3.4.2 Sectoral strategies

3.4.2.1 Risk reduction concept and concrete plan for removing fuel from SFP

The fuel assemblies (fuel in SFP) stored in the spent fuel pool of the reactor buildings of Units 1 to 3, some of which were damaged by hydrogen explosions, etc. are relatively high risk sources (see Section 2.3). From the viewpoint of reducing risks due to radioactive materials, the fuel is kept in a solid state so as not to diffuse when confined in the cladding tube. Furthermore, even though the decay heat of spent fuel is decreasing and coolant supply stops, the time until the pool water evaporates and the fuel assemblies start to be exposed becomes relatively longer. Moreover, since it is a nuclear fuel material with a substantial amount of inventory, there is a certain level of hazard potential impact. In addition, due to damage to the cooling facility due to the accident, and damage to the reactor buildings at Units 1 and 3, the same functions as the conventional containment function and management function are not completely secure and Safety Management is also high[28]. For this reason, it is planned to transfer them immediately to the common spent fuel storage pool that is sound and of low Safety Management as shown in Fig. 5.

On the basis of this, it is necessary to draw up an appropriate and concrete work plan based on a sufficient understanding of the situation at each reactor unit and to respond carefully. 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.

[28] Since the number of spent fuel assets held by each unit is different, there are slight differences in the degree of hazard potential impact. Due to the rubble status in SFPs and on the operation floor, as well as the damage to the reactor building, in terms of the diffusion suppression function, Unit 1 is inferior to Unit 2 where the upper part of the building has not collapsed. Unit 3 is superior to Unit 2, considering the installation of the fuel removal cover in SFP and the status of maintenance of the operation floor. In addition, there are failed fuels in Unit 1, and it is judged that it can affect the removal. There are differences in safety management among these.

Considering these circumstances, careful approaches focusing on safety more are necessary against dust dispersion, and the like. For example, in Unit 1, there is rubble on the operating floor. Considering that there are operational risks such as rubble falling into the spent fuel pool during the rubble removal work, as well as the impact of dust scattering on the surrounding area and workers, it is necessary to carefully prepare for the removal of fuel from SFPs.

As for the fuel in SFPs, the testing on SFP cooling shutdown was performed, and it was confirmed that the rise in water temperature after cooling shutdown was slower than expected. As a result of incorporating this insight, the risk of fuel in SFPs is lower than previously estimated, because the time margin before this risk becomes apparent increases.

3.4.2.2 Specific plan for fuel removal from SFPs

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

In Unit 1, the roof slabs, steel frame building materials for the upper part of the buildings and fuel handling machine were scattered around the operating floor. The removal work for 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, based on the surveillance on radiation dose on the operating floor conducted in FY 2018, a method to access the operating floor is being considered, and fuel removal from the SFP is scheduled to start around FY 2023.

For Unit 3, there were some delays due to dealing with malfunctions of the fuel handling machine in the test runs. However, the fuel removal work from the SFP was started since April 2019 based on the safety first policy towards the completion of removal within FY 2020.

Unit 4 was under periodic inspection at the time of the accident, so all fuels were kept in the SFP without suffering significant damage. Although the rubbles had fallen into the SFP due to the influence of hydrogen explosion, after carefully installing a cover for fuel removal from the SFP, installation of a frame for supporting the crane was performed and the fuel removal work from the SFP started prior to other units and was completed in December 2014.

The fuel in Units 5 and 6 SFP are being stored under stable conditions same as a normal nuclear power plant. The Mid-and-Long-term Roadmap states that the fuel of Units 5 and 6 SFP should be properly stored in each SFP for the time being and should be removed from each SFP so as not to affect operations of Units 1 to 3. Part of new fuel is planned to be transported to a fuel processing manufacturers, but the spent fuel should be removed at an appropriate time in view of the capacity of the common spent fuel storage pool and the dry cask temporary custody facility.

While conducting the above-mentioned safety measures properly, fuel removal operations from SFPs should be carefully and steadily pursued by fully considering the status of each unit. Although these efforts are first examined according to the condition of each unit, as a whole, operation space (yard) adjustment and resource management, etc. between interfering operations are necessary. Also, when removing fuel handling equipment, it is necessary to reuse or treat waste. Based on the above and on the technical considerations described in Sub-section 3.4.3, detailed build plans should be considered from the viewpoint of global optimization described in Section 3.6.

3.4.2.3 Storage plan for removed fuel

For removal of fuel from SFPs, appropriate storage capacity should be reserved both in the common spent fuel storage pool and the dry cask temporary custody facility. As of now, despite there is sufficient free capacity to transfer fuel of Unit3 SFP in the common spent fuel storage pool, additional capacity to transfer fuel of Units 1,2, 5 and 6 SFPs is insufficient (Fig. 18). Accordingly, it is necessary to advance the expansion of the dry cask temporary custody facility etc. and to secure the spare capacity by transferring the fuel out of the site. Incidentally, in terms of design, dry casks store fuels that satisfy conditions such as fuel type and cooling duration. Among the fuels currently stored in the common spent fuel storage pool, those that satisfy the conditions and have a relatively long cooling period are to be stored.

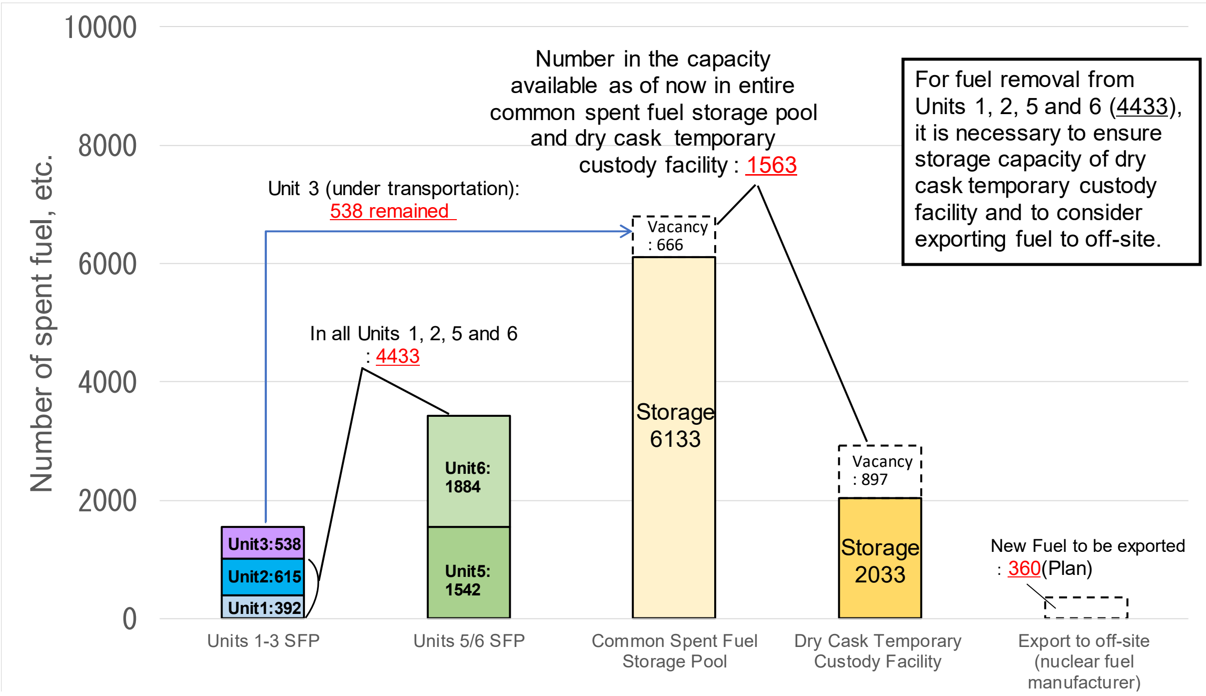


Fig. 18 Storage situation of spent fuel, etc. (as of August 29, 2019)

3.4.2.4 Decision on future treatment and storage methods

The fuel in SFPs includes many kinds of spent fuel such as damaged spent fuel before the accident by embrittlement of the cladding tube and falling of the fuel body, and that may be damaged by the fallen rubbles into the spent fuel pool, as well as flawless one. There was also a history of seawater injection into the spent fuel pools of Units 2, 3 and 4 when the accident occurred. Although the effects on long-term integrity and treatment of spent fuel due to this are expected to be small, it is necessary to identify and confirm whether there are technical factors that impedes the same treatment as ordinary spent fuel.

In the future, considering the status of fuel removed from Unit 3 SFP, future treatment and storage methods for such fuel will be decided around FY 2020 based on the investigation results on long-term integrity assessment and treatment method for them.

3.4.3 Technical issues for promoting sectoral strategies and future plans

3.4.3.1 Removal of fuel from SFPs

(1) Items common to each unit

Operating floor dosage reduction measures are necessary in order to limit operation exposure during the installation work of fuel removal installations (fuel removal cover, fuel handling equipment, etc.), manned work during removal work, maintenance check of installations and so forth. Meanwhile, depending on the dosage reduction condition, it is necessary to reflect shielding to instrument design related to removal and introduction of remote devices, etc., based on experience such as decontamination in other units, it is necessary to determine the final operational dosage at an appropriate time.

Also as stated in Sub-section 3.4.2.2, there are a number of things to be prepared in parallel, such as fuel removals from SFPs of both Units 1 and 2 that start for FY 2023, preparation work on fuel debris retrieval at the time of removal of fuel from Unit 3 SFP. Therefore, it is necessary to adjust yards (securing flow line) with interfering works and resources management and to prepare a detailed construction plan. As described before, fuel of Units 5 and 6 SFPs should be removed in appropriate time. In case such operations use common spent fuel storage pool, adjustment is required as such removal work becomes not to affect fuel removal work, etc. of Units 1 to 3.

(2) Unit 1 fuel removal from the SFP

For Unit 1, the roof collapsed due to the hydrogen explosion and has accumulated as rubble on the operation floor, and the fuel handling machine (FHM) and the overhead crane that are deformed and damaged are covering the spent fuel pool. When removing rubble, it is important to take measures against rubble, the FHM, and the overhead crane falling onto the spent fuel pool. The necessary work, such as protection for the spent fuel pool and support for the overhead crane, needs to be carefully performed over a certain time. 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 the impact on the surrounding environment, it is necessary to take measures against dust dispersion at the time of removal of the rubble and for the removal of rubble on the well plug. It is confirmed that the well plug is shifted from the original position and, on the plug, and the radiation dose rate of approx. 200 mSv/h is confirmed, making it difficult to get close to the area easily. Further, there is a concern of skyshine (the effect that the radiation going upward from the radiation source falling to the ground surface due to diffusion in the air causing the dosage near the surface to rise). Hence, rubble removal should be promoted while coordinating safety measures such as preventing dust dispersion and radiation dose monitoring and following that, action should be taken for the well plug based on the investigation results of the condition of the well plug and its contamination status, which has been conducted from July 2019.

Regarding the 67 fuel bodies damaged by the cladding stored before the earthquake, although the radioactive material concentration in pool water before the earthquake was also sufficiently low, its influence is considered small, but appropriate response is required for handling when removal.

(3) Unit 2 fuel removal from the SFP

In the case of Unit 2, based on the plan to dismantle the entire upper part of the operating floor of the reactor building, examination was carried out for the plan to share the container for removing fuel from SFP with the container for fuel debris retrieval, as well as the plan to install a cover for removing fuel from the SFP individually. In addition, from the viewpoint of safe and stable construction, a plan has been examined, that includes the construction method of accessing from the south side of the reactor building to reduce risk of dust dispersion during the dismantling of building, without dismantling the upper part of operating floor as much as possible.

When selecting a plan for removing fuel from the SFP, it is needed to comprehensively consider the feasibility with dust dispersion countermeasures, securing safety in the surrounding environment, ensuring the safety of workers, measures against rainwater, and the other work to be conducted concurrently.

As mentioned in Sub-section 2.3.3.3, there is an exhaust stack of Units 1/2 in the vicinity of Unit 2. There is a possibility that radioactive materials, mainly cesium released from the accident, are attached to the inside of the stack and that the joints of diagonal bracing of the steel towers supporting the exhaust stack are broken or deformed. Therefore, the collapse of the exhaust stack may affect the fuel removal process from the SFP. Based on this, prior to the removal of the fuel from the SFP, the dismantling of the upper part of the exhaust stack using a remote device has started from August 2019 and is to be completed within FY 2019.

(4) Unit 3 fuel removal from the SFP

As for Unit 3, malfunctions in the fuel removal device caused a significant delay in starting the removal work as described in the initial plan. However, of the fuel in the SFP, removal of 28 new pieces fuel from the SFP was started in April 2019, which has been transferred to the common spent fuel storage pool. For the remaining fuel in the SFP, steady progress should be made to complete the removal within FY 2020.

3.4.3.2 Proper storage of removed fuel

For systematic transfer of the fuel in SFPs retained at the entire site to the common spent fuel storage pool, a fuel transport plan needs to be developed, taking the fuel stored in Units 5 and 6 into account, and the installation of an additional dry cask temporary custody facility according to the plan is needed as well.

In particular, when retrieval of fuel in Units 5 and 6 SFPs precedes other units, it is necessary to take measures such as additional installation of dry cask temporary custody facilities by the appropriate time so as not to put pressure on the capacity for transferring fuel in Units 1 and 2 SFPs to the common spent fuel storage pool. As mentioned earlier, some of the new fuel is planned to be moved to the fuel processing company and it is important to secure the capacity of the common spent fuel storage pool by these efforts.

3.4.3.3 Decision of future treatment and storage methods

As described in Sub-section 3.4.2.4, if there are technical matters necessary for treating the removal fuel as equivalent to ordinary spent fuel for long-term soundness assessment and processing of the extracted fuel, it is necessary to organize and identify the same.

So far, in the Government-led R&D program on Decommissioning and Contaminated Water Management, R&D on the long-term integrity of the fuel in SFPs which has contacted with seawater or fallen rubble has indicated that removed fuel can be stored safely under the environment of the 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. In addition, proposals have also been made regarding a fuel inspection method for dry storage.

Furthermore, another R&D on potential for processing retrieved fuel in SFP showed a technical perspective that the impact to fuel by earthquake disaster including contamination of chloride ions and concrete is very limited.

In the future, necessity of further study on possibility of its long term storage and processing need to be evaluated based on the investigation results of the fuel taken out from Unit 3, which is experienced the hydrogen explosion caused during the accident and may be damaged by the fallen rubble.

3.4.3.4 Summary of key Technical issues

The major technical issues and future plans described in this section are summarized as shown in Fig. 19.

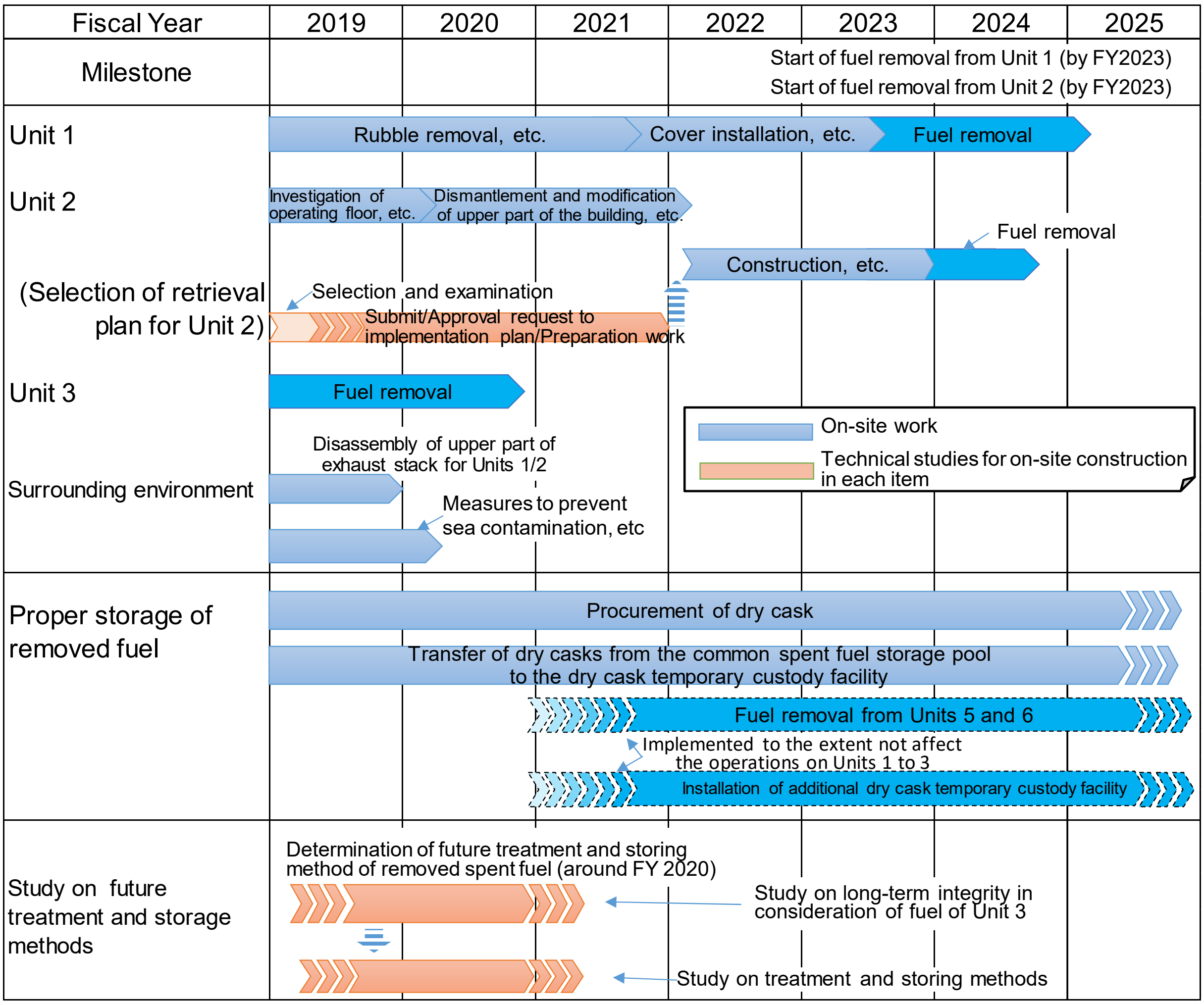


Fig.19 Technical issues and further plan on removing fuel from the spent fuel pool (Process chart)

3.5 Other specific measures

3.5.1 Sustaining of reactor cold shutdown status

Currently, the plant conditions in Units 1, 2 and 3 are judged to be in a stable cold shut-down status based on the internal PCV plant data monitored continuously since the accident, including radiation dose, temperature, hydrogen concentration, pressure, and radioactive material concentration, etc. As an example, the concentration of Xe-135, a continuously monitored short-half-life fission product, does not exceed the criticality level of 1 Bq/cm^3, showing no signs of criticality [29]. Because fuel debris generates decay heat, 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, to maintain the stable state in the future.

Considering the fact that the decay heat of fuel debris seems to have decreased significantly, in April 2019, a test was conducted at Unit 2 that is highly reliable in measuring the temperatures of the RPV bottom surface and the PCV to halve the flow rate of reactor water injection for fuel debris cooling for about a week. In May in 2019, a test was also conducted to stop the injection of water into the reactor for about seven hours, and it was confirmed that there was no abnormality with the status of cooling reactors. 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. From the viewpoint of reducing the burden of contaminated water management and reducing the criticality risk, as alternatives for examination, cooling fuel debris by air can be considered. However, the internal information on the plant that is available as of now is considered to be still insufficient to judge the appropriateness, and this matter will continue to be examined.

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

3.5.2.1 Prevention of sea contamination expansion

Immediately after the accident, radioactive materials flowed out to the port, as can be seen from the fact that high-concentration contaminated water in the turbine buildings flowed out through the underground trenches. To tackle this problem, emergency measures were taken, such as soil improvement in contaminated areas, pumping up of underground water, and removal of high-concentration contaminated water in trenches. Fundamental measures were also taken, such as installation of the sea-side impermeable wall and covering of the seabed soil including radioactive

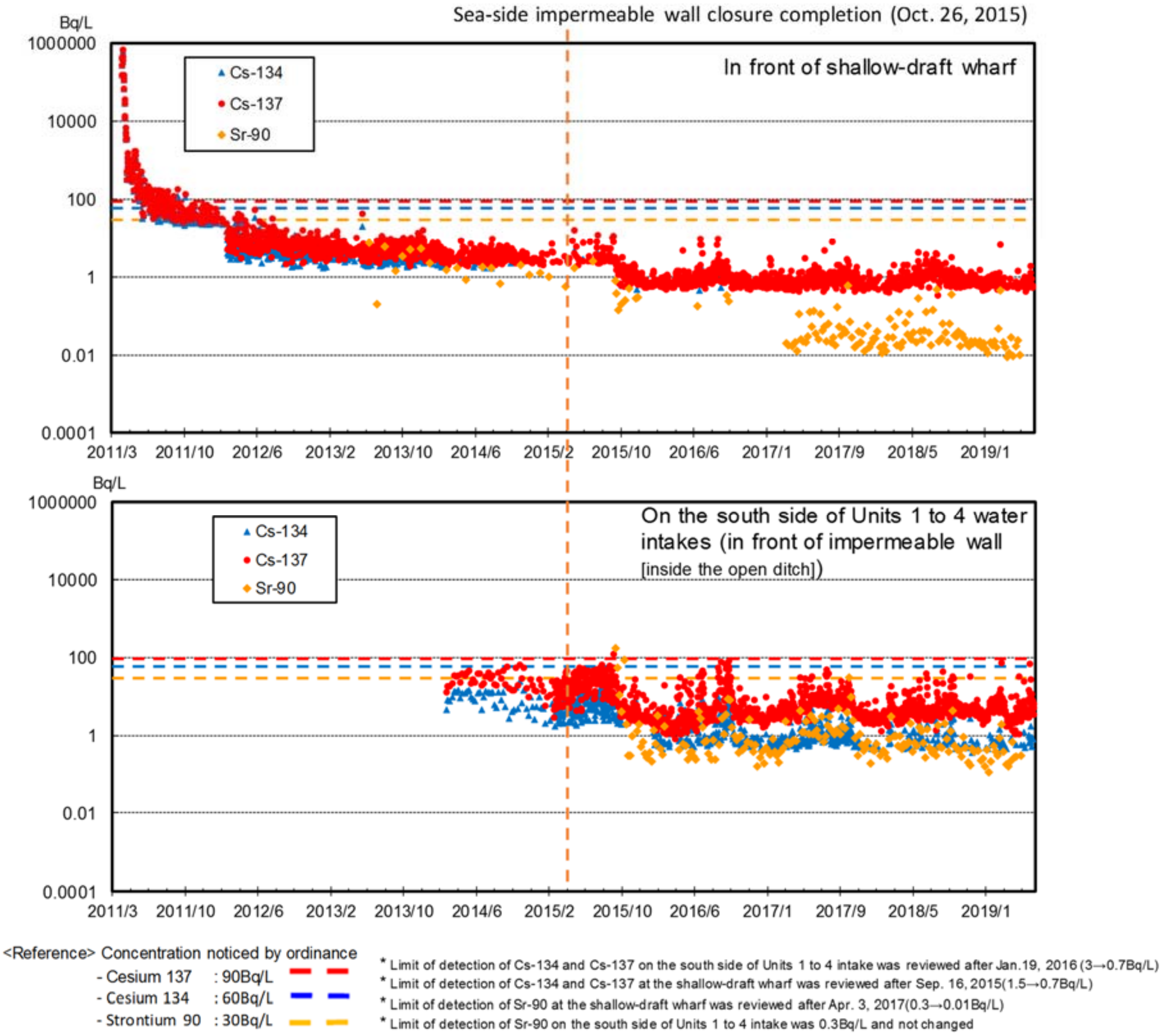
[29] For example, refer to the in-core condition data and diagrams (at the portal website for Decommissioning R&D Information) at http://www.drd-portal.jp/assets/files/current_data_jp.pdf. The website posts the in-core condition data released by TEPCO regarding the Fukushima Daiichi NPS (each unit's in-core temperature, dose rate, feed water rates, Xe concentration, etc.).

materials. As a result, the radioactive material concentration in the port was lowered to 10 Bq/L, although it rises slightly when rain falls (in the open ditch, Pu-137) (20). It is lower than the limit concentration specified by the radiation dose regulations announcement for the area outside the “warning area” (average three-month concentration: Cs-134, 60 Bq/L; Cs-137, 90 Bq/L). (Fig. 20)

Because of these various measures, the ingress of radioactive materials into the port water has been strictly controlled; however, even today, the concentration of radioactive material in the port rises when it rains. It is therefore important to suppress the ingress of contaminated surface water by way of drainages. In particular, the radioactive material concentration in drainage K, which runs near the buildings, is higher than that in drainages A, B and C, and the concentration in drainage K rises when it rains. Thus, the radioactive materials eluted from contaminated rubble or the laid sand on the top of the buildings or rubble on the Tokyo Peil (T. P.) 8.5-meter bed, and eluted radioactive materials from the bed, are considered to be reaching the water in the port from the branch pipes of drainage K. Based on this supply mechanism, measures for reducing the concentration of radioactive material in the drainage channels that flow into the port need to be continued to further reduce the concentration, such as installing a purification system in the K drainage and cleaning, measures against rainwater ingress from the top of the buildings, and paving around the buildings.

Because soil near the port has contaminants in the shallow layers, the long-term environmental impact evaluation involves technical challenges; namely, unlike the relocation analysis of the geological disposal of high-level radioactive waste, knowledge of which been obtained, the influence of unsaturated layers and the effect of adsorption reaction rates need to be considered. It is important to continue R&D such as understanding the migration mechanism of nuclides and refinement of analytical models with a view to long-term impact assessment on the future environment restoration[30].

[30] Refer to “(6) Environmental fate studies of radioactive materials generated during decommissioning” included in Attachment 15.



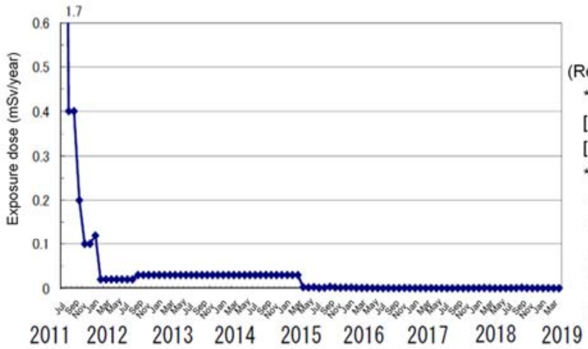
(TEPCO data edited by NDF)

Fig.20 Radioactive material concentration in seawater in the port

3.5.2.2 Management of gas and liquid waste

The Mid-and-Long-term Roadmap specifies that 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.

For the control of air release, centralized control by the monitoring system of exhaust stacks cannot work because of the impact of the accident, the PCVs of Units 1 to 3 are continuously monitored with gas control equipment (dust monitors and gas monitors), while the reactor buildings of Units 1 to 4 are continuously monitored with equipment (dust monitors) installed in the upper part of the building or nearby. The release control target from Units 1 to 4 is set to a total Cs-134 and Cs-137 of 1.0 x 10^7 Bq/h, and it is confirmed that the dust monitors near the boundaries of the premises indicate values lower than the concentration limit for the outside the surrounding monitoring area, and the radiation dose evaluation is conducted once a month. When the emissions from Units 1 to 4 are 1.0 x 10^7 Bq/h, the effective radiation dose evaluation value near the boundaries of the site should be 3 x 10^{-2} mSv/year. The effective radiation dose (radiation exposure dose) evaluation based on the actual measurements of March in 2019 was about 2.2 x 10^{-4} mSv/year, indicating that air release is controlled at a sufficiently low level (Fig. 21).



(Reference)
*Gas-phase concentration limits outside the surrounding monitored area:
[Cs-134]: 2 x 10^{-5} Bq/cm^3;
[Cs-137]: 3 x 10^{-5} Bq/cm^3
*Monitoring posts (MP1 to MP8) data
The monitoring posts (MP), which measure the air dose rate around the site boundary, indicated 0.413 μSv/h to 1.384 μSv/h (July 24, 2019 to August 27, 2019; 10-min value). To more accurately measure the fluctuations of the MP2–MP8 air dose rates, environmental improvement measures have been taken (cutting of surrounding trees, removal of surface soil, and shield installation).

(Note) Since different calculation formulas and coefficients were used in the facility operation plan and the monthly report, the evaluation method was unified in September 2012.
Unit 4 was added to the evaluation list in November 2013 based on the work of removing fuel from the spent fuel pool.
Since fiscal 2015, the evaluation method has been changed to take the value of continuous dust monitor into consideration, and the result is disclosed in the following month.

(Source : TEPCO)

Fig.21 Evaluation of annual radiation exposure dose at site boundaries due to radioactive materials (Cesium) emitted from Units 1 to 4 reactor buildings[31]

Regarding drainage control of the water purified after being pumped up from the sub-drains and underground water drains, four major radionuclides: Cs-134, Cs-137, Sr-90, and H-3, plus 44 other radionuclides have been selected for control based on the core inventory and other related information, as significant target radionuclides for radiation exposure evaluation.

- Before water drainage, it should be checked that the concentrations of four major nuclides are below the standard values[32].
- A monthly analysis with a lowered detection limit concentration should indicate no significant increase for the six indicators, which are the four major nuclides, all beta and all alpha emitters.
- It should be checked quarterly that the sum of the ratios to the notified concentration limits of all the target nuclides for confirmation is less than 0.21.

As described above, drainage is strictly controlled. In addition, nuclides with the notified concentration limit ratio of 0.01 or less, isotopes of Cs-137 with very small radiation dose contribution and daughter nuclides are excluded from the nuclides to be checked. In the application for change in April 2017, the number of nuclides to be checked was 41, including the four major nuclides.

The underground bypassed water pumped up on the mountain side before entering the reactor buildings is temporarily stored in tanks, and is released after checking that it satisfies the operational target; namely, the notified limit concentration rate of less than 0.22.

3.5.2.3 Radiation dose reduction through the site decontamination

Of primary concern immediately after the accident was the workers' radiation exposure in the

[31] Reference 2 : Overview of decommissioning and contaminated water treatment from The secretariat Meeting of 69th Team meeting on decommissioning and contaminated water treatment, August 29, 2019, http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2019/08/2-1.pdf
[32] The standard values are as follows: Cs-134 and Cs-137 < 1 Bq/L; Sr-90 < 5 Bq/L; and H-3 < 1500 Bq/L

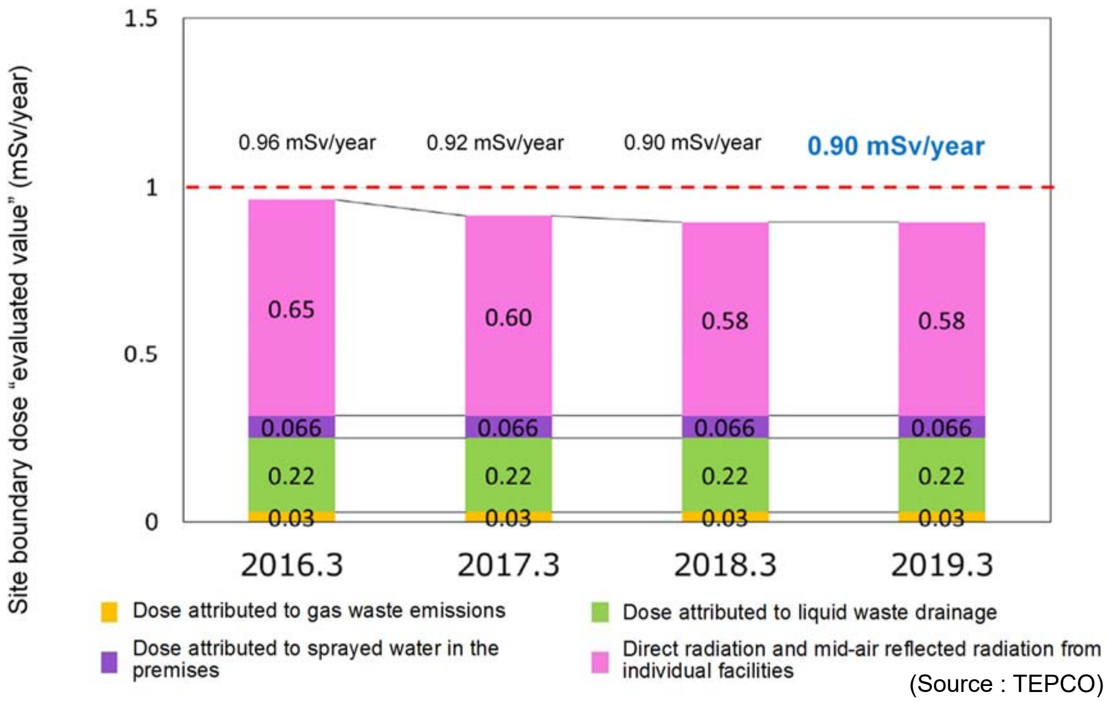
Fukushima Daiichi NPS. Possible causes were fallout contamination across the entire site and direct radiation from the plant. In March 2014, TEPCO formulated “Implementation Policy of Radiation Dose Reduction on the Site of the Fukushima Daiichi NPS”[33] and set target radiation dose rates in stages for each area in the sites to reduce the radiation dose. As a result of the removal of high radiation dose rubble, decontamination and shielding by cutting down trees, removing topsoil and facing, etc., the target radiation dose equivalent rate of 5 μSv/h was achieved at the end of FY 2015 in the areas around Units 1 to 4 as well as the areas where many workers are working, excluding the waste storage area, and radiation dose reduction has been progressing since then. In the vicinity of Units 1 to 4, the area where workers can work with general work clothes, etc. has expanded to about 96% of the entire site due to the identification of the radiation source by directional monitoring and the progress in the installation of shields. In addition, from October 2018, it became possible to move between the seismic isolation building, rest center near the west gate, and access control building without additional equipment.

Improving the radioactivity environment and labor environment in the site is essential for protecting workers’ health and safety (refer to Section 4.1). TEPCO should continuously maintain an average level of 5 μSv/h or under as specified in the Mid-and-Long-term Roadmap and should gradually reduce the target radiation dose equivalent rate to ultimately reach the pre-accident level.

3.5.2.4 Reduction of environmental impact

As to the radiation dose evaluation at the boundary of the site (“effective radiation dose”), encompassing additional emissions from the entire site, attained the target radiation dose of 1 mSv/year or less was attained at the end of FY2015, as a result of the previously described efforts to reduce the radiation dose and prevent the expansion of contamination; namely the purification of high-concentration contaminated water described in Section 3.3, adequate storage of solid waste specified in Section 3.2, and the entire risk inspection including the inspections described below. Since then, 1 mSv/year or less has been maintained, and at the end of FY 2018, it was 0.90 mSv/year (Fig. 22).

[33] TEPCO, “Efforts for Dose Reduction inside the Fukushima Daiichi NPS”, presented as Handout 3-2 at the 19th Meeting of The Committee on Supervision and Evaluation of the specified Nuclear Facilities (March 31, 2014). http://www.nsr.go.jp/data/000051045.pdf



(Source : TEPCO)

Fig.22 Effective radiation dose evaluation at site boundaries[34]

Besides high-concentration contaminated water, other water with radioactive materials has been thoroughly inspected as a risk that may have an impact on areas outside the site, and efforts such as contaminant removal and drainage cleaning are being made. Solid waste such as rubble is reduced in volume where possible and is placed indoors to eliminate temporary outdoor storage areas. The effective radiation dose at the boundary of the site contributes not only to the direct radiation doses from radiation sources on the premises but also to the radiation emitted upward from sources, dispersed in the air, and radiated down to the surface soil. It is therefore important to adequately control and shield the radiation sources. Risk reduction outside the site of the Fukushima Daiichi NPS is continued through such efforts, to retain the effective radiation dose of under 1 mSv/year.

The representative individuals in the radiation dose evaluation for public protection should be selected from among those with relatively high exposure, in consideration of actual lifestyle habits and environmental conditions in the vicinity of the site. Intermediate radioactive waste storage facilities are placed near the Fukushima Daiichi Power Station, and the representative individuals should be realistically selected from this perspective. Setting control targets and evaluation conditions is desirable. Discussion is desirable from the viewpoint of the possible integration of the 2007 Recommendations[35] of the International Commission on Radiological Protection ("ICRP") into Japanese law.

[34] TEPCO, "Dose Conditions in the Fukushima Daiichi NPS Buildings", presented as Handout 3-6 at the 65th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment, April 25, 2019
http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2019/04/3-6-2.pdf

[35] The International Commission on Radiological Protection (ICRP), The 2007 Recommendations of the International Commission on Radiological Protection, ICRP Publication 103, Annals of the ICRP, 37 (2-4), (2007).

3.5.2.5 Comprehensive risk review

TEPCO conducted a comprehensive inspection of risk sources that may affect the outside of the site, and systematically established the following six categories of additional measures mainly for leakage passages (liquids confining radioactive materials) and for work (dust), and announced them in April 2015: (1) Research required; (2) Measures required; (3) Measures being taken; (4) Conditions being observed after implementation of measures; and (5) Measures not presently required. As a result, 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 Mid-term risk reduction target map, which has been updated from time to time, is characterized by a risk reduction work schedule of about three years emphasizing the presentation of residual risk. In regard to this Target map for reducing the mid-term risk of Fukushima Daiichi NPS, TEPCO reported the current approach, issues and responding status according to the further schedule as needed after May 2018. In it, for example, a very large floating structure (VLFS, Megafloat) can become a drifting object and damage nearby equipment if hit by a tsunami; and therefore, it is positioned as a measure against earthquakes and tsunamis in the target map for reducing the mid-term risk of Fukushima Daiichi NPS. TEPCO plans to move this VLFS to the open ditch of the water intake channel for Units 1 to 4 and position it in contact with the sea bottom, to effectively use it as a revetment and shallow-draft wharf for the preparation of a newly built port yard. To achieve this, TEPCO started construction in November 2018, with the aim of completing the reduction of tsunami risk by the end of the first half of 2020 and completion of construction within fiscal 2021.

Regarding to the other countermeasures against earthquake and tsunami, building of tide embankment is being studied at the sea side of Unit 1 to 4 buildings. TEPCO should continue this kind of efforts for the purpose of avoiding increases in stagnant water as a result of water inflow into the building due to tsunami, and reducing damage to essential facilities in preparation of a Kuril Trench Tsunami, which was identified as a highly imminent possibility.

In the future, it will be important to comprehensively understand the risk sources and to continuously reduce the implementation of each measure while comprehensively considering the positioning and priority in the overall decommissioning project of the Fukushima Daiichi NPS as described in Section 3.6.

3.5.3 Plan for decommissioning measures for nuclear reactor facilities

In the Mid-and-Long-term Roadmap, TEPCO should formulate the decommissioning plan for the Fukushima Daiichi NPS in phase 3 after commencing fuel debris retrieval, aiming at the completion of decommissioning in 30 to 40 years, depending on the progress of tasks such as fuel debris retrieval, and R&D. 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[36,37].

3.5.4 Concrete efforts toward securing safety

3.5.4.1 Efforts to ensure work safety

In FY 2018, the average number of workers per day was 4000 - 5000, which is on a slightly decreasing trend. Safety activities are being continued in order to reduce the number of accidents. The number of accidents (number of people involved in disasters) was 20 in FY 2016 and 11 in FY 2017, but it was 13 in FY 2018. When analyzed the three causes of “people, facilities, and management”, many accidents are caused by human factors (assumption and lack of risk sensitivity). In particular, taking into account that there are many accidents involving workers with less than 1 year of experience, a safety policy has been formulated from the viewpoint of “Awareness, skill improvement and management” to reduce accidents and the work environment is continuing to improve[38].

Similar to fuel debris retrieval operations, for the work plans that require workers to intervene in a high radiation dose environment and for which complete remote-control system operation is difficult, it is important to control the individual radiation dose, evaluate the environment according to the resources introduced from the viewpoint of “justification and optimization”, examine diversified approaches while noting the mid-to-long term radiation management, and aim to ensure the safety of the work environment as much as possible. 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 mock-up in order to design, implement and verify effective work procedures and test methods. To prevent labor accidents, it is important to verify the procedures and at the same time repeat preliminary training using a virtual reality (“VR”) system, and to map out a safe, reliable work plan with clear hold points. Therefore, VR system reinforcement is effective, by updating the method information and site conditions.

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[36] NRA, Direction of review for regulations concerning TEPCO Fukushima Daiichi NPS (draft), handout 4 of 10th Nuclear Regulation Authority Meeting, May 29, 2019, http://www.nsr.go.jp/data/000271371.pdf

[37] NRA, Maintenance of laws and regulations for introducing new inspection system (Nuclear regulation inspection) (First stage) and invitation for public comment, handout 6 of 20th Nuclear Regulation Authority Meeting, July 31, 2019, http://www.nsr.go.jp/data/000279077.pdf

[38] TEPCO, “FY2018 Accident Occurrence Conditions in the Fukushima Daiichi NPS” and “FY 2019 Safety Action Program”, Handout 3-7 of 65th Meeting of Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment, April 25, 2019.
http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2019/04/3-7-2.pdf

On-site work including the preliminary work for retrieval of fuel debris is expected to include: decontamination in reactor buildings; investigation of PCV leakage positions; repair of PCV lower and upper sections; construction of a network system; preparations for the installation of fuel debris retrieval devices and systems; fuel debris retrieval operation; and fuel debris containing, transferring and storing. Therefore, for each work stage, a detailed work plan should be prepared, and in the case of an accident or problem, prevention measures should be taken based on the proper preliminary risk assessment and measures. It is necessary to examine how to handle an unexpected accident: in the event of an accident or problem, a maintenance work area should be provided to deal with it quickly. In the future, it is necessary to review the radiation dose reduction work in the reactor buildings conducted so far and the PCV internal investigation, and use the information for preliminary measures, such as preparations, planning, and training, for other work.

In January 2019, an event occurred in which the inspection scaffold of the Units 3 and 4 exhaust stack fell. No work was being performed in the surrounding area, and there was no damage to people. However, considering the passage of time since the accident, similar events may occur in other facilities. Therefore, it is important to consider measures to improve safety.

In line with the Mid-and-Long-term Roadmap, it is stated that measures for industrial accident prevention (joint operation of the labor safety and health control system by TEPCO and the original contractors; risk assessment by TEPCO, etc.; thorough communication and coordination between tasks; experience-based education and training facilities for improvement of new employees' risk expectations capability, etc.) 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 exposure as much as possible. It is important to ensure a perfect system of work safety by continuing these efforts.

3.5.4.2 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. TEPCO has been preparing a complete set of information, such as databases, maintenance plans for individual tools and devices, and drawings[39]. Measures for retaining and improving reliability will be taken in the future to ensure long-term use, based on the maintenance plans for individual tools and devices, by steadily performing periodic investigations, updating equipment at the proper timing, and making equipment permanent.

Particularly important safety assurance equipment, such as circulation system to cool fuel debris, nitrogen gas separation system, and PCV gas control system, are operated, inspected, maintained, remote-controlled, monitored, and otherwise properly managed by TEPCO, based on maintenance plans and other schedules. 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 servicing

[39] TEPCO, "Development of Database and Maintenance Plan for equipment, etc.," presented as Handout 1-6 at the 23rd Decommissioning and Contaminated Water Treatment On-Site Coordination Meeting (July 27, 2015). http://www.meti.go.jp/earthquake/nuclear/osensuitaisaku/committtee/genchicyousei/2015/pdf/0727_01k.pdf

but from management and operation standpoints as well.

When installed new equipment or facility, it is critical to avoid defects on site as much as possible, and steady quality assurance should be conducted through design reviews and testing and examinations.

In the last fiscal year, there was a malfunction with the fuel removal device at the time of the removal of the fuel from the 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 matters 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 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.

3.5.4.3 Security enhancement

At decommissioned nuclear power plants, appropriate fuel removal is conducted, and, when nuclear material protection concerns are removed, dismantling and other decommissioning work is performed. Because a great quantity of nuclear fuel material is stored in the Fukushima Daiichi NPS, 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.

Along with these measures to be continued, it is necessary to implement appropriate measures in operation to allow accepting visits of inspectors including locals to see the progress of the decommissioning work as it is, at the Fukushima Daiichi NPS on site, as described in Section 7.2, because showing the progress with their own eyes is extremely valuable for building the public’s understanding of the decommissioning operation. On the other hand, it is crucial to further strengthen access control to the NPS in consideration of Olympic that will be held in 2020.

3.6 Comprehensive efforts for the decommissioning project of the Fukushima Daiichi NPS

As mentioned in Chapter 2, in the decommissioning project of the Fukushima Daiichi NPS in the future, it must be addressed more complex, uncertain challenges over the long term, such as fuel debris retrieval. For this reason, when making efforts in each of the fields listed in Sections 3.1 to 3.5, it is necessary to systematically promote efforts to resolve issues by looking ahead and securing lead time for sufficient preparation; though there had to carry out work while accumulating work to respond to the challenges that are facing us in the short term as emergency responses from right after the accident onwards.

Decommissioning of the Fukushima Daiichi NPS is a complex and multi-layered large-scale project, and various efforts undertaken within the project are carried out simultaneously and in parallel and in a mutually related manner. In particular, when the retrieval of fuel debris is started in the future, the relevance of the work in each field will be strengthened further, such as the issue of the treatment of cooling water used to cool debris, the issue of the establishment of storage facilities to temporarily store the removed debris, and the issue of the space coordination for various works such as the removal of fuel in SFP conducted in the upper part of the building and the installation of related facilities in the yard. In order to proceed the entire decommissioning project in a stable manner over the mid-and-long-term in the context of increasing complexity in the relation between the mutual work, it is important to optimize 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 proactive and systematic work and the necessity of coordinating the intricately-related work as a whole, to proceed with the decommissioning project steadily and efficiently in the future, it is necessary to formulate a consistent long-term plan for the entire decommissioning from the current state to the short, medium, and long terms, so that various efforts can be managed comprehensively in accordance with this plan.

In addition, individual work in each field of decommissioning work is generally carried out through processes such as technological development → conceptual design → detailed design → production → site installation work→ inspection→ operation. In addition, safety inspections and other inspections by the Nuclear Regulation Authority will be conducted as necessary. In order to carry out this series of processes without omission or delay, it is effective to set up the large work flow defined in the long-term plan as an individual project as a management unit of appropriate scale. IN addition, it is important to promote a comprehensive approach under a sophisticated project management system so that correlation and time-series relationships between the projects can be optimized and risks inherent in the project can be appropriately managed.

Even if a long-term plan is drawn up, it is virtually impossible to draw up a plan with high accuracy into the future at this point because there are still large uncertainties regarding the status of the decommissioning of reactors in the distant future and the necessary work. Therefore, as a long-term plan, it is considered to be practical to optimize the work plan for the longest possible range where the work can be specified to a certain extent; from the viewpoint of showing the road to decommissioning inside and outside, though there are restrictions on the level of detail to such specification can be realized.

As to the decommissioning of the Fukushima Daiichi NPS, it is an unprecedented challenge and a project that needs to be carried out while accumulating experience and results, while improving the site, investigating the situation, and developing technology, with limited information and a severe environment due to contamination and impact of tsunami. In order to safely and steadily advance a decommissioning project that contains many uncertain elements, it is important to draw up a plan based on the current information 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 choosing the best approach for the situation or the safest approach under the situation, thereby impeding the progress of safe and steady work.

Thus, while it is necessary to formulate a long-term plan and to proceed with the work in a planned manner under the project management system, the formulated long-term plan should not be rigidly positioned and operated. For concrete use of the long-term plan, it is more important to set decision 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.

Fig. 23 shows the image of decision points and the review of the long-term plan.

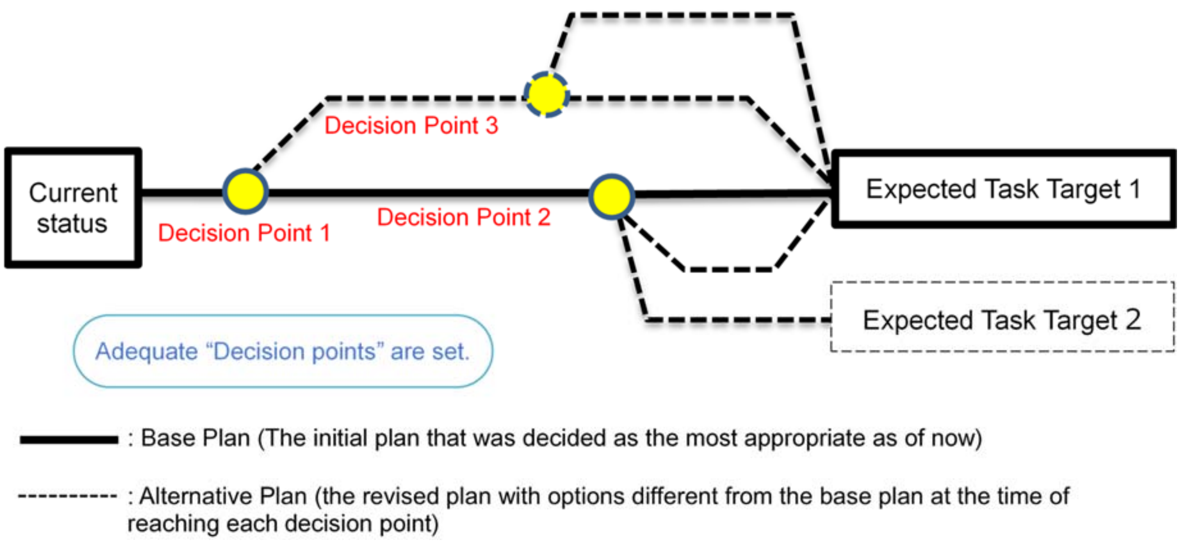


Fig. 23 Decision points and review of the long-term plan

4. Handling critical enablers for smooth operation of the project

4.1 Actions toward improvement of working environment and conditions

The working environment of the Fukushima Daiichi NPS has been steadily improved. Needless to say, this improvement is essential for protecting and respecting the rights of workers. For the Fukushima Daiichi NPS decommissioning project, which will continue for a long period of time after the end of the emergency status, a good working environment is the basis for ensuring safe and steady implementation on a healthy foundation. To name a few typical efforts, TEPCO is improving the working environment infrastructure by consolidating and removing existing rest stations and setting up alternative rest stations, a cafeteria, convenience store, and shower booths, which are infrastructure for improving the working environment. The company conducted a questionnaire survey on the working environment for those working in plant, and is using the results to improve the working environment[40].

A variety of measures are taken to improve working safety and health, according to the "Guidelines for Safety and Health Control Measures for the TEPCO Fukushima Daiichi NPS" [41] established in August 2015 by the Japanese Ministry of Health, Labour and Welfare. Reinforcement of the safety and health control system that integrates TEPCO and the original contractors is implemented, by designating necessary positions such as the safety and health supervisor and by establishing a health cooperation organization, while proceeding with steady efforts, such as risk assessments regarding dangers and hazards caused by on-site materials, working behavior or other duties; implementation of measures based on the risk assessment results; implementation of health education for new staff members; centralized radiation exposure dose control; reinforcement of entry/exit control of those working in the station facilities; and integration of effective radiation exposure reduction measures into the project plan at the stage of placing purchase orders.

As measures against heat attack, fixed WBGT[42] indicators and clocks have been installed on site, enhancing acclimation to heat, and medical history of heat attack and health conditions have been confirmed (early detection of poor physical condition). In fiscal 2018, the period for strengthening measures to prevent heat attack was extended from April to October. As a result of various measures, the number of heat attack patients increased by only two from fiscal 2017 despite the unusually hot weather (6 persons--> 8 persons). In fiscal 2019, the rules for preventing heatstroke in fiscal 2018 will be continued, and because heat attack occurred in October for three consecutive years, a new rule was added to encourage workers to prevent heat attack in case

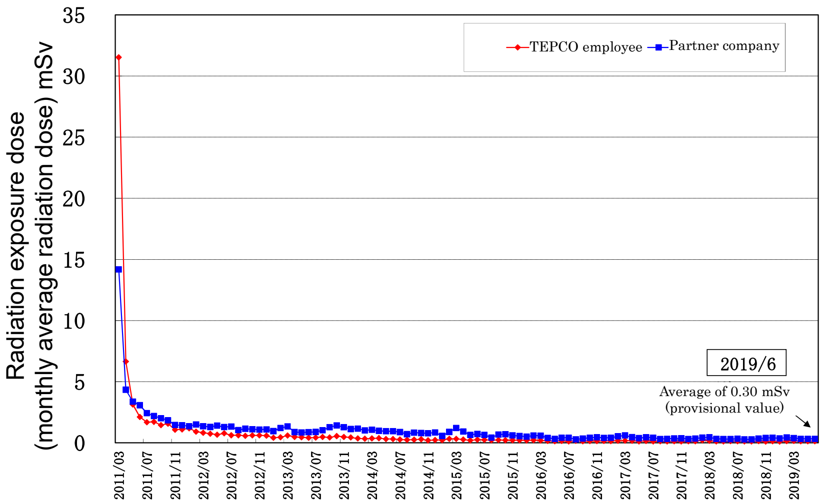
[40] TEPCO, "Results of Questionnaire for a Better Labor Environment (9th Meeting) and Future Improvement Plans", presented as Handout 3-7 at the 61th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment (December 27, 2018).
http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2017/12/3-07-02.pdf

[41] "Reinforcing safety and health control measures for the TEPCO Fukushima Daiichi NPS", Press release data announced by the Ministry of Health Labour and Welfare, Aug.26, 2015,
http://www.mhlw.go.jp/stf/houdou/0000095466.html

[42] Wet-bulb globe temperature : that incorporate humidity, radiant heat, and temperature, which have a significant impact on the heat balance of the human body)

temperature may change significantly by confirming weather forecast (WBGT and temperature change) in advance.[43]

As radiation exposure control, the monthly average radiation exposure dose in fiscal years 2014 to 2018 has been about 1 mSv/month or lower (Fig.24). The average radiation exposure dose in FY2018 was about 2.4 mSv/year, individual maximum radiation exposure dose is low enough[44] as no worker radiation dose exceeded 20mSv/year. The radiation exposure dose of most workers is large enough for the radiation dose limit. Furthermore, the ICRP's statement regarding the equivalent radiation dose limit for the lens of the eye[45] was voluntarily adopted, and 150 mSv/year was reduced to 50 mSv/year as voluntary control from April 2018, in addition, the limit radiation dose of 100mSv for five years has been applied since April, 2019. With the progress of the project, work in a high radiation dose environment is expected to become more frequent. To comply with the radiation dose limits of individual workers, a limit should be designated that will be lower than the legislated limit. When a worker's radiation exposure is at or above, or may be above the limit, such worker is to be excluded from engaging in radiation work or request that the worker prepares a radiation dose control plan where the radiation dose control methods will be determined in detail and work according to the control plan to ensure that the radiation dose does not exceed the legislated limit radiation dose. Such management needs to be carried out without fail.



(Source : TEPCO)

Fig.24 Changes in workers' monthly radiation exposure dose (monthly average radiation dose) (Radiation exposure dose by month after March 2011)[46]

[43] TEPCO, "Status of accidents in FY 2018 and safety activity plan in FY 2019", issued in FY2019, presented as Handout 3-7 of 65th Meeting of for the study group on Countermeasures for Decommissioning and Contaminated Water Treatment, April 25, 2019.
https://www.tepco.co.jp/decommission/iinformation/committee/roadmap_progress/pdf/2019/d190425_12-j.pdf

[44] TEPCO, "Status of radiation exposure dose for radiation workers in Fukushima Daiichi NPS", April 24, 2019
https://www.tepco.co.jp/decommission/iinformation/newsrelease/exposure/pdf/2019/exposure_20190424-j.pdf

[45] ICRP, ICRP Statement on Tissue Reactions and Early and Late Effects of Radiation in Normal Tissues and Organs – Threshold Doses for Tissue Reactions in a Radiation Protection Context, ICRP Publication 118, Annals of the ICRP,.41(1-2), (2012).

[46] Reference 2 : Overview of decommissioning and contaminated water treatment from The secretariat Meeting of 69th Team meeting on decommissioning and contaminated water treatment, August 29, 2019
http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2019/08/2-1.pdf

As measures for radiation dose reduction on site, as described in Sub-section 3.5.2.3, high radiation dose rubble removal, surface soil removal, and decontamination by facing and shielding have been performed, and as a result, the target radiation dose equivalent rate of 5 μSv/h was achieved by the end of FY 2015 (excluding the vicinities of Units 1 to 4 and waste storage areas). The area where workers can wear ordinary uniforms or similar attire has extended to approx.96% of the entire premises. In addition, since March 30, 2017, the areas that have been confirmed to be free from the spread of radioactive contamination within the areas in which it is permitted to work with general work clothes (Access Control Building, Rest Area, Seismic Isolation Building, etc.) was designated as areas where people can move around without a shoe cover and only with gloves. As a result of promoting environmental improvement of the areas only with gloves needed, those areas was designated as areas where additional protective cloths including even gloves are not necessary for workers to move around after October 1, 2018. Such area has been enlarged and it was apply to the pavement connected between surrounding Rest Area and Seismic Isolation Building, too. Moreover, this was applied to the upland located on west side of Units 1 to 4 from November 2018, it became possible for people to inspect only with the clothes as they wear.[47]. As it is no longer necessary to wear protective masks and protective clothes, improvement has been achieved in terms of narrowed sight, longer moving time due to the load on the body, and the possibility of a heat attack. This has helped improve safety and health control measures not associated with radiation.

In the future, while continuing the actions specified in Mid-and-Long-term Roadmap for improvement in the working environment and conditions, it is needed to specifically design internal radiation exposure prevention measures in preparation for the fuel debris retrieval that will generate α-dust, which contributes significantly to radiation dose in the event of internal radiation exposure. Specifically, it is necessary to control signs through appropriate measurement and monitoring, in addition to confinement in specific areas using contamination expansion prevention methods, prompt contamination removal, and wearing of protective gear. Especially, at the entrance and exit control (control of surface density), measures against the contamination of protective gear that have direct contact with the body are important, because adhering radioactive materials may indirectly contaminate the skin and may become airborne particles that could cause internal radiation exposure. TEPCO has an agreement with Japan Nuclear Fuel Limited regarding the radiation dose evaluation of internal radiation exposure due to α-nuclides derived from fuel debris, (internal radiation dose evaluation using bioassay analysis), and a system has been prepared to enable action. For further safety purpose, study on organizing a system to evaluate internal radiation exposure dose by themselves is being examined in considering further progress of operation.

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[47] TEPCO, Status of improvement in the work environment at the Fukushima Daiichi NPS, Handout 3-7 of The 60th Meeting of Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment, November 29, 2018,
https://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2018/12/3-7-3.pdf

4.2 Enforced management structure for steady mid-and-long-term decommissioning

TEPCO Fukushima Daiichi Decontamination and Decommissioning Engineering Company (hereinafter referred to as “Decommissioning Company”), established in April 2014, has introduced a project system to promote the safe and steady decommissioning of reactors, and is working to transform from the conventional routine-based operation management to project-based operation management. With the introduction of the project system, targets and deadlines are clearer than before, and certain achievements have been obtained in the work of contaminated water management and removal of fuel in SFPs. However, as difficult tasks such as fuel debris retrieval are scheduled in the future, the project management function is needed to be enhanced more, rather than satisfied with previous achievements.

To that end, the Decommissioning Company restructured its project framework last October and is preparing to shift to a framework in which project managers have sufficient responsibilities and authority. Program Management Office (PMO) has been established for the overall management of the related projects and line operations, and the PMO is in charge of promoting the enhancement of project management functions.

<Examples of enhancing Project Management functions>

(1) Empowering Project Managers
(2) Integrated management of all projects utilizing project management tools
(3) Visualize projects with the Earned Value Management (EVM)
(4) Decision-making based on stage gate process
(5) Preparation of long-term plan and project management based on the long-term plan
(6) Improving (kaizen) Supply Chain Management (Procurement based on long-term plans)

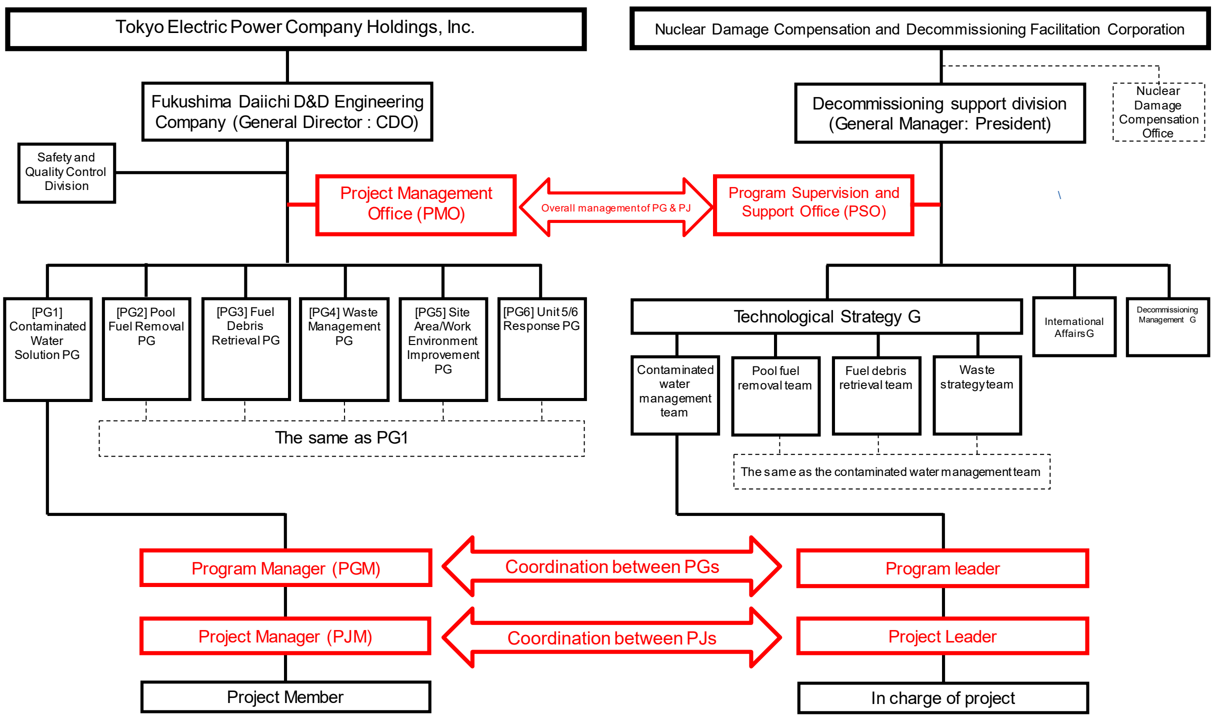
On the other hand, the NDF, which manages and supervises TEPCO's decommissioning work, established the Program Supervision and Support Office (PSO) in February 2018 to support the strengthening of TEPCO's project management functions in cooperation with the TEPCO PMO.

The cooperation between the two organizations is also strengthened in the implementation of the project. In the NDF, counterparts are assigned to coordinate with the program manager (PGM) and the project manager (PJM) of the Decommissioning Company, and the NDF counterparts attend project-related meetings hosted by the Decommissioning Company to share issues specific to the project and provide technical support to resolve issues as necessary (Fig. 25).

In addition, program projects implemented by TEPCO need to be clearly defined as plans under the decommissioning Reserve Fund System. In the Policy for Preparation of Withdrawal Plan, NDF has recently shown TEPCO, which is the licensed decommissioning company, the following: 1) the status quo of the decommissioning project and operational targets for the mid-and-long-term perspective based on the planning of the project; and 2) the tasks to be implemented and their purposes, as well as the targets and major tasks for the three years to come, as activities to be incorporated in the Withdrawal Plan. (Table 3 shows the preparation policy issued to TEPCO on October 2, 2018.)

TEPCO is to submit the “Decommissioning Implementation Status, Decommissioning Implementation Plan, and Other Items Specified by the Ordinances of the Minister in Charge” every year via the NDF to the Minister of Economy, Trade and Industry, who is in charge of decommissioning. TEPCO and the NDF jointly prepared the Withdrawal Plan and obtained approved from the Minister of Economy, Trade and Industry to withdraw from the fund. These documents have been created according to the planning of the ongoing program and project from the viewpoint of making steady progress in the decommissioning.

The implementation of the plan (implementation of decommissioning work) will be carried out by TEPCO, and the NDF will manage and supervise the status of how TEPCO is implementing the plan. For this reason, the NDF, in the process of preparing the Withdrawal Plan with TEPCO, not only confirms that the costs necessary for decommissioning work are appropriately budgeted by TEPCO, but also receives monthly reports from TEPCO on the status of use of the reserve funds for decommissioning and confirms the appropriateness of the use status.



* CDO, Chief Decommissioning Officer, in charge of decommissioning and contaminated water management; PG, program; and G, group.

Fig.25 NDF and TEPCO organizational system for Project Control

Table 3 Description of the Projects included in the Withdrawal Plan

Program	Objectives	Three-year targets	Major tasks (for the coming three years)
(1) Contaminated water management program	• Implementation of fundamental measures against contaminated water • Removal of contaminants that may have an impact on the Fukushima Daiichi NPS boundaries	• The effective radiation dose at the boundaries of the site should be maintained at a level below 1 mSv/year. • The total volume of contaminated water under an average rainfall amount should be controlled (no greater than 150 m^3/day in total). • Tank capacities should be secured according to a plan. • While the difference in level between stagnant water in the buildings and underground water is retained, the water level in the buildings should be lowered (keeping a situation to prevent the outflow of stagnant water from the reactor buildings into other buildings).	• Reinforcing sub-drain and land-side impermeable wall related operation • Measures to prevent the inflow of groundwater/storm sewage into the buildings • Installation of welded tanks and removing of flange tanks, etc. • Transferring stagnant water in buildings and installation of purification equipment • Purification process of stagnant water in buildings • Measures for stable storage of sludge from decontamination equipment • Appraisal and implementation of other risk reduction measures
(2) Program for removal of fuel in SFPs	• Spent fuel removal from Units 1 to 3 • Storage in common spent fuel storage pool, etc. in stable condition	• Installation of Unit 1 fuel removal covers should be started in FY 2021. • Unit 2 buildings upper part dismantling and related work should be able to be completed in FY 2022. • Fuel removal from Unit 3 SFP shall be complete. • Improvement of surrounding environment of Unit 2 shall be completed.	• Unit 1 operating floor rubble removal • Unit 2 internal investigation of operating floor of R/B and building upper part dismantling • Installation of cover for fuel removal, fuel removal and stable storage at Unit 3 • Dismantling of upper part of Units 1 and 2 exhaust stack
(3) Fuel debris retrieval program	• System establishment for fuel debris retrieval methods from Units 1, 2 and 3 • Retrieving, containing, transferring and storing of fuel debris of Units 1 to 3	• The fuel debris retrieval method of the first implementing unit has been determined and its engineering work behind the method should be implemented. Then, preparation for retrieval is to be made.	• Examination of fuel debris retrieval methods for each unit (Steady implementation of engineering, etc.) • Detailed investigation of the conditions in the PCVs • Preparatory work for fuel debris retrieval • Technology development led by TEPCO HD
(4) Waste management program	• Formulation of waste storage management plan and appropriate waste storage	• Solid waste is safely and reasonably stored and controlled, and the required storage capacity should be secured. • Steady implementation of efforts to reuse, recycle and reduce volume of waste	• Installation of waste storage and volume reduction treatment equipment (incinerators, etc.) • Formulation of Mid-and–long-term Storage plans (Including Storage of adsorption vessels, concentrated waste liquid and slurry) • Technology development led by TEPCO HD
(5) Site area / working environment improving program	• Formulation of site use plan and establishment of the management processes • Improving working environment for workers	• Various measures for decommissioning are being steadily implemented through the operation of the site use plan. • Infrastructure is in place to maintain and improve the working environment within the power station	• Retention of buildings in good order • Improvement of decommissioning infrastructure • Provision of buildings and rest facilities
(6) Management of Units 5 and 6 program	• Maintenance of Units 5 and 6 equipment • Decommissioning planning and its implementation	• Spent fuel shall be stably kept cooled.	• Maintaining cooling equipment • Decommissioning planning and proposal development • Relocation of VLFS

In the second withdrawal plan approved by the Ministry in April this year, costs related to decommissioning work for three years from FY 2019 to FY 2021 are included. As the decommissioning progresses, it is expected that various things would be clarified with the progress of work and technological studies. For this reason, the following points should be fully considered in the subsequent withdrawal plan.

- In order to proceed with safe and steady decommissioning work, in addition to enhancing the project management function mentioned above, it is essential to develop human resources to accomplish the project. In particular, since it is important to enhance project management skills, as well as engineering capabilities, specific plans should be drawn up for this purpose and efforts should be accelerated.
- As for R&D, some projects are carried out by TEPCO on its own, but most of them are carried out by the Government-led R&D program on Decommissioning and Contaminated Water Management. However, with the progress made in TEPCO's engineering, it is expected that there will be an increase in the number of field-oriented research and technology development tasks that could not be found by this Government-led R&D program. The R&D with high technical difficulties that require the support of the government should be carried out by the government-led decommissioning and contaminated water management projects as before. As for technology improvement to apply the achievements of those R&D to the site and new R&D tasks the necessities of which were found by TEPCO engineering, TEPCO should take the initiative.
- In addition, coexistence with the local community is indispensable to continue decommissioning for a long time. To achieve that, it is important for TEPCO to create more contacts with local communities through procurement of goods and services associated with decommissioning from them and employment of human resources in these regions. For instance, the technology developed by a local company was applied to the field for the dismantling of the exhaust stack of Units 1/2, and it is desirable to increase such good practices. TEPCO should proactively improve the environment that more local enterprises can participate in the decommissioning work through engineering support, while balancing the safe and steady decommissioning with the priority given to local communities.

Column : What is "Project Management" ?

What is a project in the first place? PMBOK (Project Management Body of Knowledge), an international standard for project management, defines projects as follows.

"It's a temporary endeavor undertaken to create a unique product, service or result" (cited from the 5th edition of PMBOK)

Every job has a goal. However, when it is called a project, it is characterized by being "temporary (it has a defined beginning and end in time)" and "unique (it is not a routine operation)" in addition to setting a goal. To put it simply, a project can be said to be "a non-routine operation designed to accomplish a singular goal on time".

Now that's the question. Which of the followings can be called a project?

1. It's hard for my mom to do housework while working outside. In order to reduce the burden of mom's housework, we decided to share the housework among the whole family.
2. 23rd of the next month is my daughter's 7th birthday. This year, I wanted to celebrate her birthday with her friends in commemoration of Shichigosan, so I decided to hold her birthday party, inviting her friends.
3. My child will go to a private school next year. I wanted to reduce my household waste as much as possible, so I decided to keep a household account book next month.

The answer is 2. 1 has a goal (= to reduce the burden on the mother) but no end (= until when) or it is not unique (= no routine operation). 3 is the same. On the other hand, in addition to the goal (= to celebrate a birthday with friends), there are a period (= birthday of 23rd of the next month) and uniqueness (= as a memorial of Shichigosan) in (2).

How did you understand what a project is? Next, let's consider what "project management" is.

If you read it literally, it will be "to conduct management of a project". So what does management in this case mean? When management is translated into Japanese, it becomes "an activity to control or organize works", but in the Japanese business scene, management is often used as it is without translation.

In short, project management is a collective term for "project activities* to meet the project requirement". If these activities are not coordinated, you cannot accomplish a goal of project. It is the role of a project manager to lead to accomplishment of a goal by organically bringing them together.

* In project management, these activities are defined by WBS (Work Breakdown Structure: a diagram that organizes project activities in a tree structure <Level1-Level2-Level3-…>). In large projects, this number of WBSs range over thousands to tens of thousands.

Now let's move on to the story to Fukushima Daiichi decommissioning.

TEPCO Fukushima Daiichi Decontamination and Decommissioning Engineering Company ("Decommissioning Company") was established in April 2014, three years after the accident. It has adopted a project system. Why did Decommissioning Company adopt the project system (← here is the point)?

Normally, once a nuclear power station shifts from construction phase to operation phase, works of the electric power company will be to maintain facilities in line with operations of the power plant and periodic inspections. Since the time required for a periodic inspection is stipulated by law as one year, power plants alternate between inspection (periodic inspection) and operation in a one-year cycle. For this reason, power plants are generally organized by “functional organizations” (also called sectoral organizations) such as power generation department, maintenance department, radiation management department, et al. Functional organizations are based on the concept that when each plays its own role, an overall goal of a power plant can be accomplished.

In addition to TEPCO, other electric power companies often adopt functional organizations at power plants. This is because the business cycle has been settled, and it is judged that an organization according to functions is most suitable for executing routine works efficiently without sacrificing safety and quality.

In turn, what about the decommissioning of Fukushima Daiichi NPS? Can you say that the same business style and organization as a power plant are suitable? Of course, some decommissioning operations are routine like works in power plants. However, the weight of such routine works are small, and the large portion of the main subjects are unprecedented and difficult tasks such as countermeasures against contaminated water after the accident, fuel removal from SFP, and fuel debris retrieval. Nevertheless, it is necessary to complete the decommissioning within the scheduled period. Moreover, the resources that can be used for decommissioning (people, goods, money) are limited.

In order to proceed with decommissioning in a safe and steady manner under the limited resources and to finish it within the period, Decommissioning Company decided that the project-type work style and organization, that can respond to major changes and uncertain factors flexibly and promptly, were more suitable for the decommissioning of Fukushima Daiichi NPS as compared with the routine and stable work style and organization at power plants.

◇ ◇

Decommissioning Company is steadily preparing for enhancing its project management function and engineering capabilities to transform into a genuine project-type organization from FY2020. On the other hand, NDF is in a position to manage and supervise the decommissioning conducted by Decommissioning Company. For this reason, NDF reviews the Withdrawal plan through the process of jointly developing it with TEPCO whether the expense, though which is not for the decommissioning operation itself but is required for ensuring the safety and quality of decommissioning including ones for enhancing project management functions and engineering capabilities, is properly recorded into the plan.

4.3 Developing and securing human resources

4.3.1 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. Furthermore, the technical challenges posed by the existence of enormous amounts of groundwater and others, the uncertainty of the internal site, and high radiation due to α- nuclides and fission products, etc. compose a very different condition from the decommissioning of normal reactors.

For this reason, the Decommissioning R&D Partnership Council has prepared a draft technology map in order to understand the overall image of core technology necessary for decommissioning of the Fukushima Daiichi NPS and the image of required decommissioning personnel (Attachment 13). As a result, it has become clear, for example, that there are fields in which it is possible to procure human resources through training, etc. by utilizing the existing pool of technology and human resources in the nuclear industry, such as analytical engineers whose necessity is now clear, and fields in which it is necessary to seek and systematically train technical human resources from a wide range of sectors other than the existing nuclear industry. It is expected for related institutions to utilize this map for developing and securing human resources in ways such as (1) to clearly grasp the overall picture of the technologies required for the decommissioning of the Fukushima Daiichi NPS; (2) to clearly understand the strength of their own personnel; (3) to prepare training programs; and (4) to plan recruiting strategy aiming wider areas not limited to the conventional nuclear industry. In addition, the 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 special personnel who are not only able to demonstrate expertise in their assigned area, but also have the ability to manage projects from a comprehensive perspective, including the consideration of relationship between the projects based on the overview of the entire decommissioning process. In the second test of the qualifying exam for Professional Engineers (PE) for the fields of nuclear power/radiation, from FY 2019, “Reactor Decommissioning (including handling after Severe Accident)” was added to the content of optional subject “reactor systems and facilities” and that “processing and disposal of fuel/radioactive waste after decommissioning and sever accidents of reactors” was added to the content of another optional subject “processing and disposal of nuclear fuel cycle and radioactive waste”. Accordingly, in the Government-led R&D program on Decommissioning and Contaminated Water Management, the main persons in charge are supposed to describe the status of their related qualifications for professional engineers when applying from the public offering conducted in March 2017. It is expected that companies will continue to make effort to expand the employees’ capabilities by encouraging them to acquire related qualifications such as PE, Chief Engineer of Reactors, or Radiation Protection Supervisor, etc.

The forecast of the number of workers expected to be required for the upcoming three years is shown in the Mid-and-Long-term Roadmap, however, as newer tasks will be implemented such as fuel debris retrieval required number of workers may change. Therefore, it is necessary to grasp the amount of required personnel of each field on a timeline basis by imaging a long-term prospect for the project of decommissioning of the Fukushima Daiichi NPS. According to this, the required number of personnel having sufficient skills should be steadily and systematically developed and recruited. Such long-term prospect is to be examined through the entire decommissioning plan described in Section 3.6.

4.3.2 Fostering the next generation to handle the decommissioning of the Fukushima Daiichi NPS

In order to continue decommissioning the Fukushima Daiichi NPS for a long period of time and to continue R&D activities for a long period of time, it is essential to train and secure future researchers and engineers. It is important for industrial-academic-governmental institutions as a whole related to nuclear power to steadily promote efforts for this purpose.

Specifically, 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 anywhere 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 fundamental importance. From this perspective as well, the Project for the Promotion of Nuclear Science, Technology and Human Resource Development (hereinafter referred to as “the World Intelligence Project”), which mobilizes the wisdom of the Ministry of Education, Culture, Sports, Science and Technology, was launched in FY 2015. In particular, from FY 2018, a common platform nuclear research program for young human resources such as universities has been implemented. The program sets up a young research quota for which members of the research group, including research representatives, are eligible if they are 39 years old or younger. In this program for enhancing the decommissioning research and human resource development that has been carried out since FY 2015, not only the courses related to decommissioning prepared under this program are counted in the units required for graduation, but also the program provides students with the opportunity to study decommissioning through their graduation research and to foresee future career paths. The “Conference for R&D Initiative on Nuclear Decommissioning Technology by the Next Generation (NDEC)”, intended for students, and the “Creative Robot Contest for Decommissioning”, intended for college students are held. Students exchange opinions with researchers and engineers involved in the Project of Decommissioning of the Fukushima Daiichi NPS, and those with excellent results receive awards at the events. In addition, for human resources retention and expansion through the entire industry, various initiatives such as “Nuclear Dojo” providing nuclear education programs in collaboration among 16 universities in Japan and “Nuclear Facilities Tour for College/High School Students towards Brighter Future” have been carried out. It is necessary to further promote and strengthen measures for securing human resources at universities, etc.

For the decommissioning of the Fukushima Daiichi NPS is difficult operation that has never been experienced, accordingly, knowledge in a variety of field is required. It is essential to cultivate human resource through R&D activities including wide range of areas not only nuclear field but mechanical, chemical, civil or material engineering, etc. Furthermore, in long-term and large-scale projects such as the decommissioning of the Fukushima Daiichi NPS, it is essential to develop core personnel for R&D who can perform scientific and engineering investigation 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 R&D themes described next in Chapter 5.

These activities for fostering next-generation decommissioning personnel should not be considered just as an effort to supply researchers and engineers. Approaching to a wider layer of people should be considered to enable the large cyclic rotation of personnel, from a long-term viewpoint. The previously described programs for developing decommissioning R&D personnel has brought in solid results, such as graduates joined the nuclear power industry engaged in decommissioning, while many students decided to study further at graduate schools, joined regulating authorities, and were admitted to local municipalities. It is expected that their experience in decommissioning as a student and a wide range of experience in society may provide a new perspective to the project of Decommissioning of the Fukushima Daiichi NPS and drives the project forward.

5. R&D initiatives

5.1 Basic policy for R&D

5.1.1 Basic policy

Decommissioning of the Fukushima Daiichi NPS is technically extremely difficult and involves many challenging issues never dealt with before. In order to implement various countermeasures steadily in accordance with the Mid-and-Long-term Roadmap, development of new technologies to solve such issues and of reliable technologies aiming at on-site application is indispensable. Therefore, R&D projects aiming at practical application, construction of research centers and facilities by JAEA, basic and generic research as well as applied research at researching institutions including universities have been conducted under the governmental subsidized or commissioned project and facility buildings of R&D center. At the same time, TEPCO has been working by itself.

NDF has determined the R&D duties implementation policy[48] based on the NDF Act. According to this policy, the NDF has been gathering expertise of R&D institutions and managing a variety of R&D projects, such as clarifying the inner reactor conditions, feasibility studies on fuel debris retrieval methods that support steady implementation of the Mid-and-Long-term Roadmap.

The phase of decommissioning work is shifting to a mid-and-long-term response, as seen in full-scale engineering for fuel debris retrieval, etc., and the R&D process will enter a new phase in the future. As detailed processes towards the decommissioning becomes clearer, the role of each R&D player should also be more clarified. Here, it is necessary to allocate the division of roles between the enterprise and the relevant researching institutions in an appropriate manner in order to implement R&D results on the decommissioning site steadily. To back up the implementation of the mid-and-long-term decommissioning project, it will be further expected that the government and the relevant researching institutions should establish centers of basic research/research infrastructure based on a mid-and-long-term perspective. At the same time, it is expected that with the progress of engineering, R&D tasks that are to be applied to the field will be identified, and TEPCO will be required to make efforts to put more weight on developing its own technology that is directly linked to be applied to the field to achieve decommissioning work.

For this challenge entering into an the pathless field, it is important to further enhance many approaches from different angles through the collective effort of Japan such as realizing effective R&D, cooperation between the related organizations including those overseas, utilization of research facilities, and human resources development.

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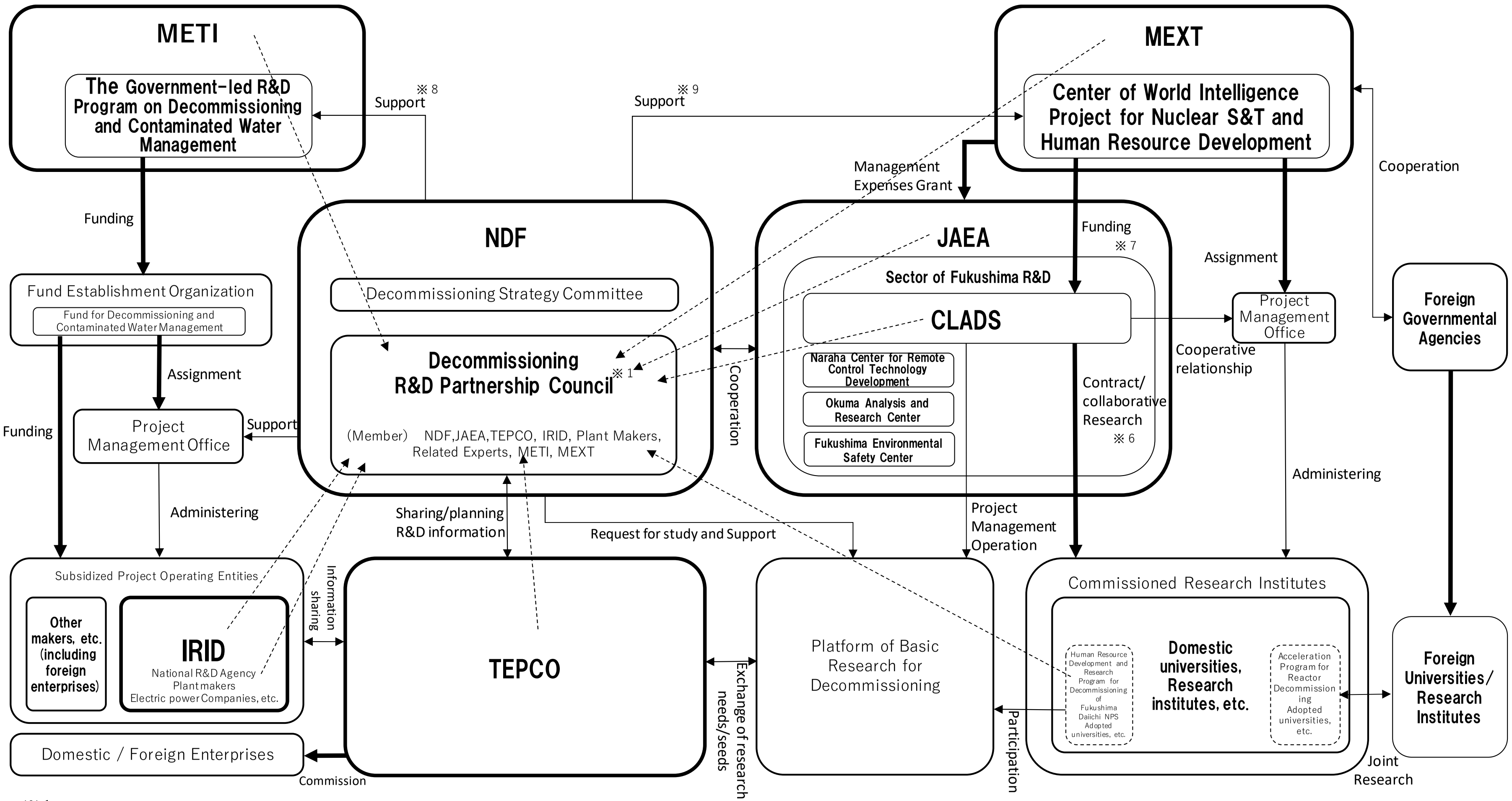
[48] Policy for conducting business related to research and development concerning the technology necessary to implement decommissioning, etc. (R&D duties implementation policy for technology such as decommissioning) http://www.dd.ndf.go.jp/jp/committee/policy/index.html

5.1.2 Entire perspective of R&D

Various issues involving difficult R&D elements exist in the decommissioning of the Fukushima Daiichi NPS. 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 projects through the areas of basic/fundamental research, applied research, and development/utilization (Fig. 26 and Fig.27). To organically link these activities and efficiently solve the on-site problems through the R&D, it is important to understand and share of the information of R&D activities conducted by the related organizations and to cooperate and coordinate between the decommissioning site and research site. Therefore, NDF holds meetings of the Decommissioning R&D Partnership Council according to the decisions of the Team for Countermeasures for decommissioning and contaminated water management. The members of the Council are NDF, JAEA, TEPCO, IRID, plant manufactures, the experts concerned and the ministries concerned. The main task of the Council is to tackle with the issues such as sharing information on R&D needs and seeds, coordinating R&D based on the needs of decommissioning work, and promoting cooperation in R&D and human resource development in matters of collaborating with related organizations, gathering international expertise and promoting it comprehensively and systematically. Moreover, NDF provides information about the activities performed by researching institutions, universities and business operators inside and outside the country through the web portal in order to enable centralized acquisition of R&D information on decommissioning. This is used by many people including access from overseas. Through these activities, NDF is working on overall optimization to promote the R&D activities of related organizations effectively and efficiently.



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

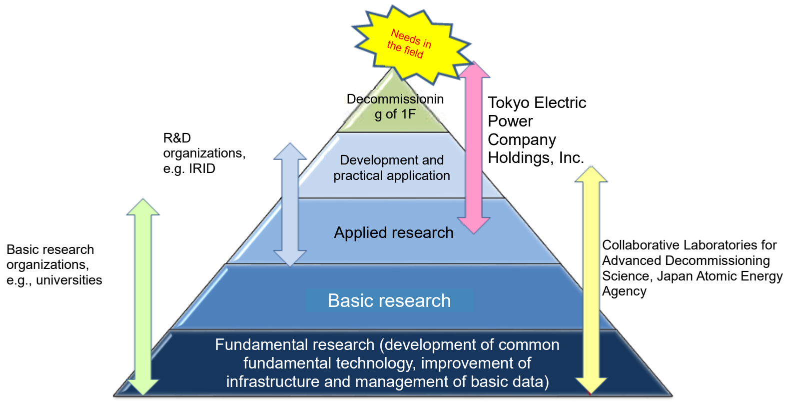


Fig.27 A conceptual picture of the division of roles among main R&D institutions for the decommissioning of the Fukushima Daiichi NPS

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

5.2.1 Promotion of effective R&D

There are two types of R&D activities towards their practical use for the accomplishment of 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 (Attachment 14).

In particular, aiming at the overall optimization of the entire decommissioning project as described in Section 3.6, project-based R&D management will be important. R&D tasks that are raised as necessary through the engineering considerations conducted by TEPCO should be shared with the NDF. An appropriate implementing institution takes over the implementation of such R&D tasks in a timely and accurate manner under the coordination of the NDF. Then, the result of the R&D will be accurately provided to the site in a timely manner. As mentioned in Section 1.1, the NDF was designated to oversee and supervise the project management of TEPCO under the Reserve Fund system, it is important to achieve effective R&D management through the system.

Specifically, according to the progress of the engineering work implemented by TEPCO, R&D tasks that are newly needed will be identified, and the timing to implement such R&D tasks will be determined through considerations of the project management. To operate an R&D management system on a project-basis like this in an effective manner, appropriate information sharing on the progresses of R&D implementation by TEPCO and engineering considerations and on the R&D tasks for which the necessity became clear should be carried out under the project management system enforced jointly by the NDF and TEPCO. To this end, it is necessary to marshal the R&D tasks currently in progress, and R&D tasks required in the future then to manage the project under the project management system, while clarifying in which project and until when the problem must be solved.

In this regard, even including implementing the tasks in the Government-led R&D program on

Decommissioning and Contaminated Water Management, implementation of R&D tasks should be considered in line with the basic concept of an appropriate division of roles between the government and TEPCO according to the substances of the tasks. Specifically, R&Ds that need supports by the government should target those with high technical difficulties that require the support of the government, and it would be appropriate that R&D with many engineering elements will be conducted by TEPCO.

Based on this concept, TEPCO is required to: (1) position necessary R&D tasks in the engineering schedule, including projects to be implemented in this 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 R&D.

5.2.2 Future approach to R&D

As a result of the R&D conducted through the Government-led R&D program on Decommissioning and Contaminated Water Management, definite results have been obtained, for instance, the internal condition of PCVs by have been gradually clarified by implementing elemental technology development and developing investigation equipment. As mentioned above, as the concrete process for full-scale decommissioning has become clearer, the R&D directly related to the on-site application of decommissioning to realize decommissioning work will be required in the future. For this purpose, it is essential for TEPCO, while performing actual work on the site, to 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, for the effective implementation of R&D that is directly linked to application in the field, TEPCO is required to put more weight on them, while establishing a system in which TEPCO will plan and manage R&D by itself. As mentioned above, regarding R&D activities, including fundamental ones, which require an approach on a mid-and-long-term basis and thus, are difficult for TEPCO to implement, the governmental support should be provided.

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

For decommissioning of the Fukushima Daiichi NPS, which is a large-scale project involving opacity and uncertainty, predicting what would be the critical technical challenges in the future is a very difficult task. Based on the available information at the moment, precedents and experts' knowledge and experience, R&D tasks which might become critical in the future should be extracted. At the same time, the infrastructures of personnel, organization and facilities should be maintained and expanded on a long-term basis so that forthcoming cross-sectional technological challenges can be managed. These are the major elements to secure smooth execution of the project.

5.3.1 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 the decommissioning sites are facing.

In addition, facilitate the decommissioning project of the Fukushima Daiichi NPS in a safely steady and effective manner, it is essential to develop mid-and-long-term R&D strategies including scientific and technological investigation based on understandings of the principles and 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. Moreover, the Platform of Basic Research for Decommissioning[49] was investigated and R&D strategies for the Themes, based on which the R&D to be executed immediately was initiated in FY2017.

Furthermore, on the occasion of transition of the World Intelligence Project into a subsidy program described in the following sub-section, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) showed NDF their intention to discuss how to proceed with the future R&D of the World Intelligence Project. This included selection of the theme for the call for proposal considering the Essential R&D Themes from the perspective of propulsion of basic and generic research based thoroughly on necessity. Therefore, the NDF has compiled its basic direction for the future to carry out six important R&D tasks, including the background of the issues, awareness of the problems by the consumer-side and the image of the research assumed, and presented it to the Ministry of Education (Attachment 15). This basic direction has been utilized for the public offering of the World Intelligence Project that was started by JAEA in FY 2018.

5.3.2 Construction of basic research center and R&D infrastructure for mid-and-long-term prospects

In order to make the long-term decommissioning project of the Fukushima Daiichi NPS proceed steadier in technical aspects, 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 described in the preceding sub-section, building up research centers, facilities and equipment, and human resource development. Decommissioning of the Fukushima Daiichi NPS is an opportunity for trial of state-of-art science and technology and such the accumulation of such activity is expected to become a source of innovation.

The building for International Research Collaboration of the Collaborative Laboratories for

[49] Promotion council of basic and generic research jointly managed by JAEA/CLADS and MEXT the Center of the World Intelligence Project: Decommissioning Research and Human Resource Development Promotion Program selection agency. See https://fukushima.jaea.go.jp/initiatives/cat05/haishi05.html.

Advanced Decommissioning Science of JAEA (JAEA/CLADS) has opened in April 2017 in Tomioka-machi, Fukushima prefecture as a location for universities, research institutes and industries inside and outside the country to create a network to integrally promote R&D and human resources development. TEPCO and some universities have moved into the building to undertake research and so on. It is expected that, in the future, interaction between various talents in universities, research institutes, industries inside and outside the country will make JAEA/CLADS a central organization acting as a hub of such activities. Following this idea, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) reformed the Center of World Intelligence Project for Nuclear S&T and Human Resource Development into a subsidy project intended for JAEA according to a proposition by NDF. The project is currently implemented by the system centered on JAEA/CLADS from the newly adopted tasks in FY2018. Moreover, "Program for Decommissioning Research by Human Resource Development" was newly established in the Center of World Intelligence Project in 2019. It created a basis of research and human resource development (Collaboration laboratory)[50] in both of educational research institutions and JAEA/CLADS, and has started R&D and human resource development project that connects these organizations by cross-appoint system. It contributes to functional enhancement of JAEA/CLADS.

It is also important to develop research infrastructure of hardware. JAEA put the Naraha Remote Technology Development Center in full service in April 2016 in Naraha-machi, Fukushima Prefecture. It is a facility with a variety of equipment for development and experiment of remotely controlled devices and installations. Specifically, prior to sending the devices into the harsh environment inaccessible for people, testing in a real-scale mock-up is indispensable for performance verification as well as for training and establishment of the operating procedure. It is desirable that the enterprises and so on utilize the mock-up actively. In order to proceed with smooth decommissioning of Fukushima Daiichi NPS, it has become even more important to effectively use this facility, e.g. mock-up test with arm-typed accessing equipment for fuel debris retrieval is scheduled.

Moreover, 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, serving as a comprehensive center of collaboration of the three agencies. In addition, 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. For the 1st building, where low radiation dose samples such as rubble will be handled mainly, the frame construction of the third floor is being carried out. For the 2nd building, where high radiation dose samples such as fuel debris will be handled, detailed design is being carried out.

As seen above, R&D infrastructures related to decommissioning, contaminated water management and environmental decontamination measures are being set up mainly in Fukushima

[50] JAEA can use the bases in Tokai and Oarai as well as the base in Fukushima,

Prefecture. These research facilities are formulating a global center of decommissioning R&D aiming at the mid-and-long-term vision.

6. Enhancement of international cooperation

6.1 Significance of international cooperation

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

In order to make steady progress on the decommissioning of the Fukushima Daiichi NPS, that deals with the advanced engineering issues, as a risk reduction strategy, it is important to learn from the measures taken for the preceeding damaged reactors and from the lessons acquired through decommissioning activities of the legacy sites, and to apply them to the actual decommissioning, while utilizing excellent technologies and human resources that each county have fostered. In addition, to maintain and develop understanding, interests and relationship from international communities on decommissioning, it is also important to give the knowledge gained from the accident and decommissioning of Fukushima Daiichi NPS proactively and strategically back through international joint activities related to decommissioning; then to engage in mutually beneficial decommissioning open to international societies.

Moreover, the decommissioning of the Fukushima Daiichi NPS is a process to solve unexplored engineering issues combining various fields of knowledge not limited to nuclear field. It can be interpreted as which the decommissioning of Fukushima Daiichi NPS may be an influential ground to create innovation. Assembling diverse wisdom and experiences to Fukushima from all over the world is primary an important effort to steadily proceed with decommissioning itself of Fukushima Daiichi NPS. It is also an important effort from the perspective of that innovation to be created through the decommissioning process leads to the reconstruction of the local industries and to establish the local community engagement that is essential to continue decommissioning over a long period of time.

In moving international cooperation forward specifically, it is also important to utilize multilateral cooperation framework through the international institutions such as IAEA, Organization for Economic Co-operation and Development/Nuclear Energy Agency (hereinafter referred to as the “OECD/NEA”), as well as to promote bilateral cooperation according to the circumstances of each country. These international institutions have roles of contribution for designing the international standard, sharing the knowledge and experiences among nations, and forming international common understanding concerning decommissioning. To proceed with the decommissioning of the Fukushima Daiichi NPS in an internationally open manner, it is crucial for Japan to participate in the activities of these institutions. At the same time, it is also expected to fulfill a part of responsibility to the international society through sharing the Fukushima experience with memberships of the institutions through participating in the discussion for designing the international standard.

6.2 Facilitation of international cooperation activities

6.2.1 Enhancement of partnership with overseas decommissioning agencies

Because the decommissioning of the Fukushima Daiichi NPS continues over a long time period, it is required to establish the definitive basis of international cooperation, as well as to build long-term and continuous partnership with overseas decommissioning agencies.

Especially, the decommissioning of legacy sites would serve, as a model for approach preceding to the Fukushima Daiichi NPS decommissioning, in many knowledge in accordance with technology and management. Each country has established its own public decommissioning organization to promote decommissioning of legacy sites because the decommissioning requires the expertise, concept, and new technologies which are different from the operation/maintenance for nuclear reactor and nuclear fuel cycle facility. Therefore, it is important for NDF to build 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) that deliver decommissioning of legacy sites in each country under government-level framework. TEPCO should also establish and reinforce a long-term partnership with overseas decommissioning operators, and these should be broad cooperation-based.

On that ground, NDF has concluded memorandums of cooperation with the NDA and the CEA, while TEPCO has concluded agreements with Sellafield Ltd. in the U.K. and so on, to construct a framework of constant exchange of opinions as shown in table 4. In the future, it is also important to learn technologies and lessons from various countries to utilize it for the decommissioning of the Fukushima Daiichi NPS, in using these framework. Moreover, with a view to reinforcing the partnership, it is also important for our country to share the technology and experience derived from the decommissioning of the Fukushima Daiichi NPS to develop an interactive cooperative relationship.

6.2.2 Integrating and utilizing wisdom in the world

In regard with the decommissioning of the Fukushima Daiichi NPS, Japan should gather and learn the wisdom in the world on a variety of approaches not only in technical aspect, but also operational aspect such as system/policy, providing strategy, project plan/operation, securing safety, regional communications, and so on. On the other hand, there are opportunities to support the decommissioning of the Fukushima Daiichi NPS by international society, and Japan has received several kinds of supports by overseas governmental institutions and experts including DAROD project led by IAEA and collaboration projects promoted by OECD/NEA.

In the technical aspect on the decommissioning of the Fukushima Daiichi NPS, while learning the use situation of technologies in the decommissioning of legacy sites among other things in each country, many suggestions from joint research by governmental projects and universities have been obtained. For example, referring also to the information that fuel debris in Chernobyl has been pulverized due to aging, the “To identify process of characteristic changes in fuel debris over time” has been extracted as the Essential R&D Themes, which should be addressed strategically and preferentially, and its R&D project has proceeded. In addition, an international tendering system was applied to the Government-led R&D Program on Decommissioning and Contaminated Water Management of the Ministry of Economy, Trade and Industry (METI) and foreign companies are participating in the project as subsidized operators. Moreover, as with the World Intelligence Project by MEXT, international joint research are implemented as well with the cooperation of overseas organizations in the U.K., the U.S.A. and universities in Japan. In addition, our country independently participates in the international joint research PreADES, “Preparatory study on Analysis of fuel DEbriS”, project led by the OECD/NEA from the viewpoint of characterizing fuel debris and so forth. As described in Chapter 5, the country and the operator must divide the roles appropriately to proceed steadily with on-site application of the R&D results and, for this purpose, it is also important to refer to the principles of the R&D system for decommissioning overseas.

In the management aspect, as for system and policy, information exchange with various countries by means of intergovernmental meetings, commissioned research on the system structure to overseas organizations has been conducted as shown in Table 4. Specifically, we learned from opinion exchanges with the NDA, case studies, and the efforts of overseas engineering firms. To give a practical use example, the project management techniques was introduced into the actual formulation of strategies and planning/management of projects. Moreover, as for securing safety, we have been studied the information on international regulations obtained through activities in international organizations and the regulatory activities related to the overseas reactors suffered from accidents and the legacy sites. We will have used them as a reference to formulate the institution for decommissioning in our country and the idea of ensuring safety described in Sub-section 2.3.3.4.

Japan has to keep on proceeding with the decommissioning of the Fukushima Daiichi NPS while gathering and utilizing global knowhow from both of technological and management aspects. For this purpose, while encouraging participation in the activities of international organizations and intergovernmental meetings and promoting international joint research, experts from overseas are to be invited to receive advice and evaluations and gather knowhow and experience with regard to decommissioning and so on overseas. As for gathering wisdoms on basic and fundamental R&D, it should collect and interact with a variety of ideas and human resources, and it is necessary to improve its environment and fields appropriately. ,As described in Chapter 5, JAEA/CLADS is one of the important base to provide such environment and fields, it is essential to reinforce the function to integrate the wisdom from in and out of Japan more in regard to further decommissioning. Moreover, regardless of whether it is inside or outside the country, decommissioning is implemented under a contract between many companies and the decommissioning operator for which the global market is widely expanding. Under the circumstance that decommissioning is being conducted across by many companies across countries, it is crucial to understand the latest status for effectively utilizing excellent technologies and human resources of the world.

Table 4 Cooperative relationship among the institutions for the decommissioning of the Fukushima Daiichi

Intergovernmental Framework between Japan and other countries		
Framework		**Descriptions**
Annual Japan-UK Nuclear Dialogue		This dialogue is held based on the appendix to the joint statement of the Japan-UK top level meeting in April 2012, "Japan-UK Framework on Civil Nuclear Energy Cooperation" (Since February 2012).
Japan-France Nuclear Energy Committee		It was established under the joint statement of Japan–France top-level meeting in October 2012 (Since February 2012).
Japan-US Decommissioning and Environmental Management Working Group		After the Fukushima Daiichi NPS accident in March 2011, the establishment of the US-Japan Bilateral Commission on Civil Nuclear Cooperation (the Bilateral Commission) was announced in April 2012 based on the relationship between Japan and the US to further reinforce bilateral cooperation. Under this commission, "the Decommissioning and Environmental Management Working Group (DEMWG)" was established (Since December 2012).
Japan-Russia Nuclear Working Group		The Nuclear Working Group was established after confirming that Energy is one of the eight areas of cooperation plan approved at the Japan-Russia top-level meeting in September 2016, (Since September 2016).
Inter-organizational Cooperation Agreement		
Domestic	**International**	**Descriptions**
NDF	NDA	Exchange of information for various technical knowledge on decommissioning, etc. and personal exchange are provided. (Concluded in February 2015)
NDF	CEA	Exchange of information for various technical knowledge on decommissioning, etc. and personal exchange is provided. (Concluded in February 2015)
TEPCO	DOE	Umbrella Contract was made and information is exchanged as needed. (Concluded in September 2013)
TEPCO	Sellafield, Ltd.	Information Exchange Agreement for site's operation, etc. was concluded. (September 2014)

TEPCO	CEA	Information Exchange Agreement on for decommissioning was concluded. (September 2015)
JAEA	NNL	Comprehensive Agreement for advanced technology on nuclear R&D, advanced fuel cycles, fast reactor, radioactive waste
JAEA	CEA	Cooperation Agreement for specific technical issues on molten core-concrete interaction, etc.
JAEA	Belgium Nuclear Research Center	Agreement of Cooperation for Nuclear R&D and Research on the accident of the Fukushima Daiichi
JAEA	Nuclear Safety Research Center (Ukraine)	Memorandum for decommissioning research, etc. of the Fukushima Daiichi NPS and Chernobyl was concluded.
JAEA	IAEA	Research Agreement on characterization of fuel debris

6.2.3 Dissemination of information to the global society

As Japan's responsibility to the international global society for having caused the accident at the Fukushima Daiichi NPS, also from the viewpoints of keeping concerns of human resource who will be able to lead decommissioning from the world and contributing to gather wisdom and knowledge, it is important to proceed with the decommissioning in a manner open to the international community. It is needed to prevent reputational damage as described in Section 7.3; therefore, the dissemination of clear information should be strengthened to formulate a precise understanding in the international community.

Accordingly, NDF takes dissemination of information about the situation of the Fukushima Daiichi NPS decommissioning globally through holding side events of the IAEA General Conference, by taking the platform at major international conferences such as OECD/NEA Steering Committee, Nuclear Safety Regulatory Information Conference (RIC) sponsored by the U.S. Nuclear Regulatory Commission's (NRC's) and Decommissioning Forum in France, and through presentations at intergovernmental meetings. Moreover, in order to clearly report the situation of the decommissioning of the Fukushima Daiichi NPS to the world, and to work on dialogue for symbiosis with the local community, NDF has held the "International Forum on the Decommissioning of the Fukushima Daiichi NPS" every year since 2016. This Forum is a trial for global dissemination of the way to communicate about decommissioning through dialogue with the local residents, which is evaluated as an important event internationally.

Furthermore, it is also important to make the latest information on the decommissioning of the Fukushima Daiichi NPS available throughout the world through publicity in foreign languages, English websites, mailing lists and other means; therefore, this efforts must be continued to provide clear information utilizing videos and so on. (Refer to Table 5, Approach for dissemination of information to the world)

6.2.4 Participation in international cooperative activities

Eight years have passed since the Fukuoka Daiichi NPS accident, there have been moves outside Japan, which are to scientifically verify and analyze this accident and the decommissioning process and to apply the knowledge gained from the result to other issues. Decommissioning as a risk reducing strategy is top priority issue for our country, it is also important to keep concerns of Fukushima Daiichi NPS high from the viewpoint of gathering wisdom and knowledge from the world in order to proceed with decommissioning. For this reason, it is essential to promote international joint research, and it is also necessary to pursue in a beneficial manner to each side, not only to pay attention to Japan's needs but overseas demand that is newly generated. It is important to bring the wisdom and knowledge gained through decommissioning as a result of these efforts back to overseas cooperation organizations properly.

Therefore, keeping in mind that Japan actively responds to these new concerns from the world, our country has launched projects including PreADES/TCOFF and taken the initiative in discussing positively, as well as joined the studies at SEREF, which was established by OECD/NEA with the accident of Fukushima Daiichi as the starting point. NDF proactively participates in international joint activities such as "Committee on Decommissioning of Nuclear Installations and Legacy Management" (CDLM, established in April 2018), that is a committee to exchange opinions on decommissioning organized in OECD/NEA, "Expert Group on Characterisation Methodology of Unconventional and Legacy Waste" (EGCUL, established in November 2018) to study characterization methodology of large amounts of waste generated from accident site under "Radioactive Waste Management Committee" (RWMC), and "Improved Nuclear Site characterisation for waste minimisation in Decommissioning and Dismantling operations under constraint EnviRonment" (INSIDER, established in June 2017), that is an R&D project of EU with the aims of improving waste management cost reduction and efficiency through the analysis of the actual cases. Then, NDF provides information about the accident of Fukushima Daiichi NPS, and it should be continued in the future in cooperation with the related organizations.

6.3 Close cooperation with relevant domestic organizations

As described in Sub-section 6.2.1, the related domestic organizations are proceeding with efforts to construct and strengthen partnerships with overseas related organizations in accordance with respective roles. On the other hand, with regard to decommissioning R&D, as shown in Fig 28, cooperation such as joint research between research institutes and universities is in progress. Since sharing knowhow and personal relationships obtained through these activities is important for our country also in the context of ensuring consistency with international cooperative activities and realizing effective international cooperation, cooperation between related domestic organizations must be promoted to be tighter than ever.

Table 5 Approach for dissemination of information to the world

Holding or attending International Conference (from April 2018 to August 2019)		
Conference Name	Period	Organization
TOTAL-DECOM Forum (UK)	April, 2018	NDF
INSIDER Project Meeting	June, 2018	NDF
The 3rd International Forum on the Decommissioning of the Fukushima Daiichi NPS	August, 2018	NDF
The 62nd IAEA Conference Side event	September, 2018	NDF, METI
Nuclear Decommissioning Forum 2018 (France)	October, 2018	NDF
Workshop on development of containing, transferring and storing technologies for fuel debris	December, 2018	NDF
The 1st G7 Nuclear Safety Security group (NSSG)	February, 2019	METI
UKAEA Workshop on Remote Technology (UK)	February, 2019	NDF
The 3rd UK-Japan Nuclear Industrial Forum	February, 2019	NDF, METI
Waste Management (WM) Symposium 2019 (US)	March, 2019	NDF
NRC Regulatory Information Conference (RIC) 2019	March, 2019	NDF
OECD/NEA Symposium on Decommissioning and Food Safety of Fukushima Daiichi NPS	March, 2019	METI, MAFF
International Meeting on Fukushima Decommissioning Research 2019 (FDR2019)	May, 2019	METI
WTO/SPS Committee, Briefing for EU countries	July, 2019	METI
The 4th International Forum on the Decommissioning of the Fukushima Daiichi NPS	August, 2019	NDF
Fukushima Research Conference	Year round	JAEA
Dissemination of information on web (in English)		
Site		Organization
Mid-and-long-term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1 to 4 （http://www.meti.go.jp/english/earthquake/nuclear/decommissioning/）		METI
Monthly report to the embassies concerning discharging and seawater monitoring from the Fukushima Daiichi NPS		METI, MOFA
Nuclear Damage Compensation and Decommissioning Facilitation Corporation's website （http://www.dd.ndf.go.jp/eindex.html）		NDF
Information Portal for the Research and Development for the Fukushima Daiichi Decommissioning (http://www.drd-portal.jp/en/)		NDF
Activities for Decommissioning（https://fukushima.jaea.go.jp/english/）		JAEA
IRID website (http://irid.or.jp/en/)		IRID
Fukushima Daiichi Decommissioning Project （http://www7.tepco.co.jp/responsibility/decommissioning/index-e.html）		TEPCO
Providing English version of Press release to foreign media		TEPCO
TEPCO CUUSOO（https://tepco.cuusoo.com/）		TEPCO
Management Office for the Government-led R&D program on Decommissioning and Contaminated Water Management(https://en.dccc-program.jp/)		MRI

7. Local community engagement

7.1 Approaches for local community engagement

In order to steadily implement decommissioning of the Fukushima Daiichi NPS that spans long periods of time, decommissioning that moves forward together with the local restoration must be aimed under the recognition that “Decommissioning and the reconstruction of Fukushima are 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 the 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-existed 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.

7.2 Actual effort for better Communication

As decommissioning operation, including fuel debris retrieval, proceeds, it is necessary to put into practice information providing or interactive communication in a further well thought-out manner, with proper cooperation between the related organizations such as the government, NDF and TEPCO referring to the various overseas experiences.

The government will work on careful communication by providing information to and strengthening communication with various people including local residents, by holding “The Fukushima Advisory Board” as an occasion to discuss public relations, by dissemination of information through videos and website that summarize the decommissioning approach and the brochure “Important Stories on Decommissioning” as well as by active explanations to and conversations with local residents and officials of related municipalities.

NDF holds the “International Forum on the Decommissioning of the Fukushima Daiichi NPS”, that focuses on interactive communication with the local residents every year, provides clear information on the decommissioning, and exchanges honest opinions with the participants, while sharing the latest progress and the technical results of the decommissioning efforts among both Japanese and foreign experts. Besides, NDF makes efforts to have attentions and interests in decommissioning by holding workshops and sessions targeted at future generations who are to face decommissioning. In addition, the brochure “Hairo no Iroha (ABCs of decommissioning)” has been prepared to disseminate accurate and clear information on the decommissioning in a simple way. Also in the future, it has been decided to continue interactive conversational activities more vigorously to seek establishment of trustful relations with the local residents.

TEPCO is continuously working on explanations and conversations through management and the risk communicators and on the explanations to and conversations with the local representatives regarding the progress of the Mid-and-Long-term Roadmap at the "The Fukushima Advisory Board" hosted by government and "Prefectural Safety Assurance Conference for the Decommissioning of the Fukushima Nuclear Power Station" sponsored by Fukushima Prefecture and so on.

Moreover, the Decommissioning Communication Center was established in November 2017, to build a trusting relationship with the regions. The center integrates management between decommissioning section and communication section facing the regions and the community under the chief executive of decommissioning.

While strengthening the structure, TEPCO seeks dissemination of clear information through PR tools such as regular press conference on nuclear, scheduled lectures to Fukushima Prefectural Government Press Club, information dissemination on decommissioning status in the conferences that TEPCO participates in at right time and accurately, disclosure on website, and magazine on decommissioning "Hairo Michi" (the way to decommissioning). In particular, the website, "Fukushima Daiichi Decommissioning Project" has been completely updated in August 2018, to make it easy to obtain desired information from the standpoint of viewers.

Upon formulating a common understanding of decommissioning, it is very effective to have people observe the real state of progress of the decommissioning task on the site. TEPCO has been proactively accepting visitors to the Fukushima Daiichi NPS, including evacuees, and 18,886 visitors were accepted in FY2018. In the future, setting the acceptance level at 20,000 visitors per year in FY2020 as a target, a further increase of the acceptance level will be attempted.

In November 2018, "TEPCO Decommissioning Archive Center" has opened as a place where enables visitors to know the fact of the nuclear accident and the progress of decommissioning operation, it drew about 21,000 visitors as of the end of May, 2019. While coordinating with the relevant facilities and surrounding regions, it is important to continue to enhance the contents and to disseminate clear information in maintaining its endeavor and to gather wisdom and knowledge from around the world by making use of these facilities.

7.3 Measures against reputational damages

Reputational damage can be caused only with the presence of anxiety even if the risk is not actualized. Moreover, it is pointed out that, even though eight years have passed since the accident, the image immediately after the accident still remains without being erased and has an influence. The delay in responding to the reputational damage, occurrence of troubles in decommissioning operations, radiation exposure of operators and the cost increase may damage the social evaluation of the decommissioning effort, which might lead to a vicious circle of further delays in decommissioning activities. In order to avoid a vicious cycle like this, it is important to promptly reduce existing risks as top priority while proceeding with decommissioning approach in a safe and steady manner. Besides, it is crucial to establish trustful relationship by communicating regularly with local residents, as disseminating information on decommissioning should be made at the right time and accurately.

In order to prevent reputational damage, the government held “Task Force on the Nuclear Hazard’s Influence Including the Negative Reputation Impact”, as it requires to expand communications with wider range of people. The concerned government agencies are working on it in an integrated manner, based on the three enhanced guidelines which are “Eliminate source of negative reputation”, “Prevent negative reputation by providing accurate and clear information” and “Support damaged industries due to negative reputation”. In December 2017, the government formulated the “Strategies to Eliminate Negative Reputation and to Strengthen Risk Communication”, and has made efforts against eliminating negative reputation.

TEPCO formulated “Action Plan to Combat Reputational Damage” in January 2018, and has made efforts to promote distribution of prefectural products of Fukushima and to provide accurate information concerning their safety.

In accordance with these, it is important for the concerned organizations to continue their concerted efforts.

7.4 Decommissioning moves forward together with the recovery of the community

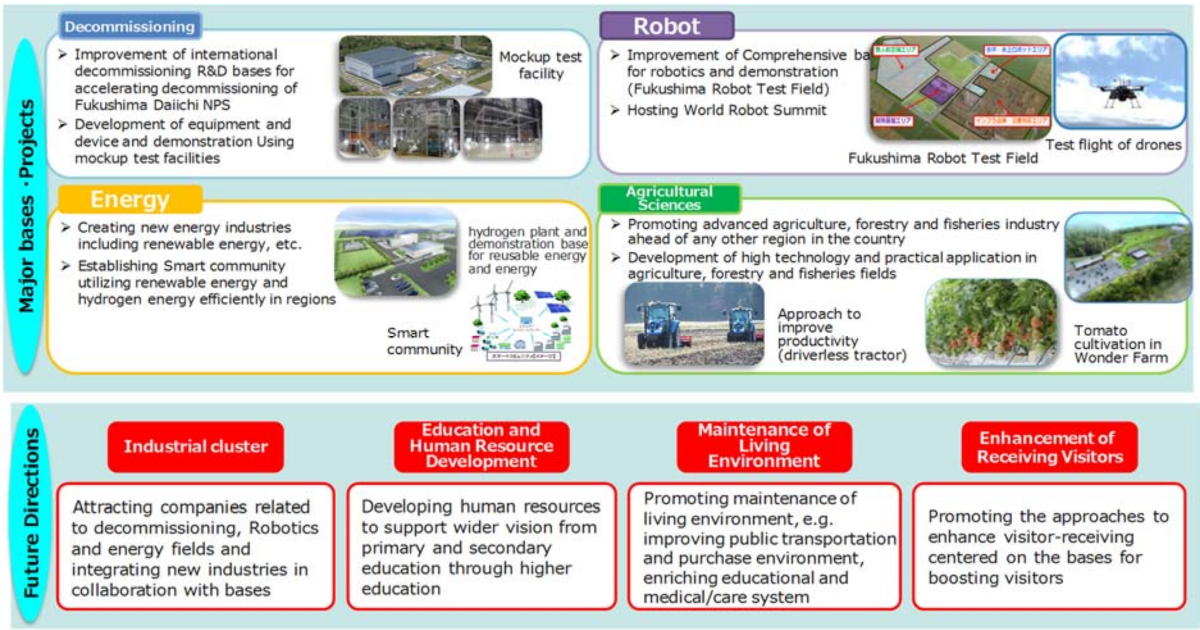
Under the recognition of “Decommissioning and the reconstruction of Fukushima as an indispensable pair”, it is important to work for developing human resources that will engage decommissioning in the region and for integrating its relevant industries, to recover the industry in Hamadori region of Fukushima prefecture where was lost by The Great East Japan Earthquake and nuclear disaster, in conjunction with “Fukushima Innovation Coast Framework (Fig. 28)” as a national project aimed to establish new industrial infrastructure.

For proceeding with decommissioning along with the local reconstruction, it is important 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 necessary to achieve not only safe and steady decommissioning but giving priority to the local product and services, based on the need to safely proceed with decommissioning as early as possible. In Fukushima Daiichi NPS, managing cafeteria and shops of the new office building and maintaining infrastructure including electricity and air conditioning facility on site are conducted with the cooperation of the local companies. In the aspect of employment, sixty percent of workers, including TEPCO employees and partner company operators, etc., are the local human resources. There are some examples of utilizing technical capabilities of local companies for decommissioning work, include cases where a company with local offices is involved in the development of full-face masks that improve safety of workers, and where a local company with high engineering capabilities on remote operations plays an active role in dismantling of the exhaust stack in cooperation with TEPCO. These technical capabilities of local companies play a part of the decommissioning work.

In the future, attracting business operators and projects associated with decommissioning, and procuring from enterprises within Fukushima prefecture will be promoted actively, it is expected to contribute to the reconstruction of the region as well, while supporting the local companies, in cooperation with Fukushima SoSo (Soma and Futaba regions) Reconstruction Promotion Agency which has a strong network and Fukushima Innovation Coast Framework which supports decommissioning-related industries by matching their needs with seeds.

In order to achieve decommissioning that moves forward together with the recovery of the community, it is strongly expected that TEPCO addresses various issues by working together between Fukushima Daiichi Decontamination and Decommissioning Engineering Company and the Fukushima Revitalization Headquarter in TEPCO, and coordinates with the government, NDF and the relevant organizations of the local government.

Furthermore, promotion of safe and steady decommissioning requires appropriateness on quality and price for goods and services to be procured, its environment should be improved which enables many of the local companies to participate in decommissioning work from the long-term perspective through use of resources and know-hows obtained by the relevant organizations and technological and business supports.



(Material provided by METI)

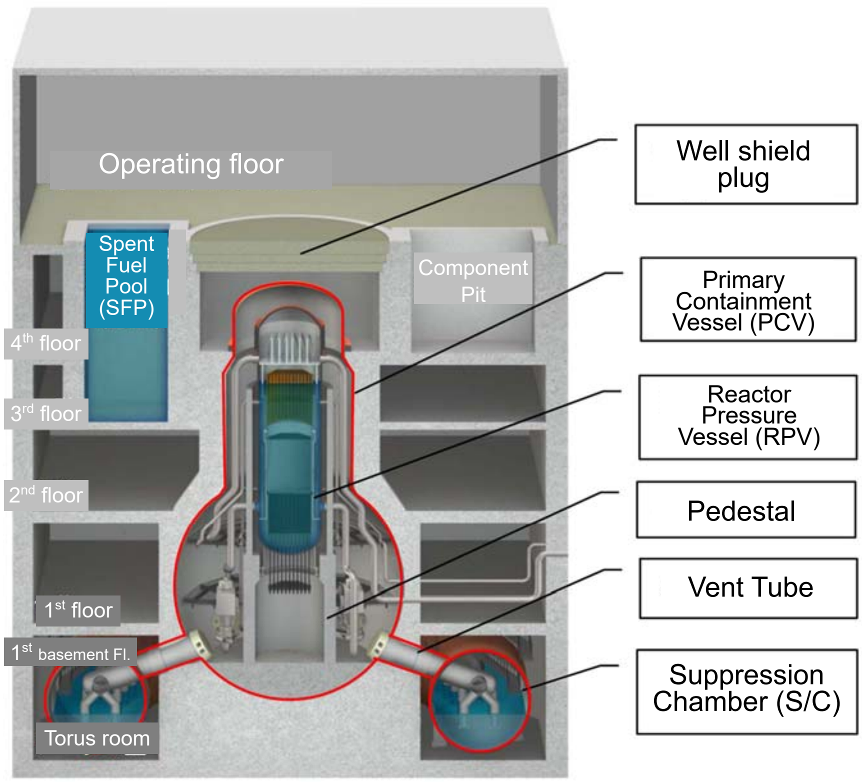
Fig. 28 Overview of Fukushima Innovation Coast Framework

List of Acronyms/Glossaries

Acronym	Official Name
CEA	Commissariat à l'énergie atomique et aux énergies alternatives
D/W	Dry Well
DOE	United States Department of Energy
FP	Fission Products
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IRID	International Research Institute for Nuclear Decommissioning
JAEA	Japan Atomic Energy Agency
JAEA/CLADS	JAEA Collaborative Laboratories for Advanced Decommissioning Science
MCCI	Molten Core Concrete Interaction
NDA	Nuclear Decommissioning Authority
NDF	Nuclear Damage Compensation and Decommissioning Facilitation Corporation
NRC	Nuclear Regulatory Commission
OECD/NEA	OECD Nuclear Energy Agency
PCV	Primary Containment Vessel
RPV	Reactor Pressure Vessel
S/C	Suppression Chamber
SED	Safety and Environmental Detriment
TMI-2	Three Mile Island Nuclear Power Plant Unit 2
VR	Virtual Reality
X-6 penetration	PCV X-6 penetration
Center of the World Intelligence project	The project that promotes nuclear science and technology and human resource development gathering wisdom and knowledge
Operating Floor	Operating Floor of the buildings
Submersible ROV	A remotely operated submersible survey vehicle (Remotely Operated Vehicle)
Strategic Plan	Technical Strategic Plan for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.
Matters to be addressed	As a specific nuclear facility, “the matters for which measures should be taken” that The Fukushima Daiichi NPS must have the necessary safety measures in place that are required by the NRA.
Mid-and-Long-term Roadmap	Government-developed “Mid-and-long-term Roadmap” toward the decommissioning of TEPCO’s Fukushima Daiichi Nuclear Power Station Units 1 to 4
TEPCO	Tokyo Electric Company Holdings, Inc.

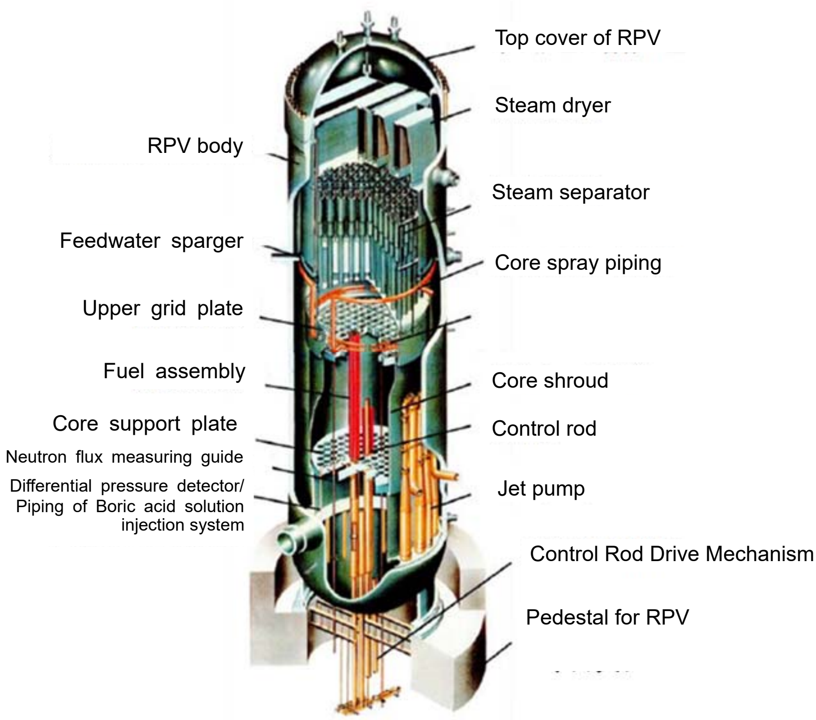
Withdrawal Plan	Withdrawal plan for reserve fund
The Policy of Preparation of Withdrawal Plan	The Policy of preparation of withdrawal plan for reserve fund for decommissioning
Fukushima Daiichi NPS	Fukushima Daiichi Nuclear Power Station of Tokyo Electric Company Holdings, Inc.

Glossary	Description
CRD housing	Housing that contains Control Rod Drive mechanism
MCCI Product	A product generated by high temperature molten core and concrete interaction (MCCI)
T.P.	A height from the average surface of the bay of Tokyo (Tokyo Peil) as a standard of elevation. (cf. O.P: Onahama Port construction level (the lowest position of the water surface)
Well plug	A top cover to screen upper part of Primary Containment Vessel made of concrete (It is the floor face of the top floor of reactor building in operation)
Basis seismic ground motion	A magnitude of shake associated with earthquake that may affect greatly to nuclear facilities. Based on the latest scientific and engineering knowledge, it is provided in accordance with the geological structure or ground structure, etc.
Submersion method	A method to retrieve fuel debris by submerging all fuel debris in watering up to upper part of Primary Containment Vessel
Partial submersion method	A method to retrieve fuel debris in a state that a part of fuel debris is exposed in the air without watering
Grating	A lattice-type scaffolding used for side ditch lid or work scaffold
Sludge	Muddy substance, dirty mud
Slurry	A mix of dirty mud and mineral, etc. in water
Fuel debris	Nuclear fuel material molten and mixed with a part of structure inside reactor and re-solidified due to loss of reactor coolant accident condition
Platform	Footing for work installed under RPV inside pedestal
Pedestal	A cylindrical basement that supports a body of reactor
Measurement by muon (fuel debris detection technology with muon)	A technology to grasp location or shape of fuel in using characteristics by change of number or track of particle depending on the difference of density, when muons (muonic atoms) arrive from the cosmos and atmospheric air and pass through a substance
Mock-up debris	An artificial fuel debris, its chemical composition and chemical form were estimated based on the case of Unit 2 of Three mile Island Nuclear Power Plant accident
Mock-up	A model which is designed and created as close to real thing to possible
Preliminary engineering	Engineering operation to determine the feasibility of engineering work preliminary in advance of basic design that is conducted at the beginning of general construction



Courtesy of IRID

Fig. 29 Structural drawing inside Reactor building



Courtesy of IRID

Fig. 30 Structural drawing inside Reactor Pressure Vessel (RPV)

List of Attachment

Attachment 1 Revision of the Mid-and-Long-term Roadmap and the earlier published strategic plan

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

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

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

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

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

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

[Strategic Plan 2015 (April 30, 2015)]

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

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

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

[Strategic Plan 2016 (July 13, 2016)]

- In response to the progress state of decommissioning after publication of the Strategic Plan 2015, concrete concepts and methods were developed based on the concept and direction of the efforts of the Strategic Plan 2015 to achieve the target schedule specified in “Policy decision on fuel debris retrieval for each unit” which is expected to be completed by about summer 2017 defined in the Mid-and-Long-term Roadmap, “Compiling of the basic concept concerning treatment and disposal of radioactive waste” which is expected to be complete in FY2017, etc.

[Strategic Plan 2017 (August 31, 2017)]

- Feasibility study was conducted on the three priority methods for fuel debris retrieval. Recommendations for determining fuel debris retrieval policy were made and efforts after policy decision including preliminary engineering were recommended as strategic recommendations.
- Recommendations were made for compiling the basic concept concerning solid waste processing/disposal.

[Mid-and-Long-term Roadmap Revised 4th Edition (September 26, 2017)]

- Policy on fuel debris retrieval and immediate efforts were decided based on NDF technical recommendations.
- Basic concepts concerning solid waste treatment and disposal were compiled.
- Individual work was defined based on the viewpoint of “Optimization of total decommissioning work”.

[Strategic Plan 2018 (October 2, 2018)]

- The Plan added contaminated water management and fuel removal from SFP, and presented the direction from mid-to-Long-term perspective that overlooks entire efforts of decommissioning of Fukushima Daiichi NPS.

Attachment 2　Major risk reduction measures performed so far and future course of action

Change in the risk level over time assessed and expressed by SED for the entire Fukushima Daiichi NPS is shown in Fig. A2-1. The vertical axis in the top graph in the figure shows the risk level in common logarithmic scale and the horizontal axis shows number of years after the accident.

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

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

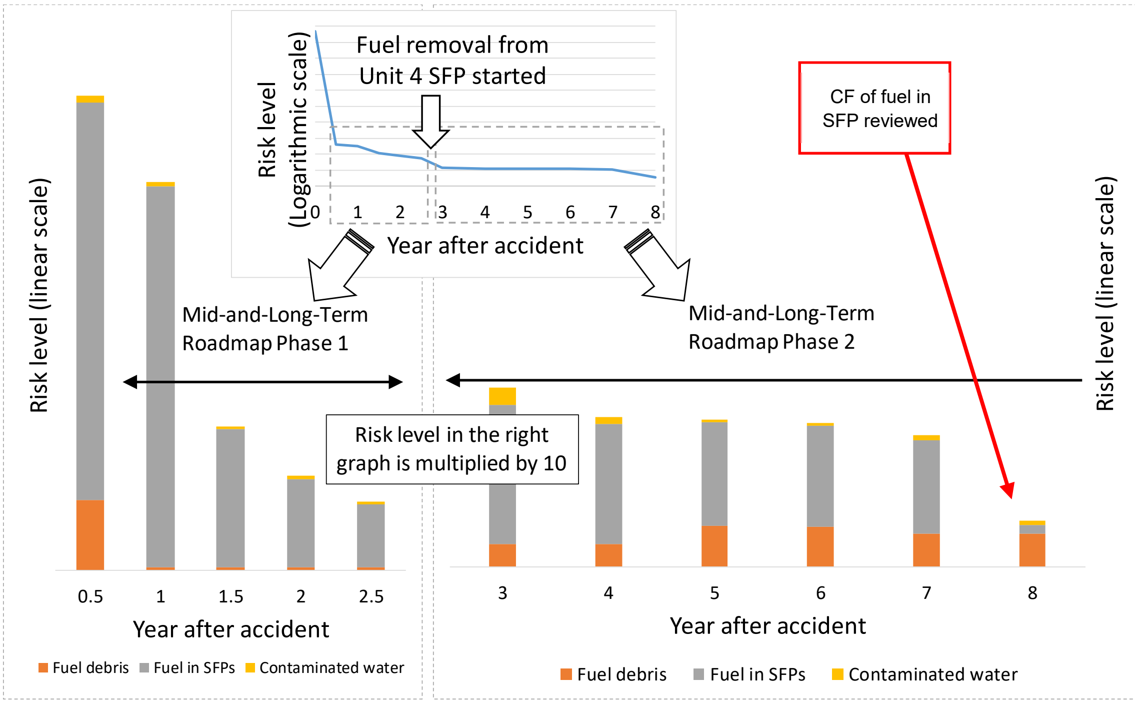


Fig. A2-1　Reduction of risks contained in the Fukushima Daiichi NPS
(Same of Fig.4 of p.16)

Change in the risk level with further breakdown of major risk source over the time since 0.5 years after the accident is shown in Fig. A2-2. In using with logarithmic scale, risk sources can be indicated that are too small to be displayed in the linear scale of Fig. A2-1. Fuel in the common spent fuel storage pool and fuel in dry cask temporary custody facility are not shown which stay in the region of sufficiently stable management.

Reasons of change in the risk level of every major risk source shown above are as follows, and the summary of the risk reduction measures described below is shown in Table A2-1.

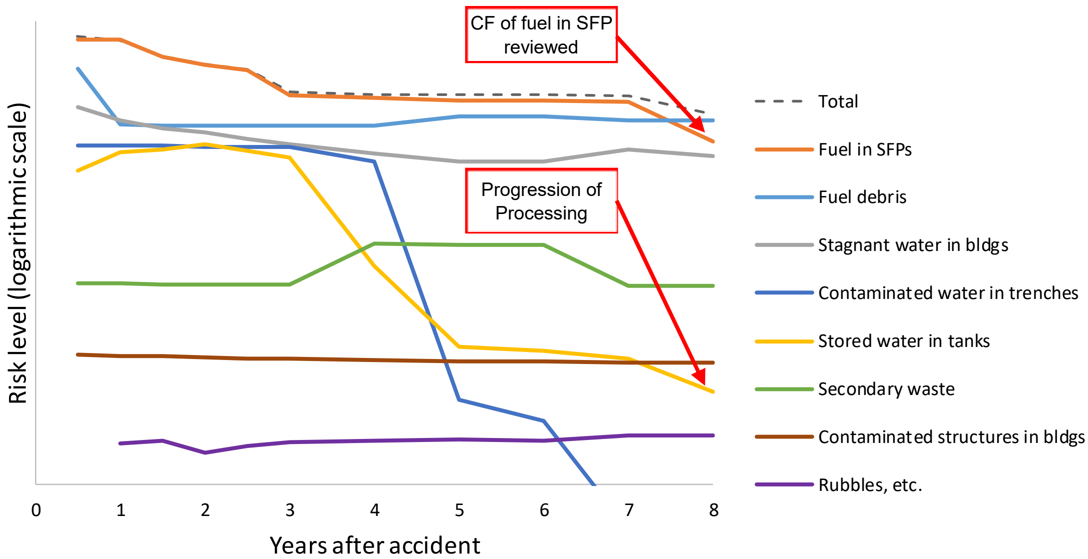


Fig. A2-2 Change in the risk level of every major risk source

(1) Fuel in SFPs

Since one year after the accident, removing rubble and installing the fuel removal cover were implemented as preparations of fuel removal in Unit 4. Fuel removal in SFP in Unit 4 was started 2.5 years later after the accident by transportation to the common spent fuel storage pool with low Safety Management, resulting in the risk level reduction (completion in 2014). Except reduction due to decay of the radioactive materials, it is this fuel removal from SFP in Unit 4 that contributes most so far to the risk level reduction of the total site.

In Unit 3, rubble removal has been conducted as preparations of fuel removal from SFP, and the cover for fuel removal was installed in 2018. Moreover, fuel removal from SFP was started from April 2019, resulting in reduction of risk level. In addition, fuel removal in SFP in Units 1 and 2 is scheduled to start by 2023 to reduce the risk level.

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

(2) Fuel debris

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

Although the risk level reduction effect was observed because of Safety Management reduction caused by diffusion control function with the building cover in Unit 1 (in 2011), this effect currently disappeared due to removal of the building cover (in 2015) to prepare for fuel removal from SFP.

(3) Stagnant water in the buildings

Stagnant water in the buildings is generated by cooling water for fuel debris and leakage of groundwater into the buildings, and its treatment has been progressed because of the starting of operation of the cesium adsorption apparatus (KURION and SARRY) (in 2011). In addition, due to the effects of sub-drain systems and land-side impermeable walls, the groundwater level was lowered and the inflow amount of groundwater into the buildings was reduced, resulting in achievement of lowering of the water level in the buildings. This also helped progress of treatment of the stagnant water. Moreover, draining of the condensers has been completed (in 2017). This stagnant water treatment in the buildings so far significantly contributes to risk level reduction of the total site following contribution by fuel removal from SFP.

This treatment of the stagnant water in the buildings resulted in generation of secondary waste from water treatment systems described in (6) below to which most inventory was transferred and the stored water in the tanks described in (5) below as the treated water.

In 2018, an increase in radioactive material concentration in the stagnant water in the building of Unit 3 is observed and the risk level of total stagnant water in the buildings has risen. This is considered as an effect that isolated water, etc., which was not included in the risk assessment, has leaked in, and the investigation and the study are underway. In recent days, the risk level of total stagnant water in the buildings is slightly decreasing due to the reduction of storing amount.

(4) Contaminated water in trenches

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

Treatment of stagnant water in the seawater pipe trench in Unit 1 with lower concentration compared to those in Units 2 to 4 is ongoing continuously, and it is scheduled to complete in 2019.

(5) Stored water in tanks

In each tank, there are several types of stored water with different radioactive material concentration. Although concentrated liquid waste generated by operation of the evaporative concentration system (in 2011) just after the accident had high concentration of radioactive materials, the evaporative concentration system stopped after a short period of operation (in 2011) and concentrated liquid waste is not generated at present. In addition, the concentrated liquid waste slurry was separated from this concentrated liquid waste and has been regarded as secondary waste from water treatment system (in 2014). The risk level of the residual concentrated liquid waste was decreased because of reduced inventory and transfer to the welded tanks that is secured more.

Processing of the concentrated salt water generated by the cesium adsorption apparatus has been completed in 2015 by operation of the Advanced Liquid Processing System(ALPS) (in 2013 with the existing system and in 2014 with the expanded system) and the high-performance ALPS (in 2014).

Reduction of risk level is devised by raising and duplicating the weir (completed in 2014 for existing tanks) and replacing tanks from flanged type to welded type (completed in FY2018). Whether it is concentrated salt water, Sr treated water or treated water, there is a small amount of residual water left at the bottom of the flange tanks, and the process is in progress to dismantle those tanks.

(6) Secondary waste from water treatment

Many radioactive materials have moved from contaminated water to secondary waste through water treatment. Secondary waste from water treatment system includes the waste sludge, waste adsorption columns by operation of the cesium adsorption apparatus (KURION and SARRY) (in 2011), HIC slurry by operation of the Advanced Liquid Processing System (in 2013), waste adsorption columns by operation of the high-performance ALPS (in 2014), waste adsorption columns by the mobile type treatment equipment that processed contaminated water in the seawater pipe trenches, etc. Although the contribution level of the waste sludge is higher as the risk level, currently the waste sludge is not newly generated. Therefore, the risk level of the total secondary waste from water treatment system does not tend to increase.

Although the concentrated liquid waste slurry separated from the concentrated liquid waste (in 2014) was stored in the welded type horizontal tanks without the weir and placed on the ground without the base, its risk level was reduced due to implementation of safety measures by installation of the reinforced-concrete base and the weir (in 2017).

(7) Contaminated structures, etc. in the buildings

There is no significant change at the present moment in the risk level of contaminated structures, etc. in the buildings comprised of structures, piping, components, etc. in the reactor buildings, PCVs or RPVs that are contaminated by dispersed radioactive materials caused by the accident since fuel debris retrieval is not started yet.

(8) Rubble, etc.

Rubbles, etc. as solid waste are stored under a variety of conditions such as in solid waste storage, in temporary waste storage and by outdoor accumulation. Each has different Safety Management, and the rubbles stored in outdoor sheet covered storage and outdoor accumulation are of the highest risk level. In the past, the facilities with better management condition have been enhanced by soil covered temporary storage facilities (in 2012), felled tree temporary storage pool (in 2013), expansion of solid waste storage facilities (in 2018), etc. Furthermore, outdoor temporary storage is planned to dissolve by increasing incinerator facility, volume reduction facility and solid waste storage, etc. by 2028 in accordance with the solid waste storage management plan.

Table A2-1 Major efforts affected directly to the risk level implemented up to today and future actions

Year	Fuel debris	Fuel in SFP	Contaminated water	Solid waste
2011	● Starting water injection by core spray system ● Starting Nitrogen injection ● Installation of building cover (Unit 1)	● Cooling function restoration	● Operation start of KURION and SARRY ● Operation start and shutdown of AREVA Decontamination System ● Operation start and shutdown of evaporative concentration system	
2012		● Investigation of internal pool（Unit 4） ● Removing rubbles in operation floor（Unit 4）		● Receipt start of soil covered temporary storage facility
2013		● Installation of fuel removal cover (Unit 4) ● Removing large rubbles in pool (Unit 4) ● Removing rubbles in operation floor (Unit 3) ● Start of fuel removal (Unit 4)	● Operation start of ALPS ● Starting transfer to welded tank	● Receipt start of felled tree temporary storage pool
2014		● Completion of fuel removal (Unit 4)	● Completion of raise and duplication of weir for existing tanks ● Operation start of expanded ALPS and high-performance ALPS ● Operation start of mobile-type strontium removal equipment ● Separation of concentrated liquid waste slurry from concentrated liquid waste ● Adding Sr-removing function to SARRY	
2015	● Removal of building cover (Unit 1)	● Removing large rubbles in pool (Unit 3) ● Investigation of internal pool (Unit 3)	● Adding Sr-removing function to KURION ● Completion of concentrated salt water treatment ● Completion of seawater pipe trench blockage (Units 2 to 4) ● Start of pumping up by sub-drain system ● Closure of sea-side impermeable walls	
2016				
2017			● Completion of condenser drainage (Units 1 to 3)	● Completion of safety measures for concentrated liquid waste slurry
2018		● Installation of fuel removal cover (Unit 3)	● Closure of land-side impermeable walls, mostly completed ● Completion of transfer of Sr treated water to welded tanks	● Installation of new solid waste storage facility
2019		● Start of Unit 3 removal	● Completion of transfer of treated water to welded tanks	
Future actions	● Start of retrieval from first implementing unit in 2021	● Start of Units 1 and 2 removal, aiming by FY2023	● Blockage of seawater pipe trench at Unit 1 in 2019 ● Completion of stagnant water treatment in the buildings in 2020	● Storing of solid waste in the storage facility in accordance with solid waste storage plan by FY2028

Attachment 3 Overview of SED indicator

Risk analysis targeting various risk sources, which have diverse characteristics and exist all over the site, was conducted in reference to the SED indicator[51] developed by the NDA. The SED indicator is an important factor to decide priority to implement risk reduction measures. It was partially modified (refer to the following pages) so that unique characteristics of the Fukushima Daiichi NPS could be easily reflected when it was applied to the Fukushima Daiichi NPS. Overview of the SED indicator and the modified part to be applied to the Fukushima Daiichi NPS are described below.

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

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

or

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

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

(1) Hazard Potential

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

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

Inventory is defined as shown below by Radioactivity of risk sources and the Specific Toxic Potential (STP) and corresponds to the effective radiation dose[52]. The STP is defined as the volume of water required to dilute 1TBq of radioactive materials and corresponds to the radiation dose coefficient. Ingestion of a certain amount of such diluted water throughout the

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

year will result in a radiation exposure dose of 1mSv. The SED indicator conservatively uses the larger radiation dose coefficient between ingestion and inhalation.

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

Form Factor (FF), as shown in Table A 3-1, is an indicator representing how much radioactive material is actually released depending on material form, such as gas, liquid, solid, etc. The indicator is set assuming that 100% of radioactive material is released in the case of gas and liquid when containment function is totally lost and that 10% of radioactive material is released in the case of powder based on the measurement data. Because of no clear basis, the indicator in case of solid is set to a sufficiently small value assuming that the solid materials are less easily released.

In Table A 3-1, several expected forms, especially for fuel debris, are added to the definition used by the NDA. The scores for the form of No.4 and No.5 are newly established.

Control Factor (CF), as shown in Table A 3-2, is an indicator representing time allowance available before restoration when safety functions maintaining current stable state are lost. CF is taking into account exothermicity, corrosivity, flammability, hydrogen generation, reactivity with air or water, criticality, etc. which are typical characteristics of risk sources. CF is the same as the one defined by the NDA.

Table A3-1 Definition and score of FF

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

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

Table A 3-2 Definition and score of CF

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

(2) Safety Management – FD and WUD

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

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

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

Table A 3-3 Criteria and score of FD

Category	Criteria (NDA definition is modified to enhance applicability to the case of the Fukushima Daiichi NPS)	NDF Score
1	No component for diffusion control function exists. Therefore, no assessment for containment function is available.	100
2	"Safety assessment criteria[*2]" are not satisfied at "the time of assessment[*1]" caused by the accident effects, etc. The component for diffusion control function is single.	91
3	"Safety assessment criteria" are not satisfied at "the time of assessment" caused by the accident effects, etc. The component for diffusion control function is multiple.	74
4	"Safety assessment criteria" are not satisfied until "the time of work (such as transfer, treatment, recovery, etc.) [*3]" for the risk source contained in the component for diffusion control function. The component or diffusion control function satisfying "safety assessment criteria" exists at "the time of assessment".	52
5	Integrity of diffusion control function has been assessed and "safety assessment criteria" are satisfied until "the time of work (such as transfer, treatment, recovery, etc.)" for the risk source. Frequency of occurrence of "contingency[*4]" is high, and when contingency occurs countermeasures preventing diffusion of the risk source contained in the component are not sufficient. The component for diffusion control function is single.	29
6	"Safety assessment criteria" is satisfied until "the time of work (such as transfer, treatment, recovery, etc.)" for the risk source. Frequency of occurrence of "contingency" is high, and countermeasures preventing diffusion of the risk source contained in the component are not sufficient. The component for diffusion control function is multiple.	15
7	"Safety assessment criteria" are satisfied until "the time of work (such as transfer, treatment, recovery, etc.)" for the risk source. Facilities dissatisfying "safety assessment criteria" exist in the surrounding area, and the potentiality is high to make (receive) the diffusion impact[*5] of the risk source to (from) these adjacent facilities. The component for diffusion control function is single.	8
8	"Safety assessment criteria" are satisfied until "the time of work (such as transfer, treatment, recovery, etc.)" for the risk source. The potentiality is high to make (receive) the diffusion impact of the risk source to (from) these adjacent facilities. The component for diffusion control function is multiple.	5
9	"Safety assessment criteria" are satisfied until "the time of work (such as transfer, treatment, recovery, etc.)" for the risk source. The potentiality is low to make (receive) the diffusion impact of the risk source to (from) these adjacent facilities. The component for diffusion control function is single.	3
10	"Safety assessment criteria" are satisfied until "the time of work (such as transfer, treatment, collection, etc.)" for the risk source. The potentiality is low to make (receive) the diffusion impact of the risk source to (from) these adjacent facilities. The component for diffusion control function is multiple.	2

[*1] This refers to "at the time" of study on SED score, i.e., "at the present time" of assessment.
[*2] "Safety assessment criteria" described in this sentence refer to "the matters for which measures should be taken" or "securing of diffusion control function within the scope of design basis event".
[*3] This refers to the time of "recovery" of the risk source for disposition and carrying out for which SED score shall be studied.
[*4] External events (natural disasters, etc.) are postulated as contingencies.
[*5] The potentiality of diffusion of the risk source exists to (from) adjacent facilities when facilities receive external impact caused by contingencies or impact caused by any events (fire, etc.), etc.

Table A 3-4 Criteria and score of WUD

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

*1 "Active" refers to possession of activity defined by CF at such a significant level as that activity affects control and work.
*2 "Inactive" refers to non-possession of activity or possession of sufficiently low level of activity.

(3) Safety Management - SSR, BER and CU

The definition of SSR, BER and CU used for Safety Management assessment for contaminated soil is the same as the one defined by the NDA and each score is shown in Table A 3-5.

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

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

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

Table A 3-5 Definition and score of SSR, BER and CU

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

Table A 3-6 shows the overview of containment function, safety equipment, the state of control and surveillance, etc. of each risk source used when Safety Management was assessed.

Table A 3-6 Characteristics of each risk source concerning Safety Management

Risk source	Characteristics
Fuel debris	No significant damage has been observed in the PCV and redundancy of criticality control, cooling system and hydrogen explosion prevention system is secured. In addition, important parameters including Xe concentration, temperature, hydrogen concentration, etc. are being monitored.
Spent fuel	The spent fuel pool of each unit is designed to maintain subcriticality, and redundancy of the cooling system is also secured. Some units have experienced falling rubble and heavy weight objects, ceiling defects of the buildings, seawater injection, etc. Common spent fuel storage pool and dry cask temporary custody facility, as well as the buildings are not damaged by the earthquake and the tsunami.
Contaminated water, etc.	For stagnant water in the buildings, containments of the contaminated water are maintained by management of the water level difference between the contaminated water and ground water. The water treated by the purified equipment was stored either in flange tanks or welded tanks, and transfer from flange tanks to welded tanks was completed. (residual water is excluded)
Secondary waste from water treatment systems	The waste adsorption column is a shielded carbon-steel vessel storing Cs-adsorbed zeolite, which is contained again in a shielded vessel, and is mounted on the box culvert or the frame. Any control of decay heat removal, etc. is not required. Waste sludge is stored in the agglomeration pit integrated in the process main building, where leak monitoring, decay heat removal, and hydrogen exhaust operations are performed. HIC slurry is stored in the polyethylene container, which is further contained in the SUS reinforced vessel, and is stored in the box culvert. Although decay heat removal is not required, measures against hydrogen generation is continuously taken. Concentrated liquid waste is the liquid waste generated by concentrating the concentrated saltwater through the evaporative concentration system and has a high concentration of radioactive material and salinity. Its precipitation is extracted as a concentrated liquid waste slurry and stored in welded tanks within the weir.
Rubbles, etc.	Rubbles, etc. that is stored in the solid waste storage facility is waste which has a high concentration of radioactive material, etc. and is contained in the container. Special control is not required for this waste. Temporally stored rubbles, etc. are waste which has various concentrations of radioactive material and is stored outdoor in various forms, then monitoring and such is required for this waste.
Contaminated structures, etc. in the buildings	They are a variety of structures and the like in the buildings that were contaminated with a part of fission products like Cs which was released from fuel due to molten core at the accident. The location and from of the contaminants are still investigation.

Attachment 4 Risk sources that include radioactive materials exists in site of Fukushima Daiichi NPS except for major risk sources

Items	Descriptions
Exhaust stack for Units 1 and 2	Dismantling is ongoing, Radiation level : 0.22 to 0.51mSv/h at the height of 115m above ground level and 0.76 to 1.50mSv/h at the height of 35m above ground level.[53]
VLFS (megafloat)	Construction of fender banking was completed. Treatment of ballast water, internal decontamination and grounding mound building in the sea bottom are in operation. Radioactivity concentration in ballast water : Cs-134 (5.49×10^{-2} to 0.315Bq/L) and Cs-137 (0.456 to 3.20Bq/L).[54]
Underground water tank	Collection of residual water in all the underground water tanks were completed. Dismantling and removal policies are under consideration).[55]
Rainwater inflow into buildings	Rubble removal and additional water seal on the roof floor, Installation of purification material into rain gutters, Installation of backflow valves into drain pipes, and Repair and blockage of roof drains.[56]
Accumulated water on site	Extracted by risk overhaul performed in 2015. Concentration of radioactive materials and volume of water are confirmed appropriately on and after.[57]
α-sludge	R/B of Unit 2 Cs-137：9.35×10^{7}Bq/L, α:13.6Bq/L in total, in a decreasing trend[58] R/B of Unit 3 Cs-137：1.66×10^{8}Bq/L, α:4.52×10^{5}Bq/L, in an increasing trend.[54]
Waste before the earthquake	Stored in 185,816 drums[59], Major nuclide is Co-60.

53) "Response to the risk overhaul may affect outside the site boundary of Fukushima Daiichi NPS", Handout 1-2 provided in The 36th The local coordination meeting for decommissioning and contaminated water management

54) NRA, Interview material with licensees "Changes to the implementation plan associated with risk reducing measurement against tsunami for VLFS", November 22, 2018

55) "Reference 1 : Process chart of the consideration and instruction items based on Target map for Reducing the mid-term risk of Fukushima Daiichi NPS", The 69th Specified nuclear facility monitoring and assessment meeting

56) "Reference 2 : Status of countermeasure against storm sewage inflow", The 70th Specified nuclear facility monitoring and assessment meeting

57) "Reference 1 : Status of the residual water on site including contaminated water (as of July 18, 2019)" from The secretariat Meeting of 68th Team meeting on decommissioning and contaminated water treatment

58) "Reference 3-1 : Analytical results of α-nuclide" from The secretariat Meeting of 67th Team meeting on decommissioning and contaminated water treatment

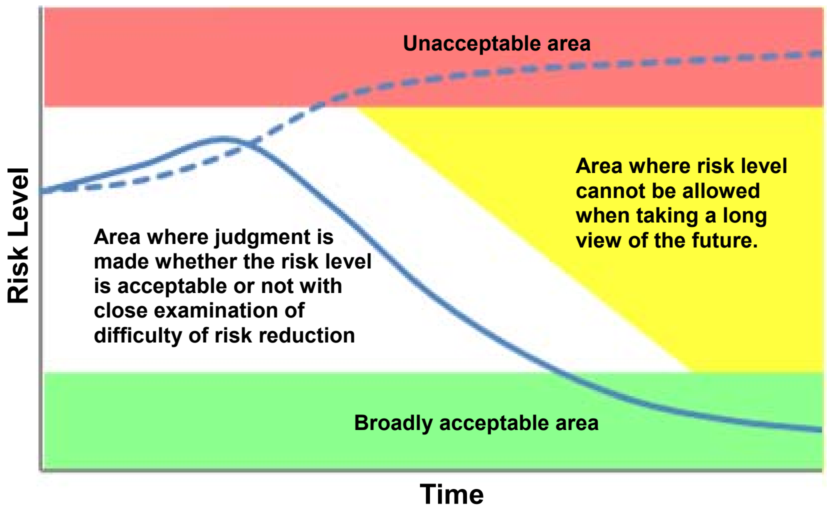
59) TEPCO, NRA, Interview material with licensees "Status of monitoring exhausted radiation of common facilities for supporting operation of SFP and recovery of air conditioning systems in fuel storage area of Fukushima Daiichi NPS" issued on September 21, 2018

Contaminated soil	As a result of the topsoil analysis, more than half of the samples are in excess of the designated standards (8,000Bq/kg) provided for in the act on special measures concerning of handling contamination by radioactive materials.[60]
Deposits on the floor	Deposits such as zeolite sandbags put on the lowest floors of process main building and high-temperature incinerator building.
Spent control rods	Spent control rods, etc. : 24,030[7,] Fragments of core shroud : 193m^3 [7,] Major nuclide is Co-60.
In-pool water	Salt removal in Units 2 to 4 was completed in 2013.
Rubbles on operating floor	Investigation was conducted in Unit 1 and Unit 3. Scattered radiation of Cs-134 and Cs-137 were measured.[61]
Dust in operating floor	Less than the target value of release control (1×10^{7}Bq/h). Gradually in decreasing trend.
Drainage	Cs-137 decreased to ND to 23Bq/L in Drainage A[62], same in Drainage K decreased to 67Bq/L by removing contamination source on the roof of R/B in Unit 2[63]. Additional measures were taken, including installation of purification materials.[64]
Rubbles around buildings	Dismantling of rubbles scattered on the roof floor of the buildings due to hydrogen explosions is now in operation and planned.[12)] The physical quantity has not been confirmed.

[60)] TEPCO, Analytical results of daily radioactive materials in Fukushima Daiichi NPS (Website)
[61)] "Reference 5-3 : Dose report in operating floor of reactor building in Unit 3 (Flash report)", The 38th Specified nuclear facility monitoring and assessment meeting
[62)] "Reference 2 : Status of measures for reducing the concentration of effluent in K drainage", The 32nd Specified nuclear facility monitoring and assessment meeting
[63)] "Reference 4 : Status of measures for reducing the concentration of effluent in drainage", The 34th Specified nuclear facility monitoring and assessment meeting
[64)] "Reference 2 : Storm sewage inflow suppression countermeasures (Status of storm sewage draining in turbine buildings and installation of clarification materials", The 63rd Specified nuclear facility monitoring and assessment meeting

Attachment 5　Change in risk over time

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



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

Fig. A5-1　Change in risk over time

Attachment 6　Coverage of fuel debris retrieval

In the Mid-and-Long-term Roadmap issued in December 21, 2011, fuel debris is described as "material in which fuel and its cladding tubes, etc. have melted and re-solidified", namely, fuel debris is "fuel assembly, control rod and structures inside reactor have melted and solidified together" according to the report by IAEA[65,66].

The condition inside PCV is as shown in Fig.A5-1, as the comprehensive estimations from the inside investigation of reactor, the past accidents including TMI-2 or ChNPP-4, and the result of the simulation test. It does not show any of specific unit. For more detail, as shown in the Fig. fuel debris can be classified by form such as damaged pellets, debris, crust, etc.

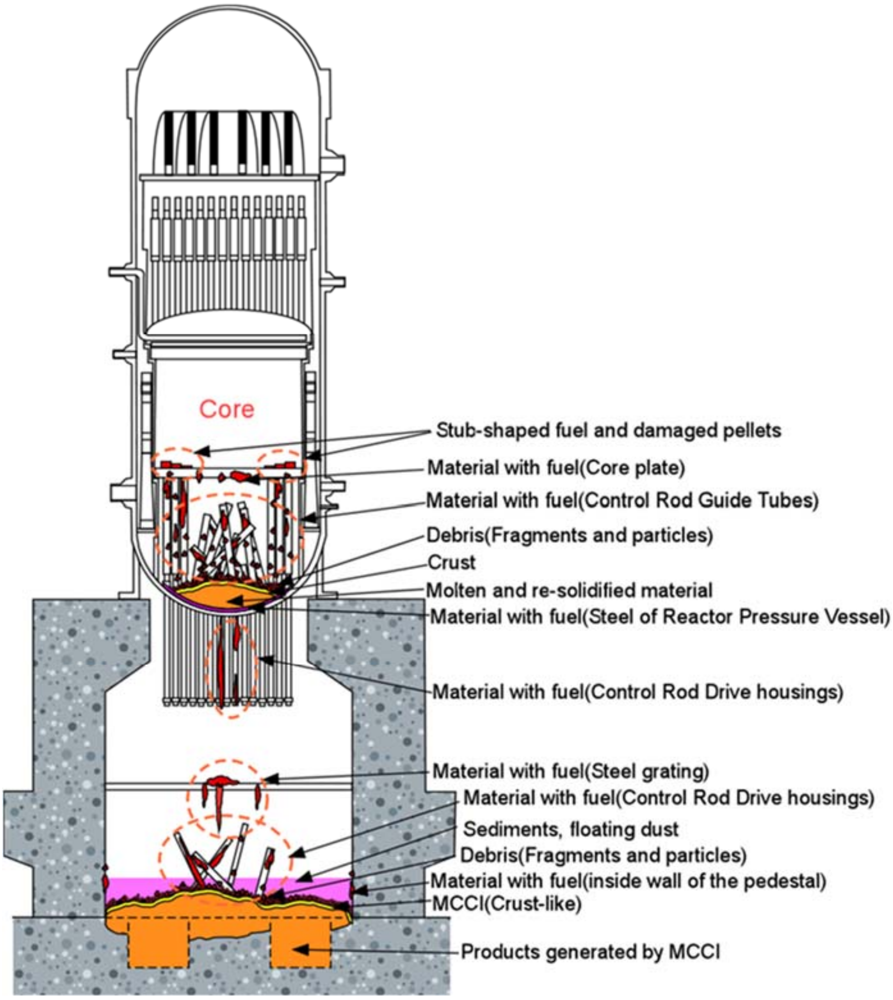


Fig. A6-1　Estimated inside of the PCV of the Fukushima Daiichi NPS

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

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

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

Based on this, an example of fuel debris concept as a retrieval target of fuel debris is as shown in Fig. A5-2. Objects generated by core damage have been classified depending on necessity of criticality measures and the content of fuel, in spite that a lot of names are used according to the content of fuel component or form in appearance.

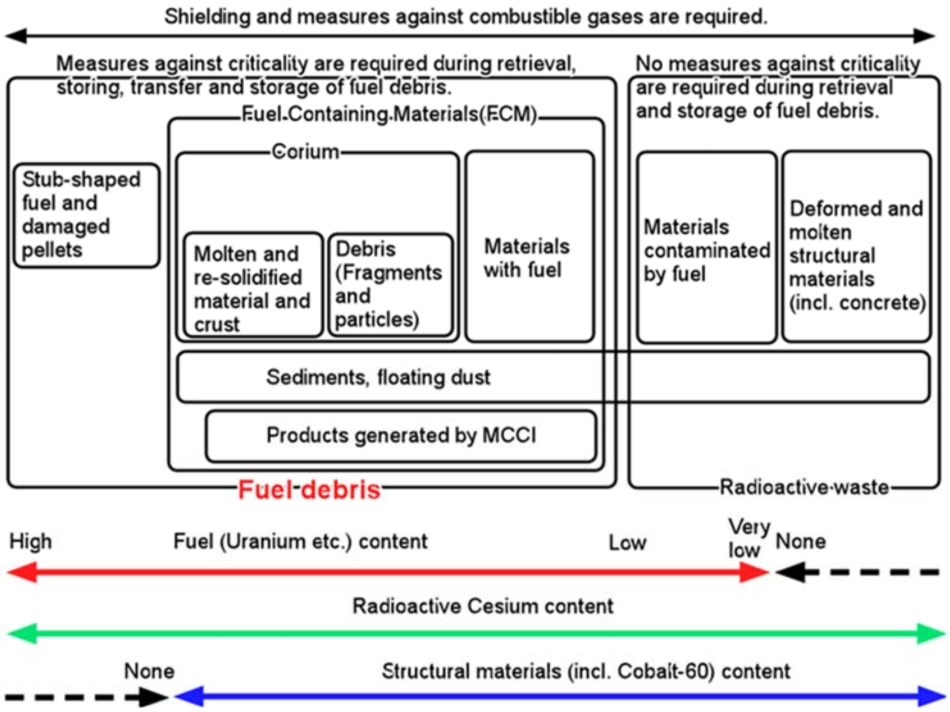


Fig. A6-2 An example of organized concept of fuel debris as fuel debris retrieval target at the Fukushima Daiichi NPS

【Glossaries and Terms】

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

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

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

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

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

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

Attachment 7: Strategic recommendations for determination of fuel debris retrieval methods for the First implementing unit

To determine fuel debris retrieval methods for the first implementing unit, the NDF investigated the first implementing unit and its fuel debris retrieval methods. The results of the study are summarized as a strategic recommendation for "determination of fuel debris retrieval methods for the first implementing unit" (hereinafter referred to as "strategic recommendation"), which is described below.

This Attachment corresponds to the Strategic Plan as follows:

Strategic Plan	Strategic Recommendation (this Attachment)
3.1.2.1 Approach to risk reduction in fuel debris retrieval work	A. Policy of study to determine fuel debris retrieval methods for the first implementing unit
3.1.2.2 Fuel debris retrieval methods for the first implementing unit (outline of the strategic recommendation for determination of fuel debris retrieval methods for the first implementing unit)	B. Recommendations for determination of fuel debris retrieval methods for the first implementing unit
3.1.3.1 Technical issues and plans related to the fuel debris retrieval from the first implementing unit	C. Initiatives after determination

Strategic recommendation for “Determining fuel debris retrieval methods for the first implementing unit”

Table of Contents

A. Policy of study to determine fuel debris retrieval methods for the first implementing unit

The intention of fuel debris retrieval is to reduce risk, and for the stable management of fuel debris distributed at each location of Units 1, 2and 3, and fuel debris retrieval is to be conducted continuously using retrieval devices, transfer equipment, storage equipment, and safety equipment for safety operation. In executing, because of the difficulty of handling fuel debris, it is essential to build a plan based on the on-site situation by working with highly reliable means after ensuring safety.

In the strategic recommendation, the scientific evidence for the fuel debris retrieval methods of the first implementing unit and the path forward are indicated, based on the information revealed so far towards “determination of fuel debris retrieval methods for the first implementing unit” by the government as well as towards fuel debris retrieval from the first implementing unit by TEPCO.

“Determination of fuel debris retrieval methods for the first implementing unit” is under study based on the “Policy on Fuel Debris Retrieval” presented in 2017 in the Mid-and-Long-term Roadmap of the Inter-Ministerial Council for Contaminated Water and Decommissioning Issues. The “Policy on Fuel Debris Retrieval” and its immediate actions are as follows:

Policy on Fuel Debris Retrieval

[1] Step-by-step approach
[2] Optimization of the overall decommissioning work
[3] Combination of multiple methods
[4] Approach focused on partial submersion method
[5] Prioritizing fuel debris retrieval by access to the bottom of the PCV from the side

“Immediate actions based on the policy on fuel debris retrieval”

[1] Implementation of preliminary engineering
[2] Continued internal investigation and accelerated/prioritized R&D

(1) Step-by-step approach

At present, the condition of the internal environment of each unit is gradually revealed by improved working environment in the field and internal investigations that have been conducted since the earthquake disaster happened. However, as the reactor building (R/B) is a high radiation dose environment and it is difficult to conduct an investigation in the vicinity of the PCV, information on the fuel debris to be retrieved is not yet sufficient.

Therefore, in the “Policy on Fuel Debris Retrieval”, the importance of the “step-by-step approach” is described, in which determination of fuel debris retrieval method to be started in advance is important to reduce the risk at an early stage, then, the direction will be adjusted in a flexible manner based on the information that will be obtained gradually. It should be recognized that the fuel debris retrieval work is not a simple, stepwise expansion or a routine project, but it has a character requiring constant reassessment based on the current technology development and the project-oriented viewpoint, while assessing the updated situation.

The “Step-by-Step Approach” is described in the Mid-and-Long-term Roadmap: “Fuel debris retrieval will start on a small-scale and the scale of retrieval will be expanded in stepwise revising operations flexibly based on new findings obtained from the characteristic of the fuel debris and working experience”. This fuel debris retrieval work is unprecedented attempt, and the first step is value to assess the internal situation by internal investigations, etc., to accumulate work experience inside PCV, and to use it in designing the fuel debris retrieval methods and devices. Then, as for the fuel debris retrieval, it should be conducted carefully little by little while ensuring safety at the initial stage. After taking procedures to verify debris retrieval steps, to check the engineering reliability of devices, and to check the environmental impact of the work, etc., the retrieval scale should be expanded gradually by using the knowledge and experiences obtained to be incorporated into the work of retrieval.

In the same way, the Approach is described as “determination of fuel debris retrieval methods to be started in advance to reduce risks at an early stage, then, the direction should be adjusted in a flexible manner as retrieval proceeds, based on information that will be obtained gradually”. In examining fuel debris retrieval methods, the conditions inside the PCV and RPV and the properties of the fuel debris have been gradually clarified, but it is still difficult to say completely clarified. It is expected such information will be gradually revealed through access to the inside. Based on this, make assessment regarding the internal conditions and debris properties to be revealed in steps by the internal investigations and characterization of debris to be conducted in the future. When the next step in the plan is affected, the next step in the plan including the method and schedule (ex. expansion of scale, review of system capacity, etc.) is to be reviewed.

(2) Internal investigation and fuel debris retrieval

In the “Policy on Fuel Debris Retrieval”, it is stated that internal investigations and fuel debris retrieval should be performed in a coordinated and integrated manner. Work elements related to the fuel debris retrieval for each unit need to be examined in detail, and the examples of the concept are shown below.

○ Internal investigation (investigation of internal situation and characterization of fuel debris)

For the internal condition of PCV and damage to internal structure, investigation and observation are to be made provided that on-site environment has not changed. This will provide information for checking the distribution and accessibility of fuel debris and for judging safety of fuel debris retrieval work, which is used for examining the fuel debris retrieval method. Fuel debris will also be collected from inside PCVs through sampling and be transferred to the facility for analysis to identify the properties of fuel debris, including the shape, existing state, composition, and mechanical/chemical properties, etc.

On the premise that analyses and investigations on decommissioning and contaminated water management to be conducted for the safe and steady decommissioning of the Fukushima Daiichi NPS, consideration shall be paid for the necessity from the viewpoint of investigating the cause of the accident and improving nuclear safety in the future.

○ Fuel debris retrieval

In the fuel debris retrieval, to reduce risks of fuel debris, a series of operations should be carried out continuously, starting with the preparatory work, followed by retrieving, containing, and transferring fuel debris to stable storage. At the initial stage of fuel debris retrieval, small-scale fuel debris retrieval (hereinafter referred to as “small-scale retrieval”) will be conducted without significantly changing the on-site situation, and internal investigations and analysis will be performed as well. It is expected the small scale retrieval will provide important prediction on the following expanded-scale retrieval and retrieval from units other than the first implementing unit in the future. The scale of retrieval and the area of retrieval will be gradually expanded based on new findings from the properties of fuel debris and work experience while reviewing the work in a flexible manner (hereinafter referred to as “expanded-scale retrieval”). Otherwise, retrieval from units other than the first implementing unit is to be commenced.

With regard to expanded-scale retrieval and retrieval from units other than the first implementing unit, the on-site situation can be significantly changed depending on the new safety devices suitable for the expansion of the scale, the extension of existing openings according to their needs, and the installation of new openings and so on. Such work should be carefully carried out after enough examination on safety based on the information obtained from small-scale retrieval.

(3) Effect of small-scale fuel debris retrieval from the first implementing unit

It is expected that the small-scale fuel debris retrieval from the first implementing unit will provide important suggestions for subsequent expanded-scale retrieval and for the retrieval from units other than the first implementing unit. In particular, as the initial stage of fuel debris retrieval, to obtain and verify information for determining the subsequent retrieval work and devices, without causing irreversible changes of state in PCVs, the following effects are expected:

[1] Enables verification of devices, facilities and safety systems, including remote operations in the phase of small-scale retrieval by obtaining information (including the release ratio of radionuclides into the air and water) on the effectiveness and work efficiency reviews of devices, 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 obtainment of information that contributes to understanding the situation inside the PCV (fuel debris distribution [Including characteristics], information on access routes, information on structural conditions, etc.).

The above mentioned information and the experience are expected to be obtained firstly by TEPCO, which is the main operator of fuel debris retrieval work. By reflecting these information in engineering, it is expected that the subsequent fuel debris retrieval plan will become more rational. However, since the content and timing of the information and experience are different depending on the progress of the work, it is necessary to start retrieval for the units other than the first implementing unit or switch to the expanded scale retrieval as it becomes required timing, checking whether the necessary information and experience were obtained from the viewpoint of overall optimization.

B. Recommendations for determination of fuel debris retrieval methods for the first implementing unit

B.1 Status of investigation

Based on the "policy on fuel debris retrieval", the following is presented for "determination of fuel debris retrieval methods for the first implementing unit":

- Specific methods for the first implementation of fuel debris retrieval ("fuel debris retrieval methods")

  "Fuel debris retrieval methods" will be selected considering the progress in preliminary engineering as well as research and development based on the "policy on fuel debris retrieval".

- The unit at which the first retrieval will be carried out ("the first implementing unit")

  The "First implementing unit" candidate will be selected from Units 1, 2, and 3. The advantages and disadvantages of each unit will be considered in accordance with the current status of each unit and the progress of the PCV internal investigation.

  In addition, the practical feasibility of the selected candidate unit will be examined. The step-by-step approaches should be also indicated such as setting hold-points leading to the start of retrieval, as well as after the start of retrieval at the first implementing unit.

The process of determining the first implementing unit and its retrieval method is described below Based on the R&D results and the PCV internal investigation results, etc., obtained so far, the conceptual design of fuel debris retrieval system, scenario of fuel debris retrieval (work schedule) of each unit and study on its applicability to the actual site need to be evaluated in the preliminary engineering by TEPCO. Then, the overall optimization combining the scenario of each unit and the arrangement plan for the whole site is to be examined, and finally, recommendations for determination of fuel debris retrieval methods for the first implementing unit will be presented. The correspondence with Fig. 6 in this the strategic plan is shown in the reference figure at the end of this report.

B.1.1 Research and Development

In the Government-led R&D program on Decommissioning and Contaminated Water Management, R&D related to the PCV internal investigations and the retrieval of fuel debris has been carried out. Table 1 shows an overview of this program.

(1) Development related to internal investigation

Currently, as part of the Development of Technology for Detailed Investigation inside the PCV, an arm-type access equipment that enables access to the inside of the pedestal through an X-6 penetration (Unit 2) and an submersible ROV to confirm the condition of the submerged portion of outside of the pedestal by accessing through X-2 penetration (Unit 1) have been developed. In particular, with regard to the arm-type access equipment, a cell (enclosure) storing the arm-type access equipment is installed outside the PCV which has the function of PCV internal investigation, removal of obstacles, picking a fuel debris sample and carrying it out from the PCV, consistently. Methods and systems for picking fuel debris samples such as gripping, sucking, and crushing are being developed. In addition, for development of technologies for analyzing and characterizing properties of fuel debris, a plan related to the off-site transportation of samples is being investigated. These results contribute to the preliminary engineering.

(2) Development related to fuel debris retrieval

Development on the fuel debris retrieval is mainly aimed at the expanded-scale retrieval and the progress is currently at the stage of conceptual studies and element tests. In the future, it will be necessary to evaluate the actual site applicability of these results and apply them to the design of actual fuel debris retrieval equipment/system. These actions have just started as a part of the preliminary engineering.

Table A7-1 Overview of the state of review in the Government-led R&D program on Decommissioning and Contaminated Water Management

Items	The Government-led R&D program on Decommissioning and Contaminated Water Management	Overview of status of review (as of March 2019)
Development related to RPV/PCV internal investigation	Development of Technology for Detailed Investigation inside the PCV	To obtain more detailed information on the distribution of deposits and fuel debris inside the PCV, investigation devices (underwater ROV for Unit 1 and arm-type access equipment for Unit 2) tailored to the condition of Units 1 and 2 will be developed and actual investigation will be carried out.
	Development of technology for investigation inside the RPV	An investigation methods by side access and top access are being developed and the development will be continued.
	Development of Technologies for Retrieving Sampling of Fuel Debris and Internal Structures	A fuel debris sampling plan will be developed and development of sampling devices and systems will be followed.
	Development of technologies for analyzing and characterizing properties of fuel debris	Retrieved fuel debris and deposits samples will be analyzed in the future, and the properties of fuel debris will be estimated based on the analysis results. Then, the fuel debris characteristics list will be enhanced. In addition, the development of technology for estimating the aging of fuel debris and for estimating the behavior of fuel debris particles will be continued.
Development related to fuel debris retrieval	Upgrading of methods and system for retrieval of fuel debris and internal structures	Development of various systems necessary for maintaining safety functions during the retrieval work and development of elemental technology for the fuel debris retrieval have been carried out. In the future, the new project will be continued to resolve the technical issues identified during the previous projects, recognized by TEPCO's engineering activities, and presented in the Strategic Plan 2018.
	Upgrading of fundamental technologies for retrieval of fuel debris and internal structures	
	Development of closed circulation systems for water through inside the PCV	To build a new circulation system of water via the PCV, technical specifications for building accessing and connecting path to the PCV will be prepared. Then, their development plans will be drawn up, and finally, development of elemental technologies for building accessing and connecting path to the PCV and verification of them by using full scale of PCV will be continued.
	Development of technology for containing, transferring and storing of fuel debris	Technology development was carried out for a system for containing, transferring, and storing including storage containers for retrieved fuel debris safely, reliably, and efficiently, and technical issues were identified. Development will continue to address them.

(3) Status of review in preliminary engineering

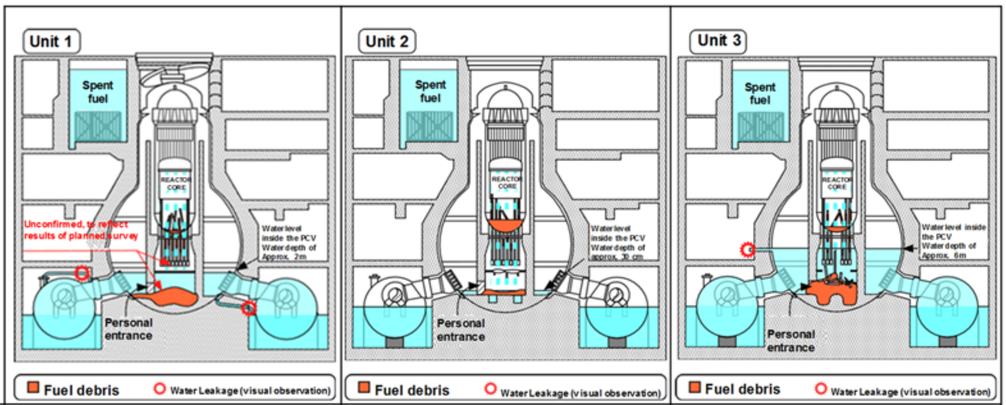
Preliminary engineering is being carried out by TEPCO based on the “policy on fuel debris retrieval” in the Mid-and-Long-term Roadmap. The preliminary engineering is the action of preliminary assessment of the practical feasibility of studied fuel debris retrieval concept from the view point of engineering aspects prior to starting the basic design. To assess the practical feasibility of studied fuel debris retrieval concept derived from the results of R&D, the work schedule of the fuel debris retrieval operation needs to be put in shape. Specifically, the arm-type access equipment and the air tightened enclosure storing it, which have been developed and their actual site applicability was in sight by the Government-led R&D program on Decommissioning and Contaminated Water Management, are being investigated to apply to the actual small-scale fuel debris retrieval. The study on the expanded-scale retrieval method/equipment have just started by taking the results obtained in this Government-led R&D Program into account.

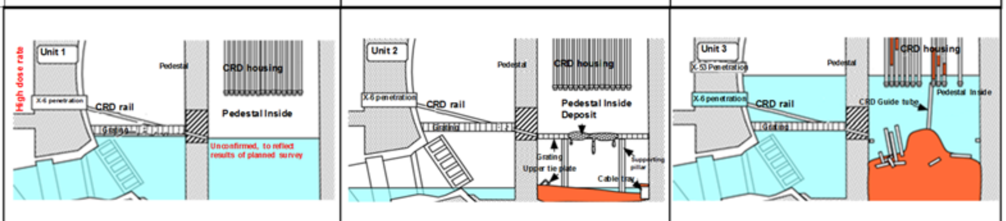
The retrieved fuel debris is currently considered to be contained in to the canister which has been developed and its actual site applicability was in sight in the Government-led R&D Program, and the canister is to be stored in the storage facilities installed within the Fukushima Daiichi NPS. Study on the expanded-scale retrieval has just been started by incorporating the results of this Government-led R&D Program. Securing an area to be used for stable storage is the one of issues to be addressed.

The status of preliminary engineering results is presented in Sub-section B. 1.5.

B.1.2 Internal Investigation of PCVs (Internal status of the PCV)

The current situation of the estimated fuel debris distribution, access routes and surrounding structures of Units 1 to 3 are shown in Fig. A7-1.



	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. A7-1 Estimated fuel debris distribution, access route and surrounding structures of Units 1 to 3

PCV internal investigations to verify the condition inside the PCV are also important for fuel debris retrieval from the lower PCV according to the Fuel Debris Retrieval Policy. Table 7-2 shows the current status.

Table A7-2 PCV internal investigation status

Unit	Inside the pedestal	Outside the pedestal
Unit 1	• Not yet performed • It may be possible to verify the condition in part by Investigation B3 (scheduled).	• Deposits on grating and in the lower pedestal were investigated in Investigation B2 (March 2017). • Investigation B3 (scheduled) will access the outside of the pedestal to verify deposits near the access opening.
Unit 2	• The condition inside the pedestal was verified in Investigation A2' (January 2018). • Contact survey on deposits at the PCV bottom was performed in Investigation A2'' (February 2019). • Detailed conditions will be verified in Investigation A3 (scheduled).	• Conditions from X-6 to near the CRD railing were verified in Investigations A2' (January 2018) and A2'' (February 2019). • Verification on access routes will be planned in Investigation A3 (scheduled).
Unit 3	• The condition inside the pedestal was verified in the ROV investigation (July 2017).	• Conditions of the access routes to the pedestal CRD opening were verified in ROV investigation (July 2017).

* A2, B2, etc., indicate the position and order of internal investigations in the Government-led R&D program on decommissioning and contaminated water management. A2 means the 2nd investigation inside the pedestal (A), while B2 means the 2nd investigation outside the pedestal (B). Since Investigations A2' and A2'' were performed with the same equipment used for Investigation A2 after improvement, they are considered as a series of investigations.

In Investigation A2'' performed at Unit 2 in February 2019 (contact survey on deposits), in particular, it was identified that some deposits could be moved by gripping. Based on the results of this Government-led R&D Program, in addition, Investigation A3 is planned (scheduled) to identify the structures and distribution of deposits inside the pedestal, followed by a small amount of sampling.

The assessment status of on-site conditions is as follows. Though the conditions differ by unit, acquiring the information on side-access is in progress (Refer to Fig. 3 in Sub-section B.1.3, for the current status of the radiation dose rate by unit).

Unit 1: Since there is a significantly high radiation dose on the southeast side, where the X-6 penetration is located, operations are difficult to perform so the self-propelled survey equipment was inserted from the X-100B penetration on the northwest side, where the radiation dose rate was relatively low (Investigation B2: March 2017). As the condition of the pedestal opening is still uncertain, an investigation with access from the X-2 penetration is planned (Investigation B3: Scheduled). The outside of the pedestal is covered with deposits, and the condition at the PCV bottom has not been observed yet.

Unit 2: The telescopic survey equipment was inserted from the X-6 penetration on the northwest side. The results reveal the damaged condition from the pedestal opening to the internal grating, etc., as well as the limited damage on the CRD housing (Investigation A2': January 2018). It has been confirmed that deposits that might be fuel debris at the PCV bottom could be moved (Investigation A2'': February 2019).

Unit 3: Because of the high water level inside the PCV and the submerged X-6 penetration, the underwater ROV was inserted from the unsubmerged X-53 penetration on the same northwest side to observe and enter the inside of the pedestal opening. Damage on the CRD housing was significant, and damage on the CRD switching equipment and deposits covering collapsed equipment were observed (ROV survey: July 2017).

Conceptual examinations for the RPV internal investigation are underway in the Government-led R&D Program. Prior to practical application, further examinations are needed including adjustment based on on-site conditions (including work interference with fuel removal from SFP).

As for the amount of fuel debris, it is estimated that 279 ton in Unit 1, 237 ton in Unit 2, and 364 ton in Unit 3 as a result of comprehensive analysis by analyzed result and the data investigated with actual equipment[67].

B.1.3 Improvement of work environment

In order to retrieve fuel debris, radiation exposure among workers needs to be managed appropriately. Therefore, appropriate work planning and radiation dose reduction in the working environment through decontamination, shielding, and other means as needed are

[67] IRID, Overview of research and development addressed by IRID, August 4, 2016

required. As described in Sub-section B.1.5, side-access from the R/B to the PCV is under examination in preliminary engineering studies for small-scale retrieval. Fig. A7-2 shows the radiation dose rate on the first floor of the R/B by unit as the working environment.

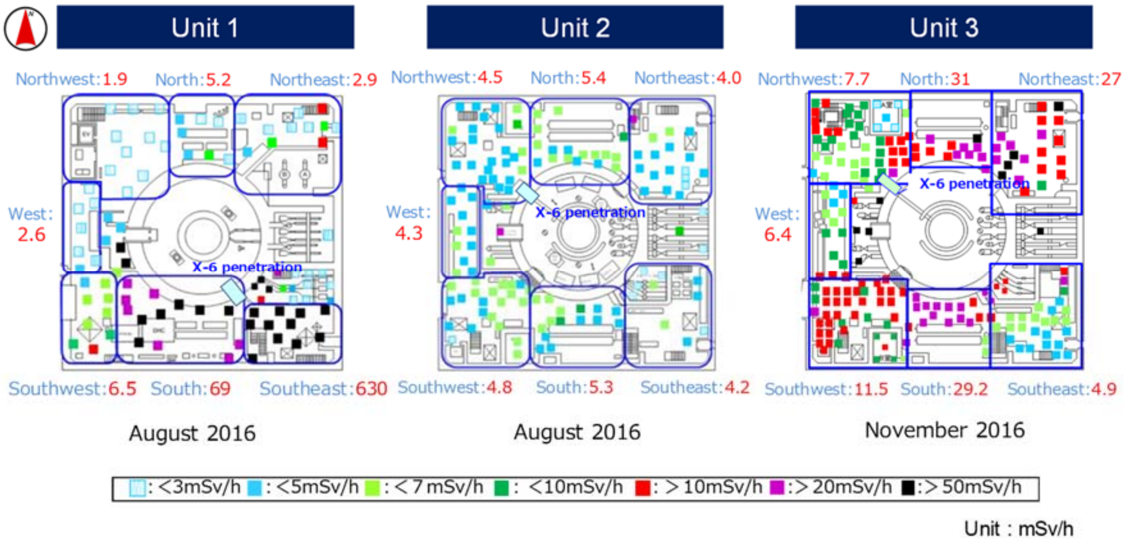


Fig. A7-2 Radiation dose rate on the R/B 1st floor by unit (mSv/h) (Source TEPCO)

The following describes the status of work environment development in each unit, based on Fig A7-2.

Unit 1: Although the radiation dose on the northwest side is relatively low, it is 630 mSv/h around the X-6 penetration (southeast side), making it difficult for workers to approach. Since the AC system piping may be the radiation source, countermeasures such as removal or shielding are necessary to secure the working environment. The radiation dose on the south side is also high, which may be affected by the DHC system. Thus, similar countermeasures are required.

Unit 2: Along with the improvement of the working environment, the radiation dose has been reduced to approx. 5 mSv/h overall. It is possible for workers to work with limitations. Further environmental improvement has been made for the scheduled Investigation A3.

Unit 3: As the working environment, the radiation dose from the southwest side, where the equipment hatch is located, to the northwest side with the X-6 penetration ranges from 6.4 to 11.5 mSv/h. Therefore, manned working hours are limited. While the radiation dose exceeds 10 mSv/h in other areas, it is difficult to execute manned operations. At Unit 3, as shown in Fig. A7-2, the current water level inside the PCV is higher than the first floor surface of the R/B. To secure the working environment, it is necessary to reduce radiation dose on the first floor of the R/B first so that workers can install drainage systems.

B.1.4 Site-wide planning

(1) Fuel removal from spent fuel pools

As the site-wide plan, the status of fuel removal from SFP, where operational interference with fuel debris retrieval is expected, is shown below.

Unit 1: Removal of rubble from the operating floor is underway. Fuel removal from the SFP is planned to be initiated in 2023 subsequent to the maintenance of the operating floor and installation of the fuel removal equipment.

Unit 2: The operating floor investigation is ongoing. Fuel removal from the SFP is planned to be initiated in 2023 subsequent to the improvement of environment on the operating floor and installation of the fuel removal equipment.

Unit 3: Fuel removal started in April 2019 and is scheduled to be completed in FY 2020.

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

(2) Contaminated water management

Treatment of stagnant water in the buildings of each unit is scheduled to be completed within FY 2020. In small-scale retrieval, the existing water circulation system will be used. In association with retrieval, sampling from stagnant water transfer lines and water treatment systems is planned for verification on the effect of fuel debris outflow from the drywell. The impact on the water treatment systems should also be verified. In expanded-scale retrieval, required safety systems will be examined. With consideration for system development to achieve containment functions during fuel debris retrieval, from now it should be coordinated with contaminated water management.

(3) Waste management

It is necessary to consider storage of waste generated along with fuel debris retrieval. Because of the limited size of the containers to be carried out of the PCV in small-scale retrieval, basically, the amount of waste for off-site transfer is also limited. Scale of retrieval is small and existing systems such as safety systems are repurposed, so no significant change in the amount of waste is expected from maintenance, inspection and other activities. In expanded-scale retrieval, the amount of waste to be carried out, including obstacles, and the system scale are large, so a plan to calculate the amount of waste and store it needs to be implemented in alignment with the retrieval plan.

B.1.5 Study through the preliminary engineering

There are two phases of fuel debris retrieval; Small-scale retrieval and expanded-scale retrieval. As mentioned in Sub-section B. 1.1 (3), investigation on small-scale retrieval are ongoing through the preliminary engineering, and actual site applicability are getting in sight. For expanded-scale retrieval, the methods (side-access, upper-access) forward effective fuel debris retrieval are under investigation through the Government-led R&D program on decommissioning and contaminated water management. However, it is requested to accumulate safety system operation experiences (containment function (gas, liquid), criticality) and information of the circumstances inside the PCV (including characteristics of fuel debris), also requested to conduct further R&D activities in order to realize safe and reliable retrieval of fuel debris.

The following shows that the progress of each technical requirement based on the study for fuel debris retrieval method as well as actual site applicability so far, through preliminary engineering.

(1) Establishing the containment functions

At present, the containment functions are stably maintained by using existing gas and liquid phase systems (gas management systems, water circulation systems, etc.). To establish concerned systems for fuel debris retrieval, the impact analysis on the existing containment functions should be performed. Fuel debris retrieval work will lead to changes the condition of fuel debris. In particular, there is a risk regarding dispersion of radioactive airborne particles due to fuel debris crushing work. Therefore, safety analysis and measures are required.

As for the gas phase, it has been confirmed that airtightness in Unit 2 is the highest of the three units according to operating experience so far (airtightness in Unit 1 is slightly lower than Units 2, Unit 3 is the lowest). Small-scale retrieval work in Unit 2 will start using equipment such as gripping and sucking as shown in (6). With regard to gripping and sucking, no significant impact on the atmosphere was observed A2'' investigation (February 2019) which contacted with deposit inside the pedestal. Therefore, the risk of fuel debris dispersion might be low. Thus, it has evaluated that the containment functions in each unit can be secured by existing safety systems. In preliminary engineering, PCVs depressurization by the existing gas management system and dust monitoring for the inside/outside R/B are planned because the pressure inside of the PCVs are positive as shown in Fig.A7-3. Then, safety environment will be enhanced. Regarding crushing work such as cutting fuel debris, safety analysis and study on the necessity of concerned safety systems depending on the scale of fuel debris retrieval should be conducted ON the other hand, detailed study regarding the expansion of the access area inside the pedestal will be required due to the possibility of removing obstacles as shown in (5).

As for the liquid phase, no significant impact on the outside was identified while Investigation A2'' (February 2019) as well as gas phase. Therefore, it has evaluated that the containment functions in each unit can be secured by existing safety systems. The design concept that enables strict monitoring has been established, where dedicated monitoring system for contaminated water installed in the existing water treatment system as shown in Fig. A7-4.

Preparation of safety analysis and safety systems according to the fuel debris retrieval method is mandatory in order to ensure containment functions in expanded-scale retrieval. In this case, safety analysis should be performed properly based on input data in line with the conditions at Fukushima Daiichi NPS.

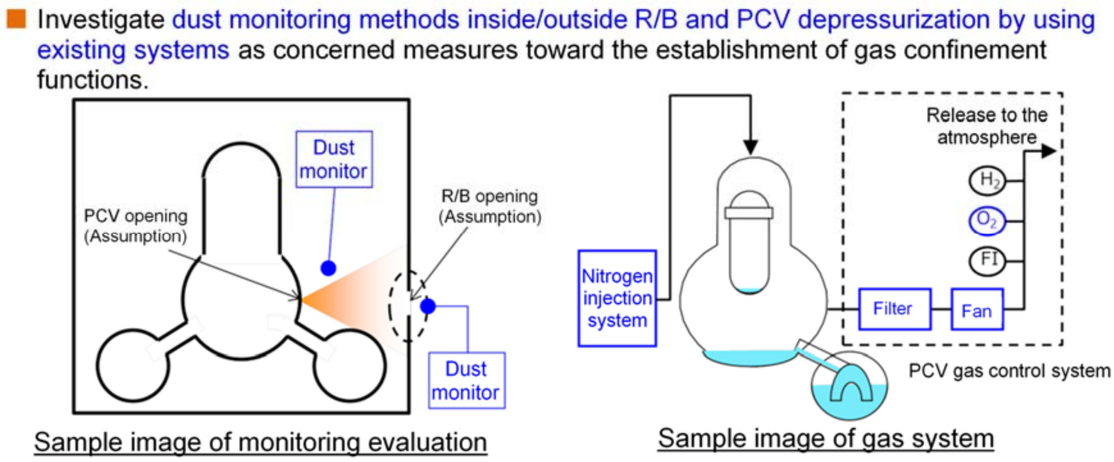


Fig. A7-3　Outline of safety system study on small-scale fuel debris retrieval
(Data provided by TEPCO)

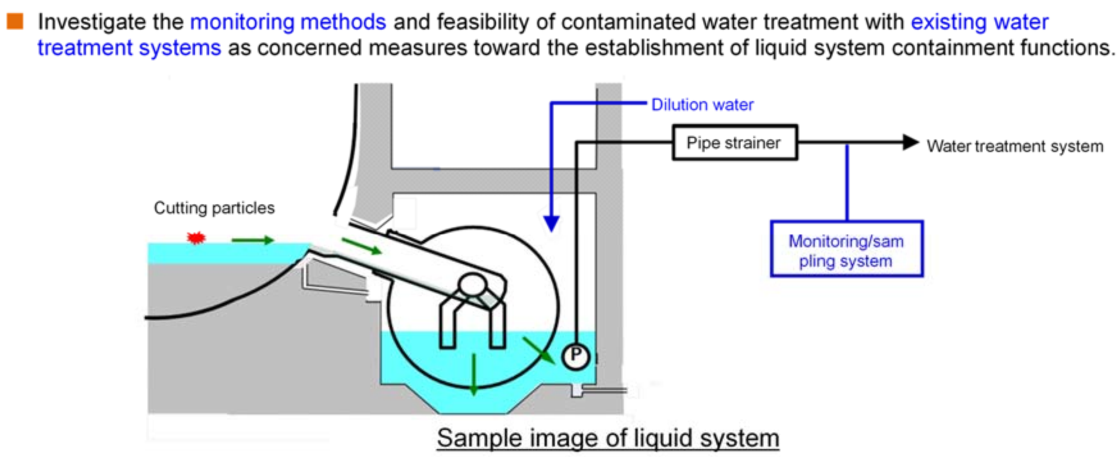


Fig. A7-4　Outline of safety system study on small-scale fuel debris retrieval
(Data provided by TEPCO)

(2) Maintaining cooling functions

The fuel debris cooling around several cubic meters per hour as injection flow rate continues in each unit by using the existing water recirculation system. Therefore, the cooling functions are basically maintained by continuous water injection. Even if current operation has no impact on existing systems during small-scale retrieval, appropriate management (i.e. maintenance or preparation of procedure) is strictly requested to ensure continuous operation.

In order to secure cooling functions while expanded-scale retrieval, dedicated studies should be performed depending on the retrieval method to be applied in each unit.

(3) Ensuring structural integrity of the PCVs and buildings

It is considered that PCVs and the buildings of each unit are not in a situation that would immediately pose a problem in terms of structural integrity. In the present small-scale retrieval plan, the equipment with a weight that is within the acceptable building floor loads will be used without modification, such as expanding existing penetration. Therefore, no impact on the structural integrity of the PCVs and buildings is expected.

On the other hand, there is a possibility of modification because the equipment to be used for expanded-scale retrieval affects the structural strength of existing structures and buildings. For assessment on actual site applicability for each unit, therefore, modification of the equipment itself and PCVs/buildings associated with equipment installation should be considered.

(4) Criticality control

Although fuel debris currently remains in a subcritical state, it is necessary to analyze and evaluate the possibility of criticality due to retrieval or its influence when changing the state of fuel debris caused by retrieval, and to examine necessary and sufficient countermeasures.

With high uncertainty in fuel debris properties and limitations in control by prior calculation, design and engineering, it is important to ensure prevention of criticality with combination of monitoring and judgment during retrieval.

In the case of gripping/sucking without fuel debris crushing, criticality is unlikely to occur. As shown in Fig. A7-5, however, examinations should be made on criticality prevention, detection methods, impact of criticality if it occurs, and countermeasures during fuel debris fabrication.

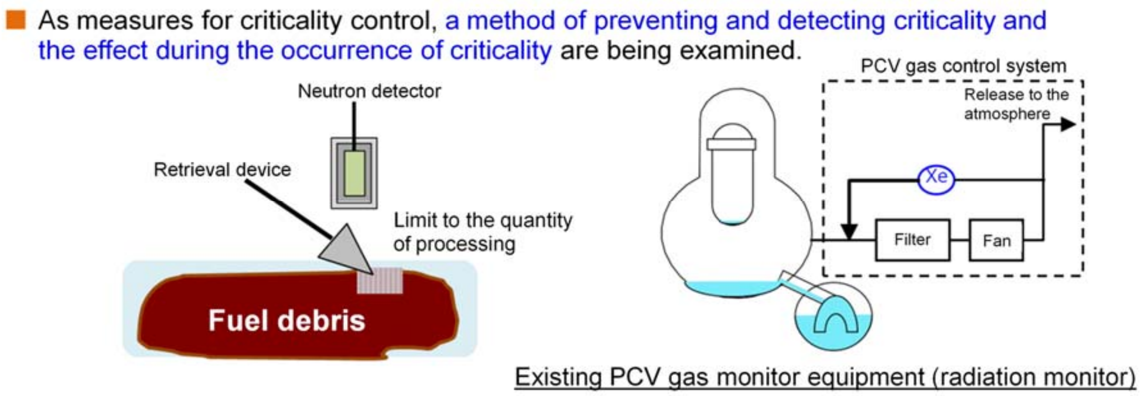


Fig. A7-5 Outline for safety system study on small-scale fuel debris retrieval (Data provided by TEPCO)

(5) Establishment of access routes to fuel debris

Based on the “Policy on Fuel Debris Retrieval”, when retrieving fuel debris by the partial submersion method accessing the bottom of the PCV from the side, there are candidate access penetration openings such as X-1, X-2 and X-6, it is considered most efficient to access the inside of the pedestal linearly from the existing X-6 penetration through the CRD opening of the pedestal based on the structure of the bottom of PCV.

Although it is necessary to establish appropriate access routes for each unit, as shown in Sub-section B. 1.2, currently, available information on access routes to fuel debris (access routes from the pedestal opening to the pedestal bottom, etc.) is limited to only for Unit 2 and Unit 3. (Fig. A7-6 shows an image of small-scale fuel debris retrieval using an X-6 penetration). However, according to the results of the internal investigation of Unit 2 and Unit 3, the access range within the pedestal may be restricted due to obstacles such as gratings and frame structures. Therefore, it is necessary to examine the removal of the obstacles as well to secure the access range within the pedestal.

Methods of expanded-scale retrieval (side access and top access methods) are still at the stage of studying the concept. Therefore, further study is required to establish access routes on the device for expanded-scale retrieval in accordance with the application of the retrieval method of each unit.

- It is possible to install the device for small-scale fuel debris retrieval on the first floor of the R/B, as in the case of the sampling system being developed by governmental program, and the device capable of accessing inside the PCV with existing through-holes (X-6 penetration) is under examination.
- For the safety system of small-scale fuel debris retrieval work (gas management facilities and water treatment system), modification of a part of the existing facilities is examined. Whether it will be actually modified or not, as well as the area to be modified, will be determined based on the results of risk assessment during fuel debris retrieval.

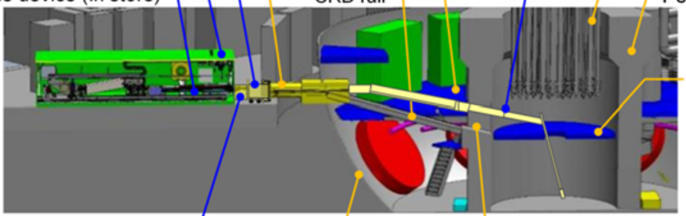


Fig. A7-6 Image of small-scale fuel debris retrieval with X-6 penetration (provided by TEPCO)

(6) Development of fuel debris retrieval devices and equipment

For retrieval of fuel debris, it is necessary to continuously retrieve fuel debris from the PCV. Retrieval devices and equipment for the purpose should be capable of getting closer to the location of fuel debris relatively easily and need to have a certain level of load capacity and containment function.

Access devices such as ROV-type, telescopic-type and arm-type have been developed as a part of the Governmental-led R&D program on Decommissioning and Contaminated Water Management (sampling technology for retrieval of fuel debris and internal structures), device to be used for small-scale retrieval is planned in the preliminary engineering based on the arm-type access equipment being developed, such as ROV-type, telescopic-type and arm-type as a part of the Government-led R&D program on Decommissioning and Contaminated Water Management (sampling technology for retrieval of fuel debris and internal structures). The arm-type access equipment is based on the boom-type arm proven in JET (Joint European Torus), UK, and the same device is scheduled to be used for the detailed internal investigation in this Government-led R&D Program. This method was chosen as the best for accessing inside and outside of the pedestal in the PCV without affecting the structure and using the existing X-6 penetration and CRD opening (See Fig. A7-7 for the conceptual diagram.).

The arm-type access equipment is designed to be stored in the enclosure with containment performance shown in Fig. A7-8 and be installed on the 1st floor of R/B.

Review is underway for the tools for gripping and sucking as shown in Fig. A7-9 based on the results of the A2'' investigation (February 2019), and they are designed to be attached to the arm-type access equipment respectively.

As for maintainability, it is designed such that parts can be cleaned and replaced during operation in the enclosure. Specifically, when the arm-type access equipment that was used for the work inside the PCV is returned to the enclosure, it can be cleaned to remove contamination, and as shown in Fig. A7-8, the enclosure is equipped with a double arm manipulator to replace tools, measuring instruments, cameras, lighting fixtures, and parts of the arm-type access equipment.

A system is being studied in which the debris retrieval container to be carried into the enclosure from inside the PCV will be placed in a sealed container inside the enclosure and delivered to a shielded on-site transport container. It is possible to carry in the parts and the like to be replaced inside the enclosure through the port. However, in the event of a failure of the arm-type access equipment itself, the arm-type access equipment needs to be removed for maintenance by a means that will prevent contamination from fuel debris from spreading inside and outside the R/B. In the preliminary engineering, the area and equipment for carrying out the enclosure for maintenance are under study. In addition, the response in the event of an abnormal situation is examined on the assumption of an accident scenario.

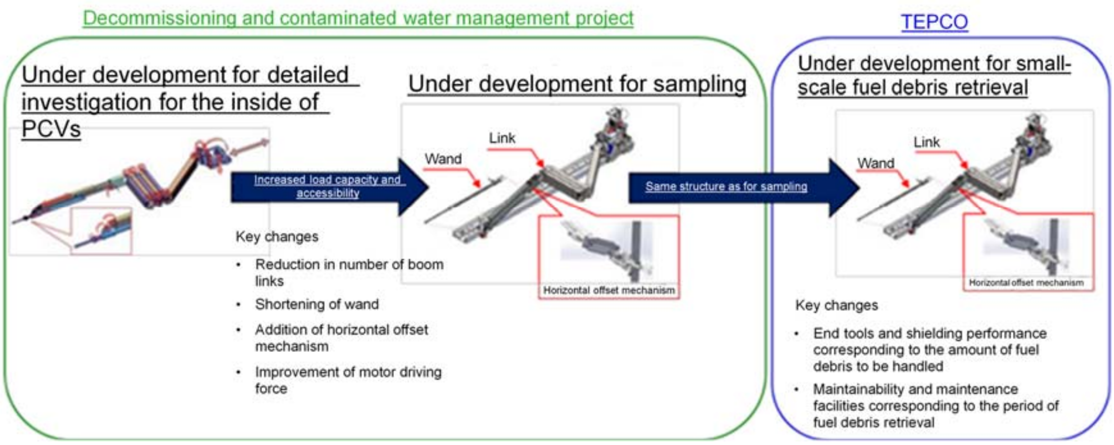


Fig. A7-7 Conceptual diagram of small-scale retrieval devices (TEPCO materials edited by NDF).

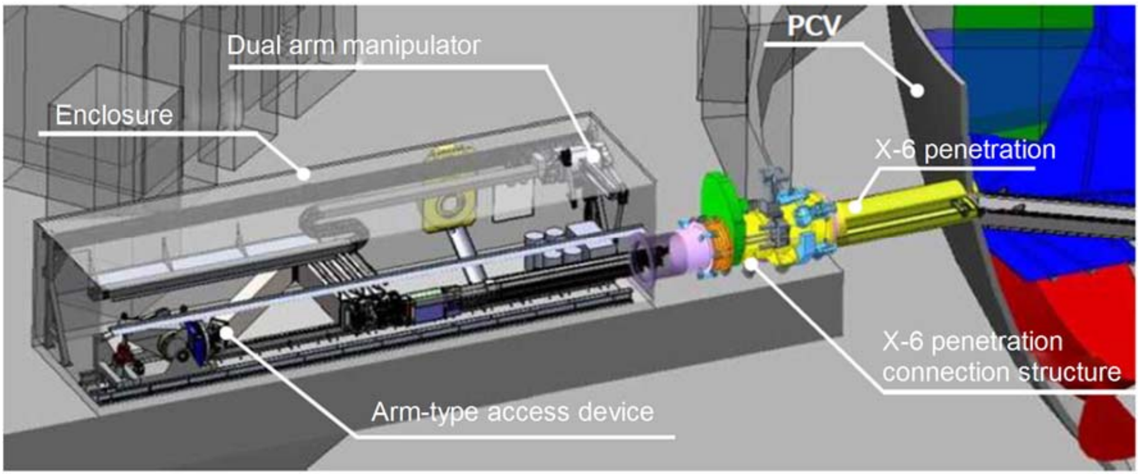


Fig. A7-8 Conceptual diagram of enclosures (for storing arm-type access equipment) (provided by TEPCO)

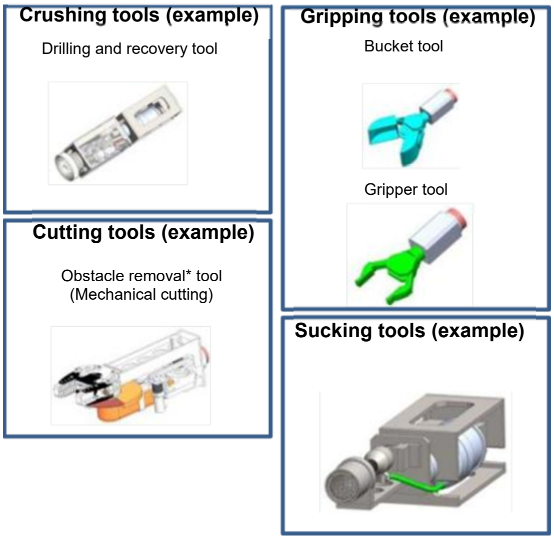


Fig.A7-9 Gripping, Sucking, and Cutting Tools (example) (provided by TEPCO)

Operation of retrieving fuel debris has the following unique difficulties.

[1] Retrieval period will be long.

[2] Harsh environment and many uncertainties such as working in a high radiation dose environment.

[3] Having no prior example, technical difficulties are high.

[4] Preparation for retrieval work needs to be conducted while developing the methods.

In light of these issues, in order to ensure technical safety and reliability of the decommissioning project at the Fukushima Daiichi NPS, it is necessary to develop a method for retrieving fuel debris and establish reliable operation procedures and maintenance methods prior to the introduction of remote control equipment at the site for retrieving fuel debris. In addition, it is necessary to utilize mock-up tests (hereinafter referred to as “remote mock-up test”) and VR (virtual reality) of the remote equipment in order to carry out the field work accurately. What is important about the remote mock-up tests for the retrieval of fuel debris at the Fukushima Daiichi NPS is, from the viewpoint of confirming the performance of remote equipment as well as training and development of operators, aligning the facilities appropriately before the tests are conducted so that the on-site conditions can be reproduced. For this purpose, planning shall be made rationally based on risk assessment, and considerations shall be made about the environment that will be revealed gradually over the long period of fuel debris retrieval period and may change unexpectedly.

Also, when retrieving fuel debris, through cutting, etc., α-nuclides diffuse into the air and water, causing internal exposure to workers. For this reason, it is necessary to establish criteria for air and water concentrations of α-nuclides, conduct appropriate monitoring, and determine necessary protective equipment. Furthermore, work efficiency can be lowered when handling heavy or long objects such as constructing work cells due to protective equipment, and safety management for workers is also necessary. Therefore, it is desirable to conduct a risk assessment before starting the work and to educate and train workers.

As for the development of devices and equipment for expanded-scale retrieval, conceptual studies and element technology development are being carried out in the Government-led R&D Program. However, further R&D, such as the development of technology to control dust scattering during retrieval is required, and engineering based on such R&D results will be necessary going forward. Fig. A7-10 shows an example of expanded-scale retrieval device and equipment.

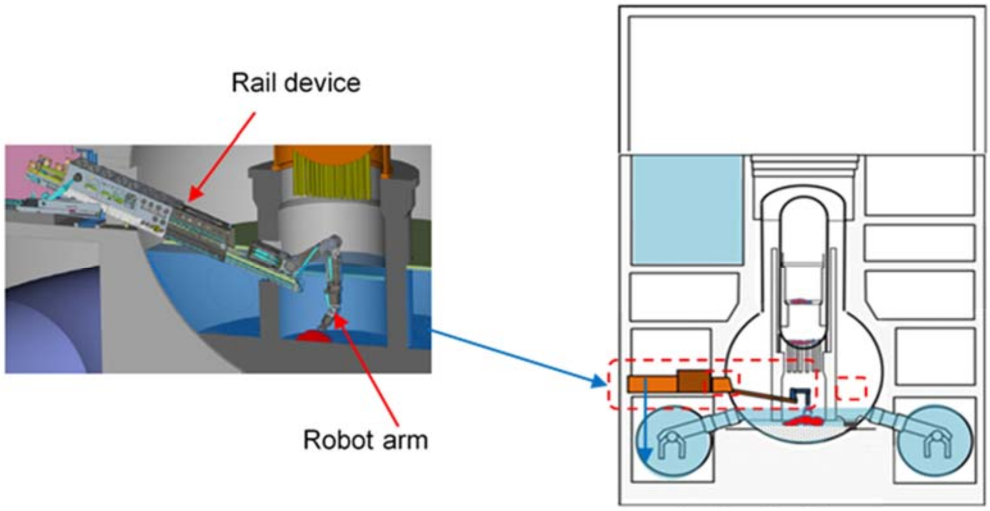


Fig. A7-10 An example of expanded-scale retrieval device and equipment (Provided by IRID)

(7) Establishment of system equipment and working areas

For system equipment to be prepared to ensure required safety functions, it is planned that the existing safety systems will be used for small-scale retrieval. In addition, strengthening of monitoring (radiation, water sampling, etc.) is planned in order to ensure the change of retrieval work.

* Gas management system, water circulation system and emergency boric acid injection system (some parts will be modified), as described in (1)

At present, safety requirements for the expanded-scale retrieval are being investigated. For establishing area to install the retrieval equipment and system equipment, requirement for the area is now being calculated. Dedicated study on the possibility of using areas outside of the existing buildings is ongoing, and also application of high radiation dose areas in the reactor building and interference with other projects are under study.

(8) Development of methods for containing, transferring and storing retrieval fuel debris

Preliminary engineering is studying a series of operations from retrieval of fuel debris to their temporary storage for a small-scale retrieval as shown in Fig. A7-11.

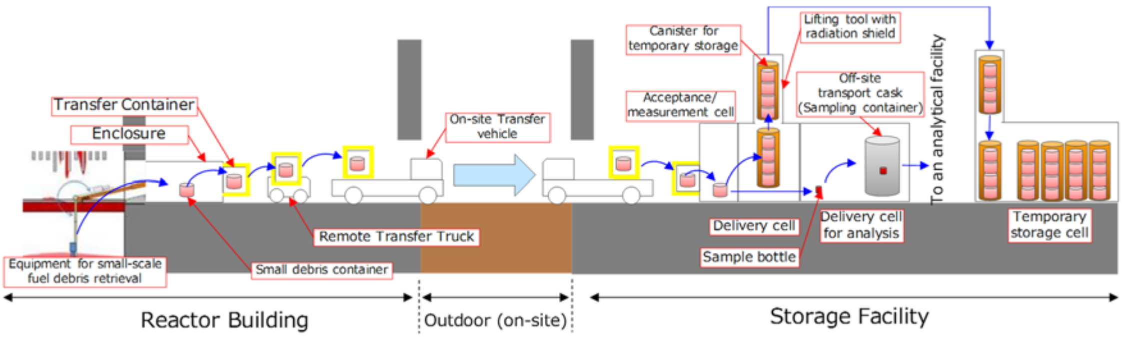


Fig. A7-11 Working image for small-scale retrieval
(TEPCO material edited by NDF)

Concepts as of today are as follows.

1) Fuel debris retrieved from the bottom of the PCV is contained in a small debris container and transferred into an enclosure tightly connected to the PCV.
2) The fuel debris contained in a small debris container is then contained into a transfer container connected to the enclosure, and transferred to the acceptance/ measurement cell by an on-site transfer vehicle.
3) The transferred transfer container is connected to the acceptance/ measurement cell and the fuel debris is taken out from the transfer container into the acceptance/measurement cell together with the small debris container. In the

acceptance/measurement cell, the fuel debris contained in a small debris container is measured (weight, radiation dose rate, surface nuclide composition, etc.) and treated (drying, etc.) as required for temporary storage. Thereafter, the fuel debris in a small debris container is moved from the acceptance/measurement cell to the delivery cell. There, it is contained in a canister for temporary storage, and moved and stored in a temporary storage cell using the lifting tool with radiation shield.

4) Some fuel debris are moved from a delivery cell to an delivery cell for analysis, where samples for analysis are taken out from the small debris container to be filled into a sampling confinement bottle, and the sampling confinement bottle is contained in a sampling container, then the sampling container is contained in an off-site transport cask and transported to the analytical facility.

Basic design of facilities and equipment shall be made based on these concepts, and they shall be available for use at the start of the small-scale retrieval. As for the storage location, preliminary engineering is studying candidate areas for the temporary storage inside of the Fukushima Daiichi NPS.

At present, conceptual study on storage facilities for expanded-scale retrieval is ongoing in preliminary engineering. The issue is to secure a space stable storage of the retrieved fuel debris, and required facilities shall be prepared through detailed study.

(9) Fuel debris retrieval scenario for each unit

In the process of determining the method of retrieving fuel debris for the first implementing unit, basic elements constituting the fuel debris retrieval scenario are site environment preparation (dose reduction, water level lowering in PCV, etc.), PCV internal investigation, small-scale retrieval (horizontal access), and expanded-scale retrieval (horizontal access, top access). The following describes the scenarios based on the conditions of each unit. Since the expanded-scale retrieval method is still in the conceptual study stage, access route construction of the expanded-scale retrieval equipment should be studied in accordance with the application of the retrieval method of each unit.

Unit 1: Radiation dose around the X-6 penetration, which has linear access to the inside of the pedestal and is considered useful for retrieving fuel debris in the pedestal, is high, and radiation dose reduction should be done if this penetration is to be used. Once access routes are secured, PCV internal investigations will start, followed by small-scale retrieval and expanded-scale retrieval. Research development and technology development are required going forward as well for the expanded-scale retrieval, and actual site applicability needs to be examined based on these studies in order to materialize it.

Unit 2: PCV internal investigation is in progress, and improving site work has advanced the most.

Furthermore, there is a prospect that the small-scale retrieval can be possible considering situations surrounding the X-6 penetration, so it will start from small-scale retrieval (Horizontal Access). In order to make the long-term field work possible, improvement of the working environment needs to be made continuously. R&D and technology development are required going forward as well for the expanded scale retrieval, and actual site applicability needs to be examined based on these studies in order to materialize it.

Unit 3: PCV water levels must be lowered in order to use the X-6 penetration. In addition, radiation dose reduction in the R/B is required in order to implement the work in the R/B continuously. Once access routes are secured, PCV internal investigations will start, followed by small-scale retrieval and expanded-scale retrieval. R&D and technology development are required going forward as well for the expanded-scale retrieval, and actual site applicability needs to be examined based on these studies in order to materialize it.

Based on the preliminary engineering results described in (1) to (9) above, Table A7-3 and Table A7-4 show results of the conceptual study of retrieval as well as results of actual site applicability study for each unit from the point of interest based on the guiding principles of NDF, which consists of 5 viewpoints “safe”, “proven”, “efficient”, “timely”, and “field-oriented”.

Table A7-3 Retrieval Concept Study Results (1/2)

Viewpoints	Point of interest	Target	Small-scale retrieval (Horizontal Access) (Retrieval work without significant change of the site condition)	Expanded-scale retrieval (Horizontal Access, Top Access) (Retrieval that significantly changes conditions of the site)
Safe	Establishment of the containment function for radioactive materials	Since the radioactive materials concentration inside PCV may change due to the retrieval of fuel debris, perspective of applicability on the containment function against the radioactive materials shall be investigated from the view point of radiation exposure on the public and workers.	Since the fuel debris retrieval will start from gripping and sucking at the beginning, the risk on dispersion of dust might be low. In addition, depressurization inside the PCV and monitoring of concerned parameters (i.e. PCV internal pressure, dust monitoring, etc.) during retrieval work will be conducted.	Although conceptual studies and element technology development have been carried out for the expanded-scale retrieval method, technical issues remain to be solved, and further R&D and engineering work are required. Further understanding of the inside of the PCV as well as feedback from the experiences of small-scale retrieval work are also necessary. For this reason, evaluation of the expanded scale retrieval method will be conducted when the details of the retrieval method are determined.
	Maintaining the cooling functions	Prospect of applicability on the fuel debris cooling function that can secure current condition shall be investigated.	Application of the arm-type access equipment enables to maintain the operation of existing water injection cooling system during retrieval work. Thus, the cooling function is to be maintained.	
	Ensuring the structural integrity of PCVs and buildings	Prospects shall be obtained that impact on the structural strength of existing PCVs and buildings by retrieval related equipment, which is planned to be installed anew, is allowable value. When an existing facility is changed from the present state, such as openings are enlarged, the prospects of the structural integrity shall be obtained regarding the enlarged opening (such as X-6 penetration) or a newly installed device in design case and beyond-design case.	Since the arm-type access equipment is brought in from the existing large equipment carrying-in opening without expanding the existing X-6 penetration, no new opening is generated and the equipment is installed within the allowable floor load of the existing building, so there is no impact on the integrity.	
	Criticality control	Prospects shall be obtained that criticality monitoring and prevention measures at the time of fuel debris retrieval are valid.	Since no new criticality risk exists at the initial stage of small-scale retrieval of fuel debris (gipping and sucking), no particular change from the current situation is considered necessary. However, when the retrieval includes working on fuel debris, such as cutting and fuel debris retrieval, it is desirable to limit the volume of the work or have the work conducted under neutron monitoring until the properties of fuel debris are confirmed.	
	Securing labor safety	Prospects shall be obtained that labor safety is secured and radiation exposure of workers is reasonable considering as well the viewpoint of establishing working environments (radiation dose reduction) at the time of preparatory construction work and retrieval work.	At present, environmental improvement plans such as radiation dose reduction in the R/B for each unit have been drafted and started. Also, the arm-type access equipment is the same device as investigated in the A3, and the learning effect such as mock-up training is expected.	

Table A7-3 Retrieval Concept Study Results (2/2)

Viewpoints	Point of interest	Target	Small-scale retrieval (Horizontal Access) (Retrieval work without significantly change conditions of the site)	Expanded-scale retrieval (Horizontal Access, Top Access) (Retrieval that significantly changes conditions of the site)
Proven	Development of equipment/device for fuel debris retrieval	Prospects shall be obtained for securing required functions and capabilities on devices and equipment used for fuel debris retrieval.	Prospects have been obtained that it will be applicable to the field, as specific design work is in progress for works such as fuel debris gripping, sucking, removing obstacles, and cutting by the similar equipment as A3 investigation equipment (arm-type access equipment.).	Although conceptual studies and element technology development have been carried out for the expanded-scale retrieval method, technical issues remain to be solved, and further R&D and engineering are required. Further understanding of the inside of the PCV as well as feedback from the experiences of small-scale retrieval work are also necessary. For this reason, evaluation of the expanded-scale retrieval method will be conducted when the details of the retrieval method are determined. At present, concept of storage facilities for expanded-scale retrieval has been studied in preliminary engineering. The issue is to secure an area that can be used stably, and details for storage facility shall be determined and required facility shall be prepared going forward.
	Establishment of system/equipment and working areas	Prospects of applicability of system/equipment for safe operation (modification of existing facilities, etc.) during fuel debris retrieval shall be investigated and required working areas for retrieval work can be secured.	The safety evaluation study has been performed and verified that the early phase of small scale retrieval work (by gripping and sucking) can be done. Removal or obstacles or fuel debris retrieval by crushing might require detail safety evaluation and additional safety system depending on the evaluation results.	
	Establishment of methods for containing, transferring and storing retrieved fuel debris	Prospects shall be obtained that the method of containing and transferring retrieved fuel debris can really be available and that the temporary storage facilities can really be ready. In addition, prospects shall be obtained that waste generated at the time of retrieval can be stored appropriately.	Designs are in progress for transfer method for retrieved fuel debris including transfer containers, as well as a cell for receiving the transferred fuel debris and delivering a storage container and an analysis sample. Plans of a temporary storage facility for retrieved fuel debris is being examined. TEPCO is considering area for temporary storage within site. The volume of generated waste is not significant matter at the initial stage of the small scale fuel debris retrieval because a volume of fuel debris is not large at this stage and retrieval operation will be done by using existing safety equipment.	
Efficient	Validity of the fuel debris retrieval plan	Plans to be utilized for the next step (including transfer knowledge to the other units) shall be confirmed depending on the information (applicability of technology, impact on environment, etc.) through the first implementing unit retrieval work.	In order to accumulate necessary information for the expanded-scale retrieval and the retrievals in units other than the first implementing unit, dedicated impact analyzes on various operations, crushing work and securing safety will be performed through the first implementing unit retrieval work.	
Timely	Early commencement of fuel debris retrieval	Possibility of early commencement of fuel debris retrieval shall be confirmed.	Small scale debris retrieval work in the first implementing unit enables to get fruitful information and experience for the expanded-scale retrieval work and the units other than the first implementing unit. Thus, the risk of fuel debris will be reduced.	
Field-oriented	Maintainability (maintenance and troubleshooting)	Maintainability and troubleshooting availability at the time of an anomaly, adjustable for the length of retrieval duration, for each device, and waste generated at the time of maintenance are considered, since it is not easy for a person to directly perform maintenance on devices used for the fuel debris retrieval.	The small-scale retrieval device (arm-type access equipment) is assumed to be used for an order of several years, and maintainability is considered. Further, since the device is same as the one used for the internal investigation, it is expected to have a proficiency effect such as mock-up training.	
	Operability	In order to ensure stable operation of fuel debris retrieval, consideration shall be given to securing operability, validating through mock-ups, and securing operator expertise, for remote operation of devices used for fuel debris retrieval.	With regard to the small-scale retrieval device (arm-type access equipment), feedback from results of the A3 investigation and a proficiency effect such as mock-up training are expected.	

Table A7-4 Study result of actual site applicability for each unit (1/2)

Viewpoints	Point of interest	Details	Conditions of each unit			Evaluation
			Unit 1	Unit 2	Unit 3	
Safe	Reduction of radiation exposure of workers (radiation dose in the workplace)	Prospects shall be obtained that labor safety is secured and radiation exposure of workers is reasonable considering as well the viewpoint of establishing working environments (radiation dose reduction) at the time of preparatory construction work and retrieval work.	Radiation dose rate around the X-6 penetration, which is suitable for the arm-type access equipment, is high (630 mSv/h).	As radiation dose rate on the first floor of the R/B is about 5 mSv/h, the working environment in which workers carry out their work is expected to be secured even though with some limitations.	Environmental radiation dose rate on the first floor of the R/B is several to several tens of mSv/h or more, making it difficult for workers to work there.	Radiation dose at the workplace of Unit 2 is considered to be the lowest compared to other units. For Unit 2, further radiation dose reduction has been implemented for the A3 investigation (which is to be conducted going forward).
	Securing a function of containing radioactive materials	Since the radioactive materials concentration inside PCV may change due to the retrieval of fuel debris, perspective of applicability on the containment function against the radioactive materials shall be investigated from the view point of radiation exposure on the public and workers.	• Currently, air tightness is slightly secured. It is estimated that air tightness might be kept after the water level in PCV comes down. • At present, opening area of the liquid phase is assumed to be same as the gas phase.	• At present, air tightness is highly secured. It is the reason why Unit 2 was not affected by the hydrogen explosion and integrity of the building is still maintained. On the other hand, when the PCV water level will come down, reduction of air tightness shall be taken into consideration. • Currently, it is assumed that opening area is in the liquid phase (S/C submerged portion).	• At present, the air tightness is less than that of Units 1 and 2. And the opening area has not been evaluated. • Dedicated test to accumulate necessary data for calculating opening area and evaluation is required.	It is established that the function of containing radioactive materials in Unit 2 is the highest compared to other units.
Proven	Status of fuel debris	Prospects shall be obtained regarding risk reduction effects from retrieval work execution, based on the investigation of fuel debris status in the target area for fuel debris retrieval.	Based on the analysis conducted so far, it is assumed that a small amount of fuel debris is present at the bottom of the pressure vessel, that most of the fuel debris is present at the bottom of the PCV, and that fuel debris may have spread to the outside of the pedestal through the worker entrance. On the other hand, at present, no information on deposits that are thought to be fuel debris has been obtained from internal investigations, etc.	Based on the analysis conducted so far, it is assumed that a large amount of fuel debris is present at the bottom of the pressure vessel, that a certain amount of the fuel debris is present at the bottom of the PCV, and that fuel debris spread to the outside of the pedestal through worker entrance is estimated to be small. At the bottom of the PCV, part of fuel assemblies was identified, and deposits thought to be fuel debris are confirmed to be movable.	Based on the analysis conducted so far, it is assumed that some amount of fuel debris is present at the bottom of the pressure vessel, that a larger amount of the fuel debris compared with Unit 2 is present at the bottom of the PCV, and that fuel debris may have spread to the outside of the pedestal through worker entrance. At the bottom of the PCV, deposits that may be fuel debris have been identified.	As for Units 2 and 3, information on the status of fuel debris is available, and prospects are considered to be obtained regarding risk reduction effects by carrying out the retrieval work. In Unit 2, part of the fuel assemblies was found at the bottom of the PCV, and it is somewhat more likely than at Unit 3 that the deposits at the bottom of the PCV are fuel debris.

Table A7-4 Study result of actual site applicability for each unit (2/2)

Viewpoints	Point of interest	Details	Conditions of each unit			Evaluation
			Unit 1	Unit 2	Unit 3	
Proven	Establishment of access routes to fuel debris	Prospects shall be obtained for the feasibility of routes inside and outside the building to access the fuel debris.	• Situations surrounding the X-6 penetration have not been identified for both inside and outside of the PCV, but access to the bottom of the PCV outside the pedestal is possible from the top of the grating outside the pedestal. • However, situations surrounding the CRD rail that connects the X-6 penetration and the inside of the pedestal and situations surrounding the worker entrance have not been confirmed, and currently no information is available about access routes to the inside of the pedestal where most of the fuel debris is thought to be present. • From the analysis and the estimation based on the results of the internal investigation of other Units, damage and falling objects equivalent to those of Unit 3 are expected to exist in the internal structure of the reactor.	• Situations surrounding the X-6 penetration have been identified both inside and outside the PCV, and situations surrounding the CRD rail that connects the X-6 penetration and the inside of the pedestal have also been identified, providing information on the access routes to the inside of the pedestal where a certain amount of fuel debris presumed to exist. • Damage to the reactor internals (CRD housings, CRD exchangers, platforms, etc.) are limited, but there are obstacles on the access route, and many items such as CRD exchangers and gratings become obstacles when the retrieval scope is expanded.	• Regarding the situations surrounding the X-6 penetration, the radiation dose outside the PCV is higher than that of Unit 2. • Situations surrounding the CRD rail that connects the X-6 penetration and the inside of the pedestal have been identified, and information on access routes to the inside of the pedestal where many fuel debris may be present has been available. • On the other hand, there are many fallen objects, the bottom of the PCV is covered with deposits, and there are many obstacles. In addition, due to the high water level inside the PCV, it is necessary to lower the water level in order to use the X-6 penetration for retrieval. • PCV water level is high, and lowering of the water level is necessary to use the X-6 penetration.	For Units 2 and 3, information on access routes to fuel debris is available, and the prospects are believed to be clear regarding the routes inside and outside the buildings for access to fuel debris. However, in both Units 2 and 3, obstacles exist on the access route, and it is necessary to remove them. There are more fallen objects and more obstacles in Unit 3.
Timely	Early commencement of fuel debris retrieval	Possibility of early commencement of fuel debris retrieval shall be confirmed based on the evaluation of preparatory work volume and schedule.	As a preparatory work for the fuel debris retrieval, reduction of the radiation dose around the X-6 penetration is necessary (removal of high radiation dose piping, etc.) for the installation of the arm-type access equipment. But this preparatory work may take a long time because careful work is mandatory.	Establishment of work area is in progress for the fuel debris retrieval. And it is evaluated that preparation for the environment around the X-6 penetration is the most advanced.	Lowering the water level of the PCV is required as preparatory work for the fuel debris retrieval. As reduction of the radiation dose around the X-6 penetration is required in order to install the arm-type access equipment, and the preparation is expected to take time.	Since the establishment of the work area is most advanced in Unit 2, early commencement of the fuel debris retrieval can be possible.
Field-oriented	Workability (site conditions, consideration for surrounding construction)	The impact of field conditions of each unit (impact on fuel removal from SFP, etc.) and interference with surrounding construction, etc., shall be adjustable and consideration shall also be given to waste generated during the work.	• There is a concern about interference with the fuel removal work from SFP, but it is considered to be avoidable by adjusting the work of the upper side and lower side. • There is a concern about interference with environmental preparation work (radiation dose reduction, removal of obstacles, etc.) on the first floor of the R/B.	• There is a concern about interference with the fuel removal work from SFP, but it is considered to be avoidable by adjusting the work of the upper side and lower side. • Preparation of the environment on the first floor of the R/B (radiation dose reduction, removal of obstacles, etc.) is most advanced, and concern about interference with the work is the least there.	• There is a concern about interference with the fuel removal work from SFP, but it is considered to be avoidable by adjusting the work of the upper side and lower side. The adjustment period for the upper side work and lower side work will be the shortest as the fuel removal from SFP is expected to be completed earliest. • There is interference between environmental preparation work (radiation dose reduction, removal of obstacles, etc.) on the first floor of the R/B and water level lowering work in PCV.	• Interference with the fuel removal work from SFP in each unit are thought to be avoidable by adjusting the work of the upper side and lower side. The concern about interference with environmental preparation work on the first floor of the R/B is the smallest in Unit 2.

B.2 Comprehensive Assessment and Recommendations

B.2.1 Comprehensive assessment

To “determine the fuel debris retrieval method for the first implementing unit”, a comprehensive evaluation for “the fuel debris retrieval method” and “the first implementing unit” should be performed based on the considerations given in Sub-section B.1. Also, based on the Mid-and-Long-term Roadmap, the study on fuel debris retrieval should be promoted as a comprehensive plan aiming at overall optimization, including coordination with other work at the site, from the viewpoint of optimizing the entire decommissioning work. In addition, it is necessary to take into account the peculiarity of the unprecedented fuel debris retrieval work in the uncertain situation of the site at Fukushima Daiichi NPS. Furthermore, experience and information accumulated in advance through the handling of fuel debris from retrieval to storage at the first implementing unit will be expected to be used (feedback) in the planning of the expanded-scale retrieval. Therefore, a highly reliable retrieval method and the first implementing unit should be selected as soon as possible under the condition that safety is secured.

<u>“Method of fuel debris retrieval”</u>

As a “fuel debris retrieval method”, the overall risk resulting from fuel debris at Units 1 to 3 will be reduced by “Promptly” starting a small-scale fuel debris retrieval operation while minimizing the increase in risks associated with the retrieval work, and “Promptly” obtaining information and experience toward the expanded-scale retrieval and the retrieval at units other than the first implementing one. Specifically, “Safe”, “Reliable”, and “Prompt” fuel debris retrieval operation is possible, based on the use of the existing safety systems without significant modification to the site condition, by starting from the methods such as gripping and sucking by employing the arm-type access equipment and air tightened enclosures to contain this equipment, which actual site applicability is getting in sight. In addition, fuel debris retrieval by crushing or cutting other than gripping and sucking also need to be performed without significant modification of existing safety system. Moreover, proposed method of containing, transferring and storing of retrieved fuel debris, that retrieved fuel debris firstly contained in the 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”.

<u>“First implementing unit”</u>

From the viewpoint 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 sufficient information on PCV internal condition and the site condition (radiation dose, degree of air tightness of the existing safety systems) has been obtained as well as that information and experience on fuel debris retrieval work can be promptly obtained by starting its fuel debris retrieval work “safely”, “surely” ad “promptly” based on the site condition such that fuel debris retrieval work and fuel removal work from SFP can be done in parallel. Small-scale retrieval operation starting at Unit 2 enables to reduce risks 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 operations of containing, transferring, and storing should be continued safely and reliably, and then information and experience required for further implementation can be accumulated promptly.

B.2.2 Recommendations for determining the fuel debris retrieval method for the first implementing unit

Based on the comprehensive evaluation, the recommendations are given below for determining the fuel debris retrieval method applicable for 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.

- From the viewpoint of performing the fuel debris retrieval work safely and reliably, actions that lead to change in the site condition should be refrained from as much as possible when the site condition is uncertain. From this point of view, a small-scale retrieval by a system (an arm-type access equipment), whose performance is expected to be verified through the detailed investigations of PCV internal, can minimize the impact on the existing systems, since it does not need significant modification such as expansion., of the existing X-6 penetrations.
- In addition, at the initial stage, fuel debris retrieval should start with small-scale retrieval by methods such as gripping and sucking without cutting/crushing of fuel debris. Consequently, scattering of fuel debris due to such operation and a possibility of criticality can be suppressed, and the impact on existing facilities can be minimized.
- Because a part of fuel assemblies was found at the bottom of the PCV of Unit 2, fuel debris is considered to be present in a certain form, as well as fuel debris (deposits, etc.) may also be present on the grating. These deposits should also be considered as potential fuel debris and the retrieval of them should be considered as well.

[2] Using information and experiences accumulated through fuel debris retrieval operations by gripping and sucking, crushing method for fuel debris retrieval work and removing method of obstacles are to be studied. Fuel debris retrieval work 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.

- From the viewpoint of carrying out fuel debris retrieval safely and reliably, it is considered appropriate at present that fuel debris retrieval will be conducted by using the existing safety systems with minimum changes. Then, it is important to take necessary measures in accordance with the confirmed site condition.
- Crushing/cutting work will definitely be required at a certain stage of the fuel debris retrieval, because some deposits are identified not to be gripped during the deposit contact investigation conducted at Unit 2. Further consideration for crushing/cutting work is required.
- Some obstacles such as gratings and frame structures inside the pedestal are assumed at Unit 2, which is considered to have the best accessibility to the bottom of the PCV. An arm-type access equipment should have functions/capabilities to remove such obstacles.
- Safety equipment for the crushing/cutting of fuel debris and removal of obstacles is also required. Based on safety assessments for this work, preparation of safety system including utilizing of existing safety systems should be studied.

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

- Facilities and equipment for storing the retrieved fuel debris will be designed by considering the properties/characteristics of the fuel debris. A step-by-step approach needs to be taken for the design of the storage facilities. The storage facilities for a small-scale retrieval at the first implementing unit needs to be designed with safety margin derived from conservative estimation on the properties/characteristics of fuel debris. Therefore, it is considered appropriate that data obtained during storage of the fuel debris at small-scale retrieval (the amount of hydrogen generated, and so on), will be used for supporting the considerations on an expanded-scale retrieval work as well as for improvement and streamlining of safety assessment of the design of storage facilities at the next unit.
- The dry type is deemed appropriate storage method because it can be placed without being lifted to a high place (superior in terms of securing safety), and it can also restrict contaminated areas (excellent in terms of waste reduction). Specific containers for fuel debris are under development, whose actual site applicability is getting in sight. The dry-type storage is also deemed reasonable for storage facilities for small-scale retrieval at the first implementing unit, because of the same reasons and from the viewpoint of obtaining useful data for the design of storage facilities for a subsequent expanded-scale retrieval work and the retrieval at the next unit.
- Fuel debris handling facility with safety system is also necessary for the transporting of fuel debris samples to an analysis facility.

- Discussions on licensing and safeguards, as well as obtaining the understanding from local communities and the general public need to be performed before starting the fuel debris retrieval work, since fuel debris to have been located in one place, so called within the PCV would be moved and stored in storage facilities separately from PCV by fuel retrieval work, that is some kind of handling of nuclear material.

[4] From the viewpoint 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 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.

- Unit 2 is appropriate as the first implementing unit, from the viewpoint of optimizing the entire decommissioning work. Its reasons are that fuel debris retrieval work can be started “Promptly”, “Safely” and “Reliably”, information and experience on the fuel debris retrieval operation can be obtained “Promptly”, the risk derived from overall fuel debris at Units 1 to 3 can be reduced “Promptly”, and the removal of fuel from SFPs can be carried out in parallel with the fuel debris retrieval by paying attention to operations at both upper and lower locations.
- The retrieved fuel debris from Unit 2, will continuously contained, transferred and stored, and the effectiveness of required systems for further implementation can be promptly confirmed through this series of operations. In addition, accumulated experiences through the series of small-scale retrieval operations including maintenance by using remote control equipment is expected to contribute to making considerations on the expanded-scale retrieval work efficiently.
- To determine the method of fuel debris retrieval at the first implementing unit, it is essential to conduct in-depth examinations of the fuel debris retrieval work schedule based on the measures to address the issues revealed through PCV internal investigations, etc., and to examine the interference of fuel removal work from SFP with the fuel debris retrieval work in detail.

[5] Retrieval methods including containing, transferring and storage of 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 PCV water level lowering, 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 experiences through fuel debris retrieval work of the first implementing unit including study on safety evaluation and actual site applicability of above mentioned engineering results.

- As mentioned above, the fuel debris retrieval work is recommended to start by the methods of gripping and sucking using a small-scale device through the existing X-6 penetration at "Unit 2". The fuel debris retrieval work should be gradually expanded based on the policy that the information and experiences accumulated during current fuel debris retrieval work need to be used for improvement of the next step of fuel debris retrieval work. In addition, the fuel debris retrieval at units other than the first implementing one need to be considered.
- On the other hand, a suitable safety equipment should be prepared for expanded-scale retrieval work because it may require a significant alteration of the site condition. In addition, modification of existing facilities may impact on current confinement capability maintained by existing facilities. Therefore, the expanded-scale retrieval work shall be considered and established to have safety function by using feedback from the information and experience on the retrieval of fuel debris at the "first implementing unit".
- Since the expanded-scale retrieval work requires not only the increased amount of retrieved fuel debris but also the wider area for necessary facilities around the reactor building, the needs for adjustment/coordination with other works would be increased, and the need for cooperation with other works would also be increased, such as contaminated water or waste management during the fuel debris retrieval work. In addition, the area needs to be secured for stable storage of the retrieved fuel debris. Consequently, the activities and organization to consider the expanded-scale retrieval work should be enhanced for the purpose of optimizing the entire decommissioning work.

C. Initiatives after Determination

C.1 Initiatives toward start of retrieving fuel debris from the first implementing unit

(1) Setting of hold points before the start of retrieving

The Mid-and-Long-term Roadmap stipulates that the "start of retrieving fuel debris from the first implementing unit" should be carried out in 2021. To this end, discussions should be made in accordance with the recommendations of "Determination of the method of fuel debris retrieval for the first implementing unit".

Specifically, it is necessary to clearly define the process leading to actual site application, detail of the tasks, and the system to materialize and realize the management guidelines, and to continue the project activities among the engineering activities promoted mainly by TEPCO. In the process designed for the implementation before the "start of retrieving fuel debris from the first implementing unit" in the project activities, it is necessary to set hold points appropriately, considering the following elements.

- ➢ Results of detailed internal investigation (equipment, verification of accessibility)
- ➢ Results of improvement of the site environment (status of radiation dose reduction, etc.)
- ➢ Verification of actual site application of small-scale retrieval equipment (when the mock-up completes)
- ➢ Results of study on the modification of safety system (including safety assessment)
- ➢ Results of study on storage facility (temporary storage, plan for the storage)
- ➢ Establishment of organization and securing human resource, etc.
- ➢ Application and approval of licensing
- ➢ Coordination for safeguards
- ➢ Feasibility of parallel operations with fuel removal from SFP, etc.

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 and development and preliminary engineering by TEPCO that the works such as the 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 the reactor building (about 5 mSv/h), where most human works take place.
- It is observed through the investigation of operating floor of Unit 2 that the radiation dose rate is decreased so that human works would be available to some limited extent. Several plans are considered on the fuel removal from SFP with the method to reduce risks of dust diffusion. Accordingly, coordination of work interferences when making parallel works both 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 implementing unit, TEPCO announced a plan of the future internal investigations in July, 2018. For Unit 2, it is scheduled to conduct [1] deposit contact investigations and [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] A deposit contact investigation was conducted in February 2019. The purpose is to contact the deposits and to check the changes in 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 gripping.

[2] The investigation to grasp the distribution of deposits as well as sampling in small amount of deposits is scheduled to be conducted in the future, and it is appropriate to conduct it before start of retrieving the fuel debris for the first implementing 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 now under consideration. 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.

Though start of retrieving fuel debris was scheduled after confirming a) of [3], it is evaluated that can be obtained by the confirmations in [1] and [2]. Specifically, 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, 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 implementing unit and [3] is scheduled to be integrally carried out.

Fig. A7-12 shows a roadmap as one of example based on these findings.

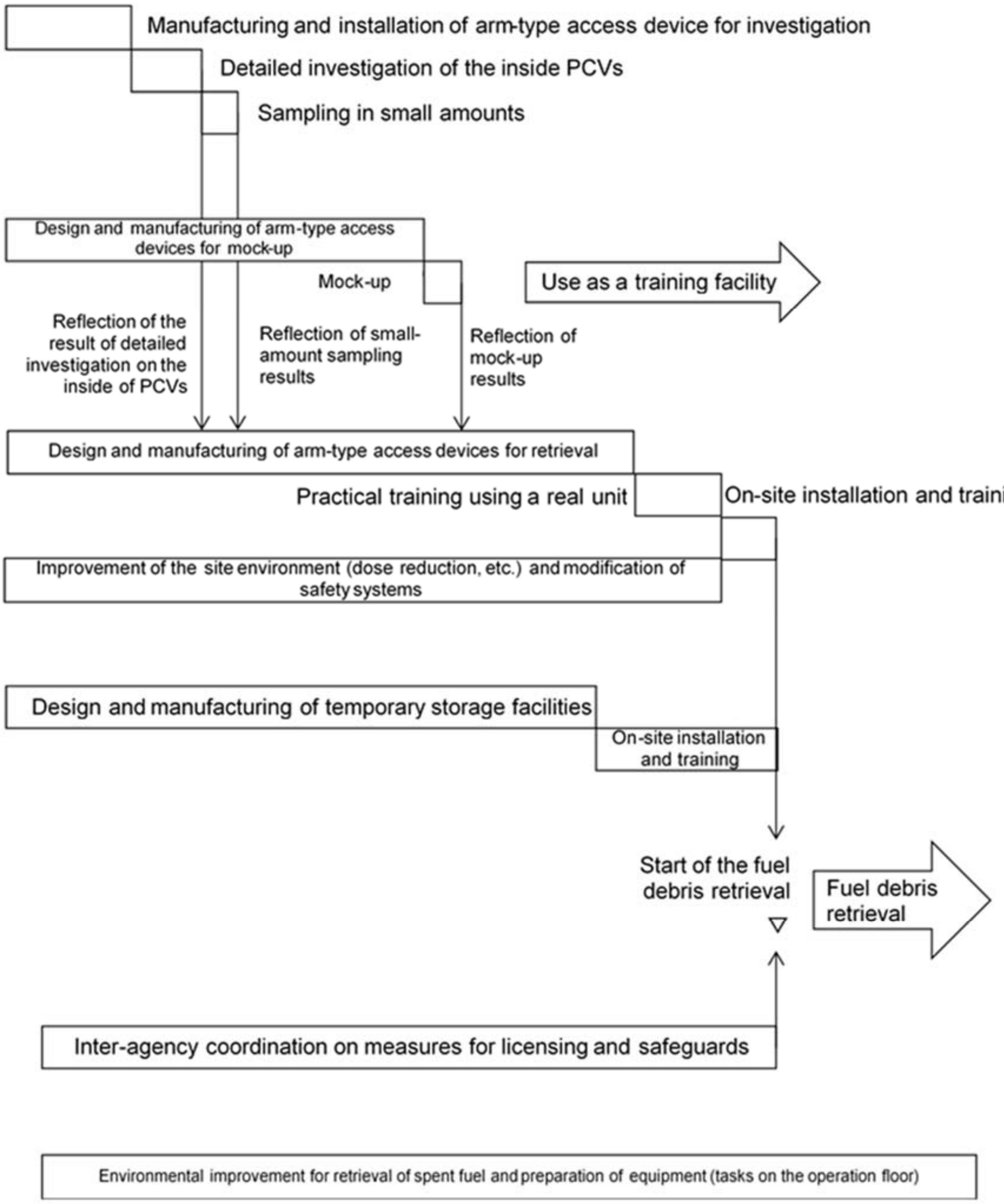


Fig. A7-12 Roadmap toward “the fuel debris retrieval at the first implementing unit” (example)

(2) Continuous implementation of a small-scale fuel debris retrieval

In a small-scale fuel debris retrieval, in order to retrieve fuel debris from the bottom of the PCV at Unit 2, the task of removing obstacles such as gratings will be carried out, and a scenario of retrieval depending on the site conditions shall be developed in the future. Basically, the scenario shall be updated as the site condition is confirmed, a scenario needs to be developed as shown in Fig. A7-13 as an example of the current situation.

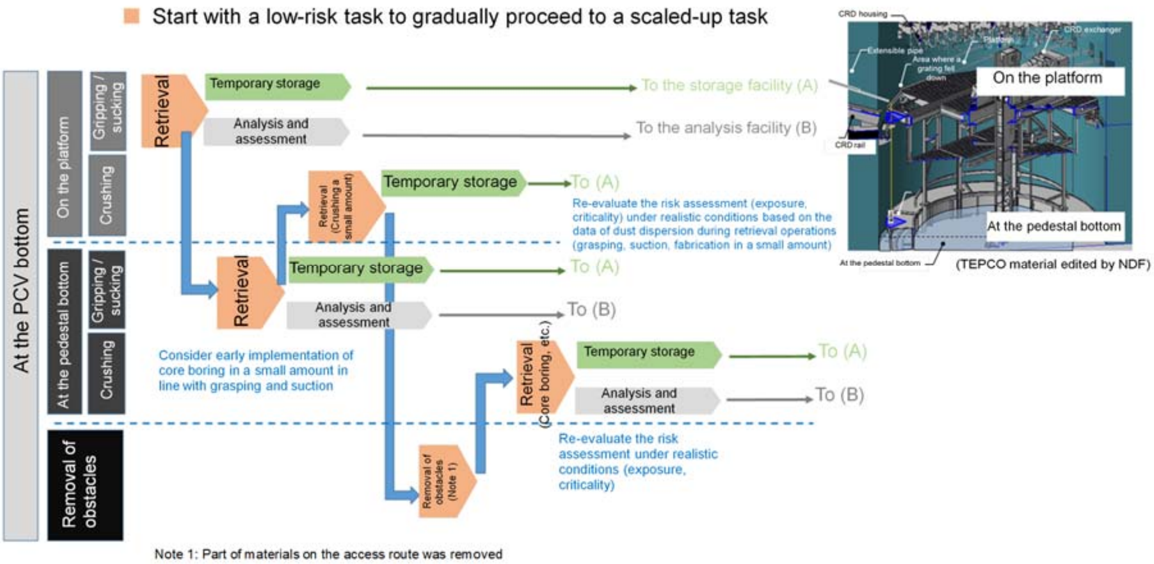


Fig. A7-13 Retrieval scenario during a small-scale retrieval (example)

Furthermore, since the tasks such as the removal of obstacles are also carried out in the initial stage of the retrieval, investigations and sampling as well as the removal of obstacles, shall be carried out in an integrated manner during the small-scale retrieval, in addition to the retrieval of fuel debris itself.

With regard to the continuation of fuel debris retrieval, scenarios as mentioned above and maintenance/inspection plans are also required and, thus, it is essential to consider a specific work plan. It is also necessary to give attention to flexibly revising and continuously updating these plants according to the situation after work commencement.

(3) Information obtained through small-scale retrieval and the shift to the expanded-scale retrieval

For the following information obtained during small-scale retrieval, it is expected that it will be reflected in the planning of expanded-scale retrieval and the examination of rationalizing the site situation and tasks, etc.

[1] Verification of equipment, facilities and safety systems at the small-scale retrieval stage

- Confirmation of retrieval equipment installation and the status of operations (including technical review)

- Verification of measuring equipment
- Efficiency of retrieval and the throughput up to storage
- Status of equipment maintenance (frequency of filter replacement, radiation exposure conditions, etc.)
- Contamination status of retrieval equipment and the work environment (changes)
- State of the environment (changes) inside the PCV, R/B and surrounding areas (safety-related)

[2] Verification of the process to master the fuel debris retrieval operation

- Fostering and securing of operators (including analysts) engaged in a long-term retrieval task, and mastering of the retrieval operation

[3] Acquisition of data related to examinations on the expanded-scale retrieval

(Data related to the fuel debris composition, impact on the surrounding environment, storage and transportation, etc.)

- Distribution of fuel debris within the PCV
- Properties (hardness, etc.) and shape of debris affecting to retrieval
- Conditions within the PCV (radiation dose, quantity and state of structures (obstacles))
- Conditions of R/B and surrounding areas (radiation dose, quantity and state of structures (obstacles))
- Properties, shape, composition, etc. of the debris retrieved
- Checking the dust transfer rate during retrieval
- Conditions of draining water, hydrogen generation, etc.
- Identification of impact on the surroundings (analysis of the transfer to the basement of the building and the water treatment facility due to retrieval)

Consideration should be given to the future taking into account of the efficiency and system life of small-scale retrieval operations: In which stage and to what extent above information should be obtained, and in which stage a shift may be made to the next step.

C.2 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 of 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 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 in 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.

Sub-sections B.1.1 and B.1.2

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.

Sub-section B.1.3

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.

Sub-section B.1.4

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.

Sub-section B.1.5, Table A7-3

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

Sub-section B.1.5, Table A7-4

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.

Sub-section B.2.1

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.

Sub-section B.2.2

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.

Reference Figure: Flow of Strategic Proposal Review
(Section numbers corresponding to this Attachment are added to Strategic Plan, Fig. 6)

Attachment 8 Analysis and investigation plan

1.1 Objectives

Safe and steady decommissioning of the Fukushima Daiichi NPS is a top priority and to accomplish the decommissioning work is needed as early as possible. To proceed with decommissioning safely and reliably, it is important to understand the current situation and what has happened by analyzing fuel debris and conducting investigations on the on-site condition. The results obtained from the analyses and investigations can be reflected in the following three areas, including decommissioning.

① Analyses and investigations of fuel debris should be carried out in the process of decommissioning so that they can directly contribute to “the accomplishment of decommissioning” through the retrieval process, safeguards, storage, processing and disposal.

② To contribute to “the accomplishment of decommissioning”, an accident history investigation represented by analyses and investigations of fuel debris, etc., shall be conducted, and the cause of the accident at Fukushima Daiichi NPS shall be clarified to disseminate the knowledge obtained overseas and to future generations.

③ As a by-product of the analyses and investigations on fuel debris, etc., improvement of the severe accident progression analysis code, emergency response and the facilities has been made, which can indirectly contribute to the improvement of the safety of nuclear power reactors.

Fig. A8-1 shows the relationship between analyses/investigations and decommissioning, clarification of the cause of the accident, and studies on safety. Needless to say, the information obtained through the analyses and investigations will not only directly contribute to the future “decommissioning at Fukushima Daiichi NPS” but also play a part in the investigation of the accident’s history. Adequate understanding, examination, and consideration of the information obtained from historical investigations on past accidents will ensure the advancement in “the understanding of phenomena”. Knowledge gained through the understanding of phenomena will, in turn, contribute to “clarification of the cause of the accident” and “decommissioning”, and, in the end, indirectly contribute to “Improving Nuclear Safety” through improvements in the severe accident progression analysis code, emergency response and the facilities.

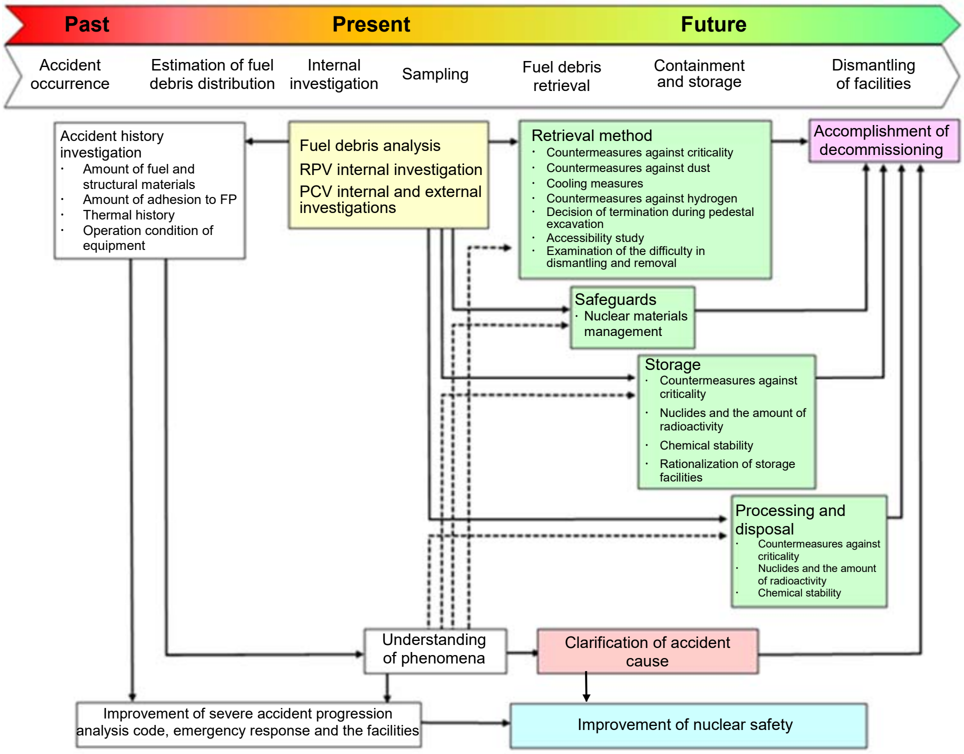


Fig. A8-1 Where analyses and investigation results are reflected and their relationships

1.2 Difficulty in unraveling the overall picture of the accident at Fukushima Daiichi NPS

The accident at Fukushima Daiichi NPS caused core damage and fuel melting at 3 reactors, thereby allowing the encapsulated FPs release into the environment. This is the world's first boiling water reactor (BWR) accident. A BWR is composed of core support structures such as core shrouds and fuel supports, to secure the flow path of cooling water within the RPV and to support the steam-water separator. Zircaloy alloy, which is a cladding tube material, is supposed to lower the melting point by way of the eutectic reaction with stainless steel[68,69]. It has also been reported that the control rod uses boron carbide (B_4C) as a neutron absorber, and that the control rod is dissolved with stainless steel and zircaloy alloys in the vicinity, lowering the melting point[70]. Since the lowering of the melting point depends on the mixing ratio of elements, it defers from locations of inside reactor and there was no record of the thermos sensors furnished at the RPV flange and at the bottom of RPV head due to electricity failure on the site during the accident. Owing to these factors, it is difficult to understand the situation at the time of the accident and the melting and mixing state of fuels.

68 Nuclear Fuel Engineering - Current Status and Prospects, the Atomic Energy Society of Japan (1993)
69 Practical Text Series No. 3: Behavior of LWR Fuel, Nuclear Safety Research Association (2008)
70 T. Hastea et. al., "Study of boron behavior in the primary circuit of water reactors under severe accident conditions: A comparison of Phebus FPT3 results with other recent integral and separate effect data", Nuclear Engineering and Design, 246 (2014).

As a measure to bring the accident under control, water was injected by way of fire engines. However, it has not been made clear how much water actually reached the inside of the RPV or when the injected water arrived, because many branches, solenoid valves, pumps, etc., were present on the route of the water being injected from the outside to the inside of the RPV. As seawater was also injected in addition to fresh water, there is a concern about the influence of salt (NaCl) contained in the seawater. Since NaCl is water soluble, it is thought that most of it does not remain within the RPV due to subsequent water injection and purification, but some of it may be contained in fuel debris. In an environment containing Cl, pits (pitting corrosion) are formed in the oxide film of stainless steel and this causes deterioration events such as stress corrosion cracking, which may affect future storage.

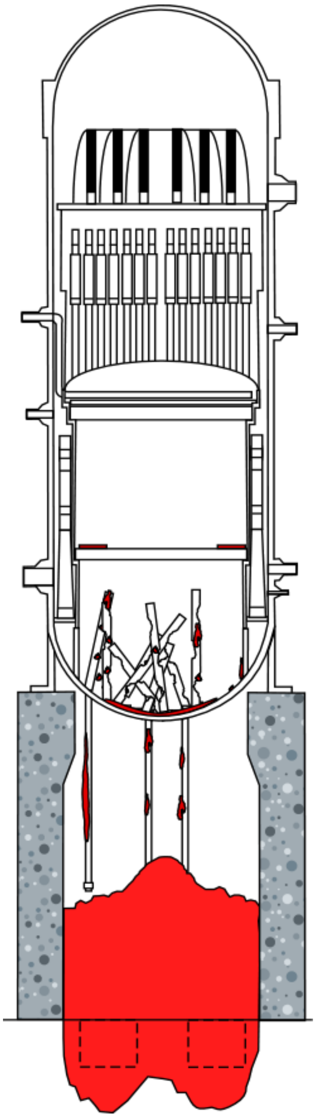
As described above, for the accident at Fukushima Daiichi NPS, it is extremely difficult to understand and evaluate the composition and properties of fuel debris and the operating conditions of equipment because of the unprecedented reactor type, complexity of the structure, melting behavior, lack of data during the accident, and the peculiarity of measures taken to settle a severe accident. To carry out decommissioning safely and reliably, it is important to correctly understand the current situation and what has happened at Fukushima Daiichi NPS through analyses of fuel debris and investigations of the on-site condition.

2 Fuel debris analysis items

A boiling water reactor is, roughly classified, composed of fuel assemblies that generate heat from nuclear fission, control rods that absorb neutrons, water that decelerates neutrons and removes heat, and components of structural materials that make up the reactor structure. During the accident, because water reacted or was discharged as steam, the remaining three components were melted, mixed and solidified. Therefore, as it drips down onto the core, the bottom of the RPV, the CRD housing, and the PCV pedestal floor, it is considered that the surrounding structural materials are involved, and the content rate of nuclear fuel and FPs relatively decreases. The key analysis items are listed in 2.1 to 2.3 below. Since the results should be reflected in criticality control and safeguards, the measurement will basically focus on fuel components, components with a large section area of neutron absorption, and the isotope ratio of fuel components. For waste management, the radioactivity of Cs-137, which has a half-life of about 30 years due to high γ-rays, should also be measured. For some FPs, the analysis priority may be required to be lowered. This is because, among FPs, the content of some nuclides is originally below 1%, and it is assumed that the structural materials were involved during the severe accident, and that the content rate has decreased further due to attenuation caused by the time spent until the analysis of samples was conducted, resulting in a fall below the detection limit (ND). For nuclides with low contents, the priority of analysis should be determined by comprehensively examining the importance of the nuclide, where the results obtained will be reflected, inventory, and the dilution degree depending on the sampling site, etc.

2.1 Fuel debris analysis items in Unit 1

In Unit 1, 400 fuel assemblies are loaded into the core. Assuming that the mass of 1 fuel assembly is approximately 300 kg, the content of U and Pu are estimated to be 55.4 mass% and 0.4 mass%, respectively, based on the inventory[71] contained therein. As the fuel melts and components other than the fuel such as control rods and stainless steel are mixed, the content rates relatively decrease. Fig. A8-2 shows the key items to be confirmed by analysis of fuel debris in Unit 1.



(1) Fuel debris at the bottom of the RPV

- Confirmation of fuel constituents and the chemical form of fuel debris in a small amount adhering to the bottom of the RPV.
- Confirmation of the isotope ratio of U and Pu.
- Density and particle size.
- Checking for the presence of boride phase (possibility of increased hardness).
- Confirmation of the amount of fuel debris adhering to and invading into the CRGT and CRD housings.

(2) Fuel debris at the bottom of the pedestal

- Checking of the components of the fuel assembly (U, Pu, Gd, Zr), control rods (B, C, Fe, Cr, Ni) and structural materials (Fe, Cr, Ni) at each position.
- Confirmation of the isotope ratio of U and Pu.
- Density and particle size.
- Checking for the presence of boride phase (possibility of increased hardness).
- Confirmation of the concrete components (Ca, Si, etc.).
- Confirmation of erosion depth by MCCI.

(3) Others

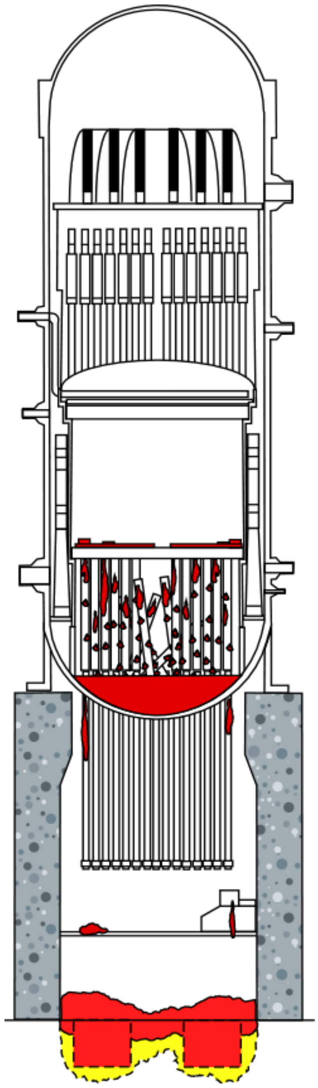
- Checking for the presence of the effects of seawater injection (Na, Mg, and Cl).
- Confirmation of the form of adhering or remaining Cs-137 and Cs-134 and the residual amounts.
- Checking of the degree of oxidation of U (the degree of secular change).
- For nuclides with a high possibility of becoming ND based on the inventory quantity, it is necessary to examine the appropriateness of analysis.
- The nuclides related to the storage, processing and disposal of waste are discussed in Stage 3.

Fig. A8-2 Items to be confirmed by analysis of fuel debris in Unit 1

[71] Kenji Nishihara et al., "Evaluation of fuel composition at Fukushima Daiichi NPS", Japan Atomic Energy Agency, JAEA-Data/Code 2012-018 (2018).

2.2 Analysis items of fuel debris in Unit 2

In Unit 2, 548 fuel assemblies are loaded into the core. Assuming that the mass of 1 fuel assembly is approximately 300 kg, the contents of U and Pu are estimated to be 55.4 mass% and 0.4 mass%, respectively, based on the inventory contained therein. As the fuel melts and components other than the fuel such as control rods and stainless steel are mixed into the RPV, the content rate is relatively low. However, because the RCIC was operating for three days at the time of the accident, the heat removal was more advanced than at Units 1 and 3 and, thus, it has been pointed out that unmelted fuel may remain in the RPV. Fig. A8-3 shows the key items to be confirmed by analysis of fuel debris in Unit 2.



(1) Fuel debris at the bottom of the RPV

- Checking of the components of the fuel assembly (U, Pu, Gd, Zr), control rods (B, C, Fe, Cr, Ni) and structural materials (Fe, Cr, Ni) at each position.
- Confirmation of the isotope ratio of U and Pu.
- Density and particle size.
- Checking for the presence of boride phase (possibility of increased hardness).
- Checking for the presence and the quantity of FP nuclides in unmelted fuel.
- Confirmation of the amount of fuel debris adhering to and invading into the CRGT and CRD housings.

(2) Fuel debris at the bottom of the pedestal

- Confirmation of the components of fuel assemblies, control rods and structural materials (fuel components may be 10% or less).
- Confirmation of the isotope ratio of U and Pu.
- Density and particle size.
- Confirmation of the concrete components (Ca, Si, etc.).
- Confirmation of the components of objects fallen onto the grating.
- Confirmation of the loading position and the falling path of the upper tie plate that has fallen.
- Confirmation of the invasion of fuel debris into the drain sump pit.
- Confirmation of erosion depth by MCCI.

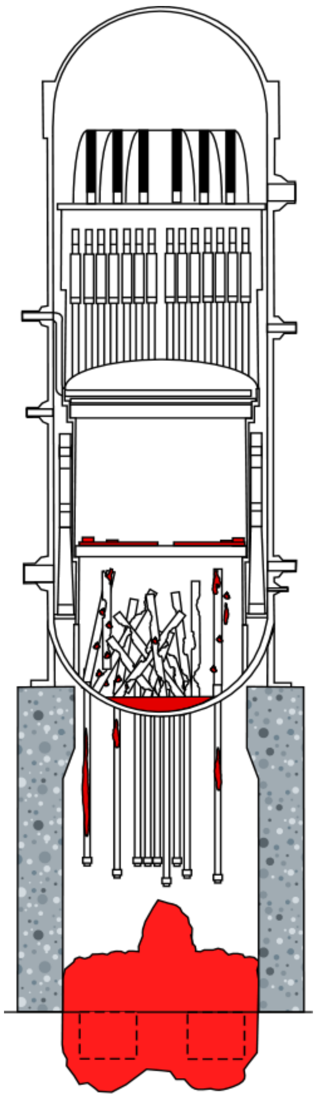
(3) Others - items in common

- Checking for the presence of the effects of seawater injection (Na, Mg, and Cl).
- Confirmation of the adhering and residual form and the residual amounts of Cs-137 and Cs-134.
- Checking of the degree of oxidation of U (the degree of secular change).
- For nuclides with a high possibility of becoming ND based on the inventory quantity, it is necessary to examine the appropriateness of analysis.
- The nuclides related to the storage, processing and disposal of waste are discussed in Stage 3.

Fig. A8-3 Items to be confirmed by analysis of fuel debris in Unit 2

2.3 Fuel debris analysis items in Unit 3

In Unit 3, as with Unit 2, 548 fuel assemblies are loaded into the core. The inventory therein shows that the content rate of U is 55.4 mass%, and that of Pu is 0.4 mass%. As with Unit 1, the content rate will decrease due to the mixing of control rods, stainless steel, etc. Although 32 MOX fuel assemblies were loaded, the inventory evaluation indicates that the Pu concentration was almost the same as that of Unit 2.



(1) Fuel debris at the bottom of the RPV

- Checking of the components of the fuel assembly (U, Pu, Gd, Zr), control rods (B, C, Fe, Cr, Ni) and structural materials (Fe, Cr, Ni) at each position.
- Confirmation of the isotope ratio of U and Pu.
- Density and particle size.
- Checking for the presence of boride phase (possibility of increased hardness).
- Confirmation of the amount of fuel debris adhering to and invading into the CRGT and CRD housings.

(2) Fuel debris at the bottom of the pedestal

- Confirmation of the components of fuel assemblies, control rods and structural materials.
- Confirmation of the isotope ratio of U and Pu.
- Density and particle size.
- Checking of the buildup in the center (CRD exchanger?).
- Checking for the presence of boride phase (possibility of increased hardness).
- Confirmation of the concrete components (Ca, Si, etc.).
- Confirmation of erosion depth by MCCI.

(3) Others

- Checking for the presence of the effects of seawater injection (Na, Mg, and Cl).
- Confirmation of the form of adhering or remaining Cs-137 and Cs-134 and the residual amounts.
- Checking of the degree of oxidation of U (the degree of secular change).
- For nuclides with a high possibility of becoming ND based on the inventory quantity, it is necessary to examine the appropriateness of analysis.
- The nuclides related to the storage, processing and disposal of waste are discussed in Stage 3.

Fig. A8-4 Items to be confirmed by analysis of fuel debris in Unit 3

2.4 Representativeness of samples

In general, in order to improve the representativeness of analysis results, a large number of samples are taken to reduce the standard deviation. However, if the number of samples is increased, the number of analyses to be conducted is also increased, requiring a lot of time, labor, and expense, and eventually generating delays in processes, which may arouse concern that the results of analysis would not be available in a timely manner.

Fig. A8-5 shows a schematic of the composition of fuel debris. Fuel debris is shown enlarged as the molten fuel has flown down with structures involved. It is assumed that the concentrations of the components vary seamlessly, depending on their location, temperature, and reaction process, eventually becoming heterogeneous. In particular, a concrete component is included at the pedestal bottom, which acts as a boundary, and then the composition changes greatly. Thus, increasing the number of samples does not reduce the standard deviation.

Since the analysis results indicate the composition and physical properties specific to the sampling site, the analysis results should be combined with the positional information to make a comprehensive judgment. It is desirable to combine the results of fuel debris analysis, including the positional information, with severe accident analysis codes, criticality assessment, etc., to evaluate safety during retrieval and storage, and to optimize equipment specifications.

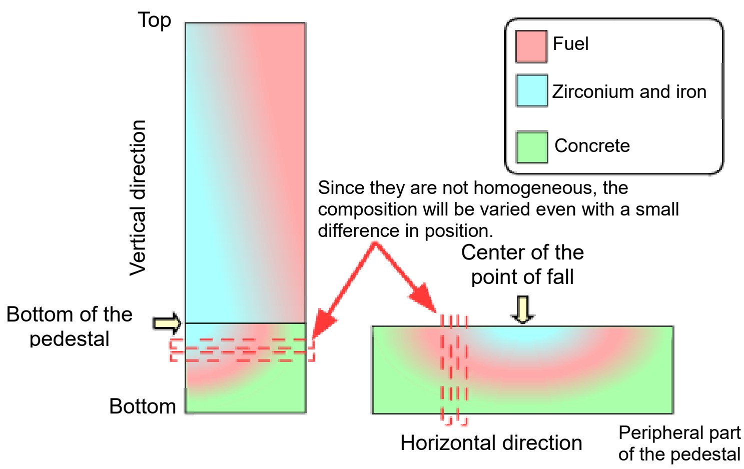


Fig. A8-5　Schematic diagram of the composition of fuel debris

The distribution and chemical composition of fuel debris in Unit 4 of the Chernobyl Nuclear Power Plant are shown in Fig. A8-6 and Table A8, respectively[72]. In Unit 4 of the Chernobyl Nuclear Power Plant, the state has changed into the black FCM, the brown FCM, and a mixture of them, depending on the horizontal and vertical directions from which fuel debris was sampled. The chemical composition in the FCM has also varied and is not homogeneous.

[72] B. Burakov, "Study of Chernobyl [lava], corium and hot particles: experience of V.G. Khlopin Radium Institute (KRI)", Data from the 2nd International Forum on the Decommissioning of the Fukushima Daiichi NPS, Day 2, (2017).

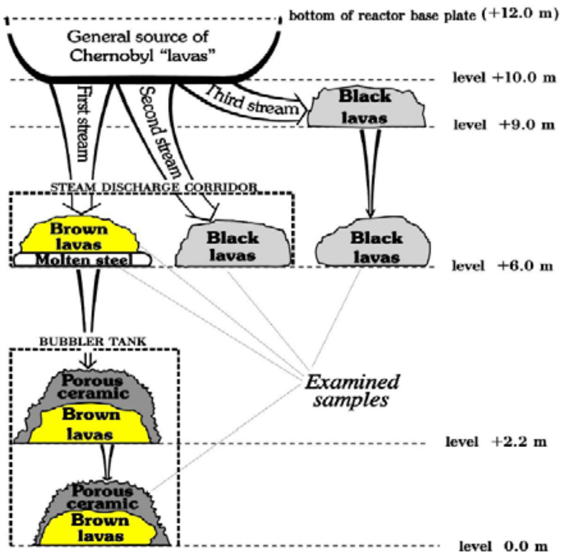


Fig. A8-6 Fuel debris distribution[67] in Unit 4 of Chernobyl NPP

Table A8 Chemical composition[67] of fuel debris in Unit 4 of Chernobyl NPP

Type of "lava"	Element content, wt. %							
	U	Zr	Na	Fe	Mg	Ca	Si	Al
Black	4 - 5	2 - 6	2 - 10	0.3 - 6	1 - 5	3 - 13	19 - 36	3 - 8
Brown	8 - 7	5 - 6	4	1 - 2	4	5	31 - 33	4

3. Investigations on decommissioning and for clarification of the accident process

3.1 How to proceed with the investigation

Considering that the accident had developed with the fuel damage, the analysis of fuel debris described above is particularly important from the viewpoint of investigating the cause of the accident. However, the traces of the accident as a result of the accident progression, such as melting, solidifying, breaking, and falling, have been left in RPV, PCV, and reactor buildings, and this information is necessary for clarifying the cause of the accident.

Since many of the traces can be used as direct inputs to the decommissioning work, including debris retrieval, i.e., "What is located where?", "How has the situation changed since before the accident?" and "How much is the radiation dose?", investigations should be rationally conducted from the viewpoint that they often overlap with the subject of "investigations for the purpose of decommissioning".

However, unlike experiments that are carried out in a planned manner, some of the investigations extracted to be conducted in order to clarify the cause of the accident are difficult in realization because of their significant impact on the decommissioning process, human resources, costs, etc., even if they are of high importance. Therefore, "investigations for clarifying the cause of the accident" should be carried out in a planned manner, considering feasibility.

Investigations for clarifying the cause of the accident are classified into the following five categories:

[1] Since we have already acquired materials for examinations, we are only required to think hard.

➡ Investigations have already been completed.

[2] Since there is a similar plan that can be used for investigations for the purpose of decommissioning, samples should be taken in an expanded form for solving issues by thinking them through.

➡ At this point, a research plan is in progress, which can be relatively easily extended. The burdens on the technology development required for expansion and on the budget are small.

[3] Items for which a plan for the current decommissioning process is not developed and that require planning from scratch, such as determining an investigation period, securing human resources and expenses, and solving technical issues.

➡ Priority is given to establishing objectives, resources, and research methods (countermeasures against high radiation doses), etc.

[4] Due to the decommissioning schedule, no investigations have been planned over the past 10 years.

➡ Since no concrete investigation plans are developed at this point and distinguishing the aging degradation from the accident effect would become more difficult, investigations should be carried out as soon as possible.

[5] An experiment to verify examinations that were conducted by thinking hard

➡ As this is an experiment, this is not included in the investigation of the accident history.

Attachment 9 Reduction of liquid phase and contaminated water (Water balance around the reactor buildings)

The containment function in the liquid is required to contain radioactive material to restrict the release of the uncontrolled radioactive material from the reactor buildings with the objective of minimizing the effect of radiation exposure to the liquid the on the public as with the exposure to the gas.

However, since the PCVs and buildings (torus rooms) are found to be pierced and damaged by the earthquake, it is difficult to statically confine the liquid to perfection. For this reason, containing radioactive material is planned by maintaining the difference in level between the contaminated water and groundwater to prevent water containing radioactive material from being released from the reactor buildings to soil outside the buildings.

Due to the difference in level between groundwater and the water inside the reactor buildings, groundwater flows into the buildings. In the torus rooms, this groundwater is mixed with cooling water coming out of the PCVs and then discharged, treated, and stored in a planned way. Still, the emergence of contaminated water should be desirably minimized to the extent possible. Fig. A9-1 shows the current mass balance of water around the reactor buildings and the mass balance that will be achieved in the future if a water circulation system is built. From the viewpoint of water mass balance, it is possible to reduce the emergence of contaminated water possible by:

(1) Reducing the inflow of the groundwater

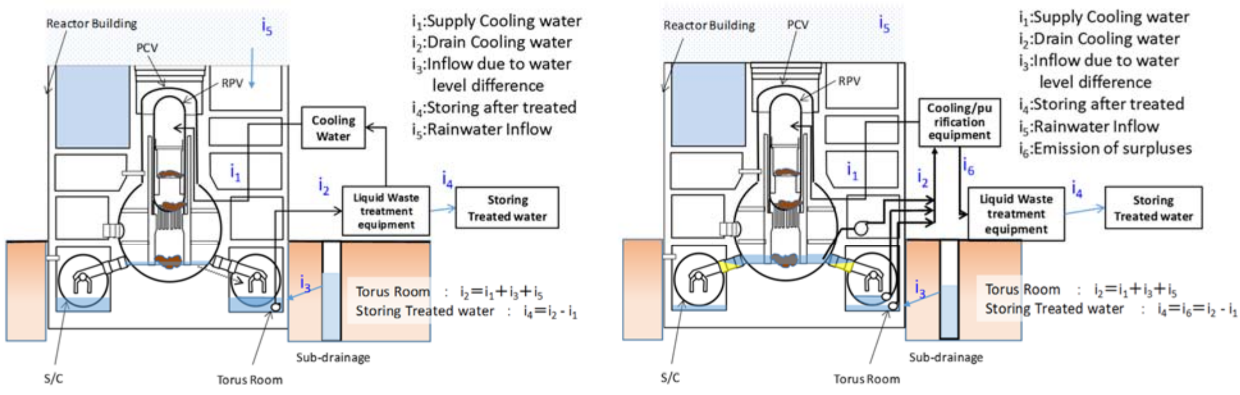
It is important to take measures to prevent rainwater from flowing into the reactor buildings and to set an appropriate groundwater level.

and/or

(2) Reducing the emergence of contaminated water

This method reduces the amount of the PCV cooling water that flows out into the torus rooms to reduce the amount of contaminated water by setting the level of water inside the PCVs (dry well sections) and building system for directly recovering PCV cooling water with a combination of the reduction of PCV cooling water and water stopping (whether it is feasible or not must be determination).

In the future, in reviewing in details of the method for removing fuel debris in light of the engineering of the undertaker, it is necessary to identify how the water level inside the PCVs should be set, whether or not it is possible to stop water, the system for directly recovering cooling water from the PCVs (dry wells), and so on.



Relationship with Water Balance surrounding the Reactor Building (Current status)

Relationship with Water Balance surrounding the Reactor Building (After established the system)

Fig. A9-1 Water balance around the reactor buildings

Attachment 10 Study on the water level at the bottom of PCV during fuel debris retrieval

Assuming that control of the water level can be performed by installation of underwater pumps, state of the water level during fuel debris retrieval at the bottom of the PCV is illustrated in the conceptual diagram (Fig. A10-1) with grouping of the following cases. Each low of the diagram shows the expected result on the water level in the following cases; the 1st low shows the case of present state, the 2nd low shows the case when water stoppage is performed by injection of the water stoppage material inside the vent pipe (vent pipe water stoppage), the 3rd low shows the case when water stoppage is performed by burial of the downcomer tip with filling of the highly workable concrete inside the S/C (Suppression Chamber) (downcomer water stoppage), and the 4th low shows the case when water stoppage is not performed. Since it is desirable to maintain the water level inside the S/C as low as possible from the viewpoint of earthquake resistance during fuel debris retrieval, it was assumed that lowering of the water level inside of the PCV down to the lowest part of the vent pipe joint can prevent water from flowing inside the S/C when water stoppage is not performed in each Unit.

Furthermore, development of water stoppage technology has just been started with installation of the water stoppage plate at the jet deflector and installation of the weir inside the D/W (Dry Well) in addition to the conventional vent pipe water stoppage, etc. as development of the water stoppage technology conducted in the Government-led R&D Program on Decommissioning and Contaminated Water Management. While considering these situations described above, it is necessary to perform setting and control of the water level based on implementation or non-implementation of water stoppage.

Progress of the study on each Unit is shown below.

A. Study on the water level in the PCV in Unit 1

Current water level in the PCV is assumed to be about 2m and most part of fuel debris at the bottom of the PCV is considered to be submerged under water. In addition, leakage of the cooling water in the PCV is found to the S/C through the vacuum break line (about 1.1m high from the bottom of the PCV) and to the torus room through the sand cushion drain pipe.

Therefore, it is necessary to lower the water level of the PCV to the level of the vacuum break line or lower before applying the water stoppage technology between the PCV and the S/C (vent pipe water stoppage or downcomer waster stoppage) or the water level in the PCV is required to be maintained at the level of the lowest part of the vent pipe joint or lower when water stoppage is not performed. In addition, even in the case of performing either measure described above, it is considered to become necessary to take action against the cooling water flowing into the torus room through the sand cushion drain pipe when retrieving fuel debris in the water or under the cooling water being kept flowing on the fuel debris. Furthermore, installation of the drain receiver by means of the remote technology at the sand cushion drain part is considered necessary.

When either vent pipe water stoppage or downcomer water stoppage is performed, as the water level in the PCV is maintained to the level of the vacuum break line or lower as described above, the amount of the cooling water stagnating in the PCV is not large. Therefore, even if the cooling water in the PCV leaks out to the torus room supposedly in case of damage at the vent pipe joint part, the water level in the torus room can be maintained at the groundwater level or lower. In addition, as the measures to prepare against leakage of the cooling water to the S/C from inside of the PCV supposedly in case of damage of the downcomer joint part, it is being studied to take measures by collecting the cooling water with pumps installed in the S/C.

When water stoppage is not performed, the water level in the PCV will be maintained at the level of the lowest part of the vent pipe joint or lower and fuel debris retrieval will be performed in the air while the poring cooling water is kept flowing on fuel debris. In this case, it is necessary to study in advance on the decay heat of fuel debris, required amount of the cooling water, etc., because a part of fuel debris will be expected to be exposed in the air.

B. Study on the water level in the PCV in Unit 2

Current water level in the PCV is assumed to be about 0.3m and most part of fuel debris at the bottom of the PCV is considered not to be submerged under water. In addition, occurrence of leakage is assumed from the S/C to the torus room because both water levels in the S/C and the torus room are almost the same.

When either vent pipe water stoppage or downcomer water stoppage is performed, the water level in the PCV can be raised and fuel debris retrieval at the bottom of the PCV will be able to be performed in the water. In this case, expected measures to be taken when the cooling water leaks out from inside of the PCV are the same as ones taken in case of Unit 1.

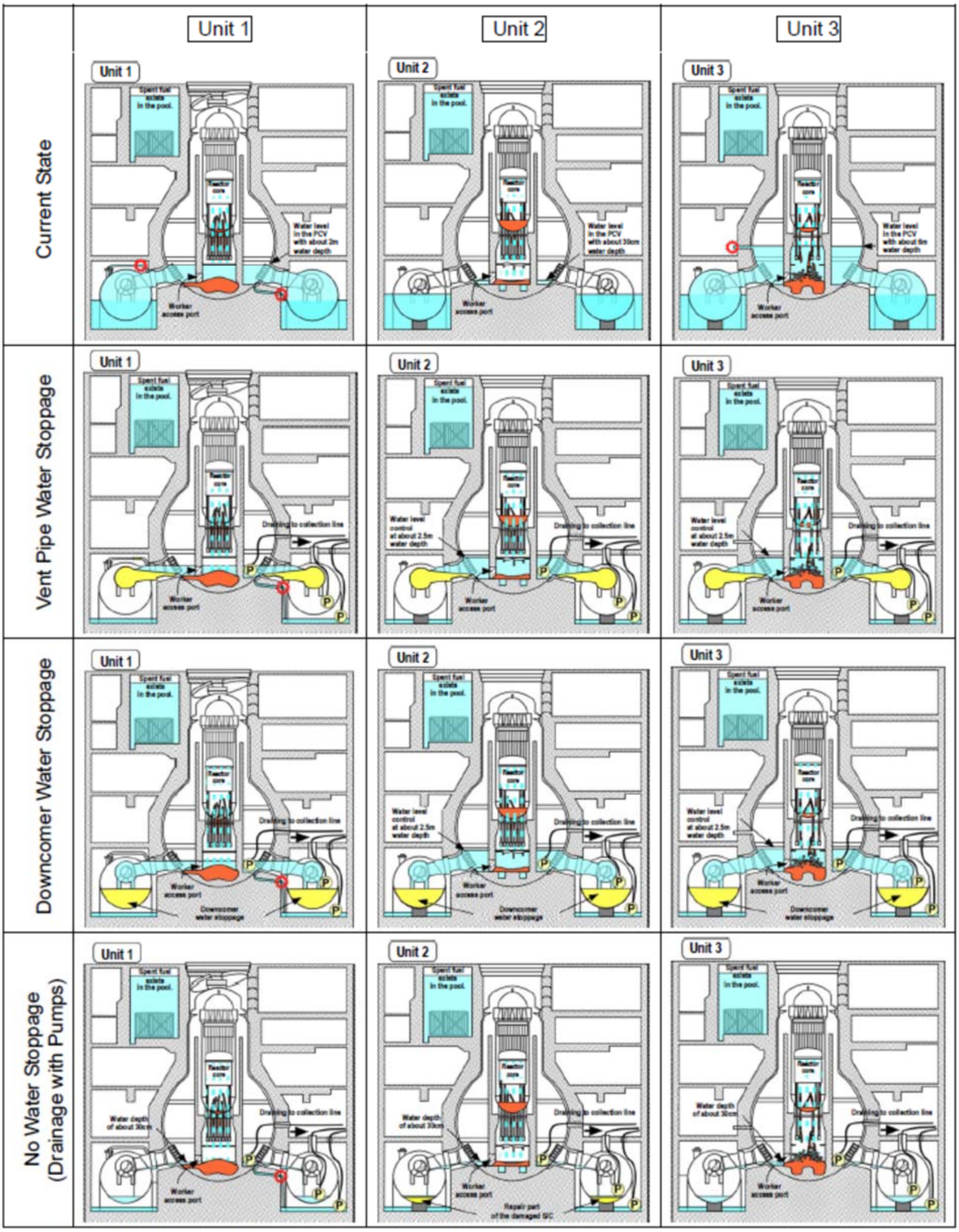
When water stoppage is not performed, the water level in the PCV will be maintained at the same level of the current one and fuel debris retrieval will be performed in the air while the cooling water is kept flowing on fuel debris. In this case, it is necessary to identify and repair the damaged part of the S/C to prevent leakage of the cooling water from inside of the PCV to the torus room via S/C.

C. Study on the water level in the PCV in Unit 3

The current water level in the PCV is assumed to be about 6m and is higher compared to those of Units 1 and 2. Therefore, fuel debris at the bottom of the PCV is assumed to be submerged under water. On the other hand, the water level in the PCV is required to be lowered for the side entry method to be performed from the viewpoint of leakage prevention of the cooling water from the access part.

When either vent pipe water stoppage or downcomer water stoppage is performed, fuel debris retrieval can be performed in the water, although the water level in the PCV is required to be lowered to almost the same level (about 2m) of the current one in Unit 1 due to the reason described above. In this case, measures expected to be taken when the cooling water leaks out from inside of the PCV are the same as ones taken in case of Unit 1.

When water stoppage is not performed, the water level in the PCV will be maintained at the level of the lowest part of the vent pipe joint or lower and fuel debris retrieval will be performed in the air while the cooling water is kept flowing on fuel debris. In this case, it is necessary to study in advance about the decay heat of fuel debris, required amount of cooling water, etc., because a part of the fuel debris will be expected to be exposed.



- Current water level in the PCV is as follows; Unit 1: about 2m water depth, Unit 2: about 0.3m water depth and Unit 3: about 6m water depth.
- When vent pipe water stoppage is performed, fuel debris retrieval can be performed in the water at each unit. Operation of the collection system from D/W (Dry Well) is started to control the water level in the PCV, for example, the water level at Unit 2 is raised and lowered at Unit 3. When the water level is lowered, fuel debris retrieval can be performed in the air while the cooling water is kept flowing on the fuel debris.
- As for water stoppage other than vent pipe water stoppage, downcomer water stoppage is performed at Unit 1 and water inside of the S/C is collected from the viewpoint of seismic resistance. At Units 2 and 3 the downcomer water stoppage is performed to separate the D/W from the S/C. Operation of the collection system from the D/W and the S/C is started to control the water level, and fuel debris retrieval is performed in the water or the air while the cooling water is kept flowing on the fuel debris.
- When water stoppage is not performed, the water level in the PCV is very low at the bottom and fuel debris retrieval is performed in the air while the cooling water is kept flowing on the fuel debris.

Fig. A10-1 Water level at the bottom of the PCV and water stoppage in the PCV (Conceptual diagram with assumed results)

Attachment 11 Terms related to radioactive waste management

IAEA Safety Requirements GSR-Part 5[73] explains that predisposal of radioactive waste encompass all stages of radioactive waste management from generation to disposal, including processing, storage and transportation. Terms related to the management of radioactive waste as defined in the IAEA glossary are shown in Fig. A11-1. Within the pre-disposal management, processing of radioactive waste is classified into pretreatment, treatment and conditioning. Processing is carried out to be in the form of waste suitable for selected or anticipated disposal options. Radioactive waste may also be stored in for its management, therefore it is thought to be necessary that the form is suitable for transportation and storage.

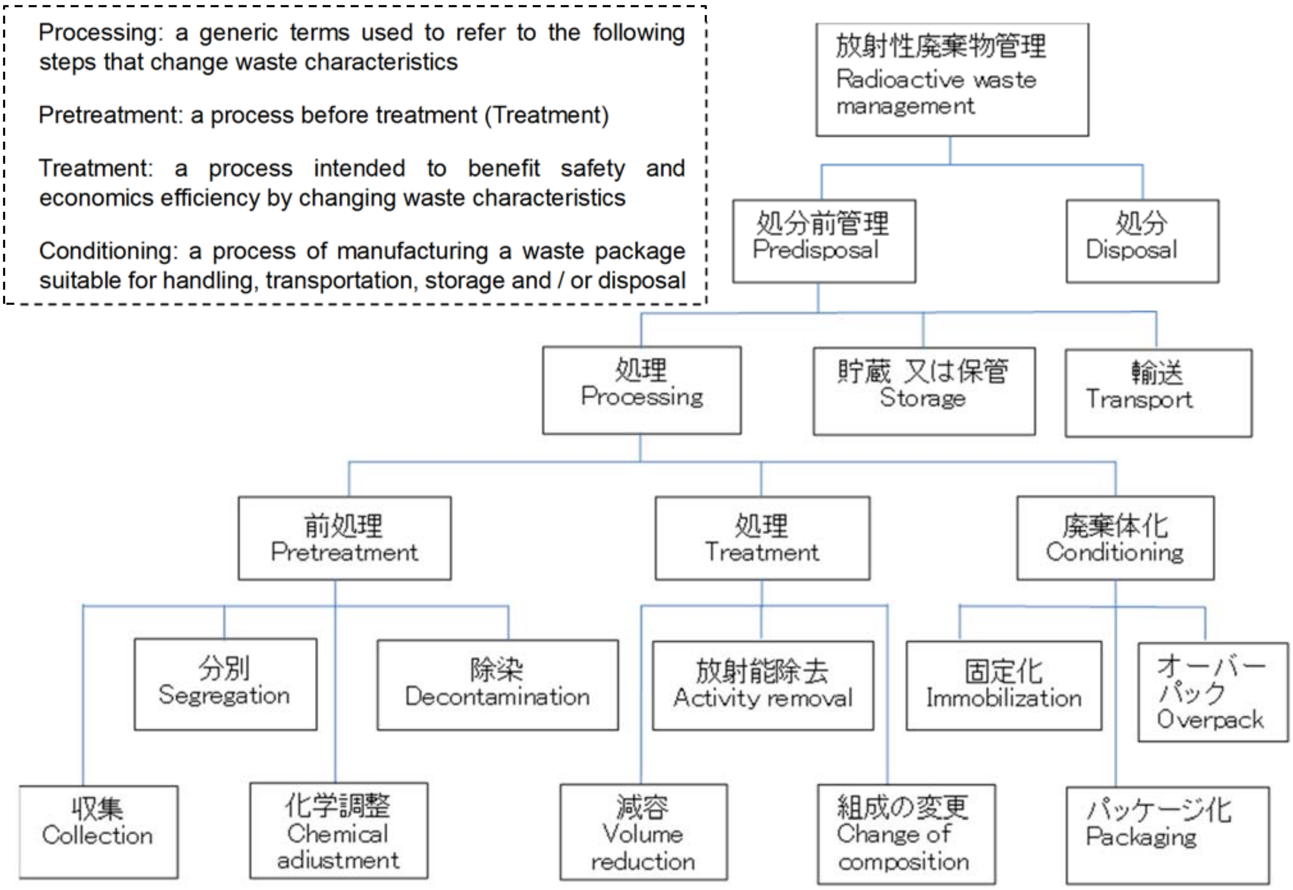


Fig. A11-1 Terms related to radioactive waste management (IAEA)[74] and their translation examples (For the Japanese translation example, refer to the materials of the Atomic Energy Society of Japan (AESJ)[75,76]

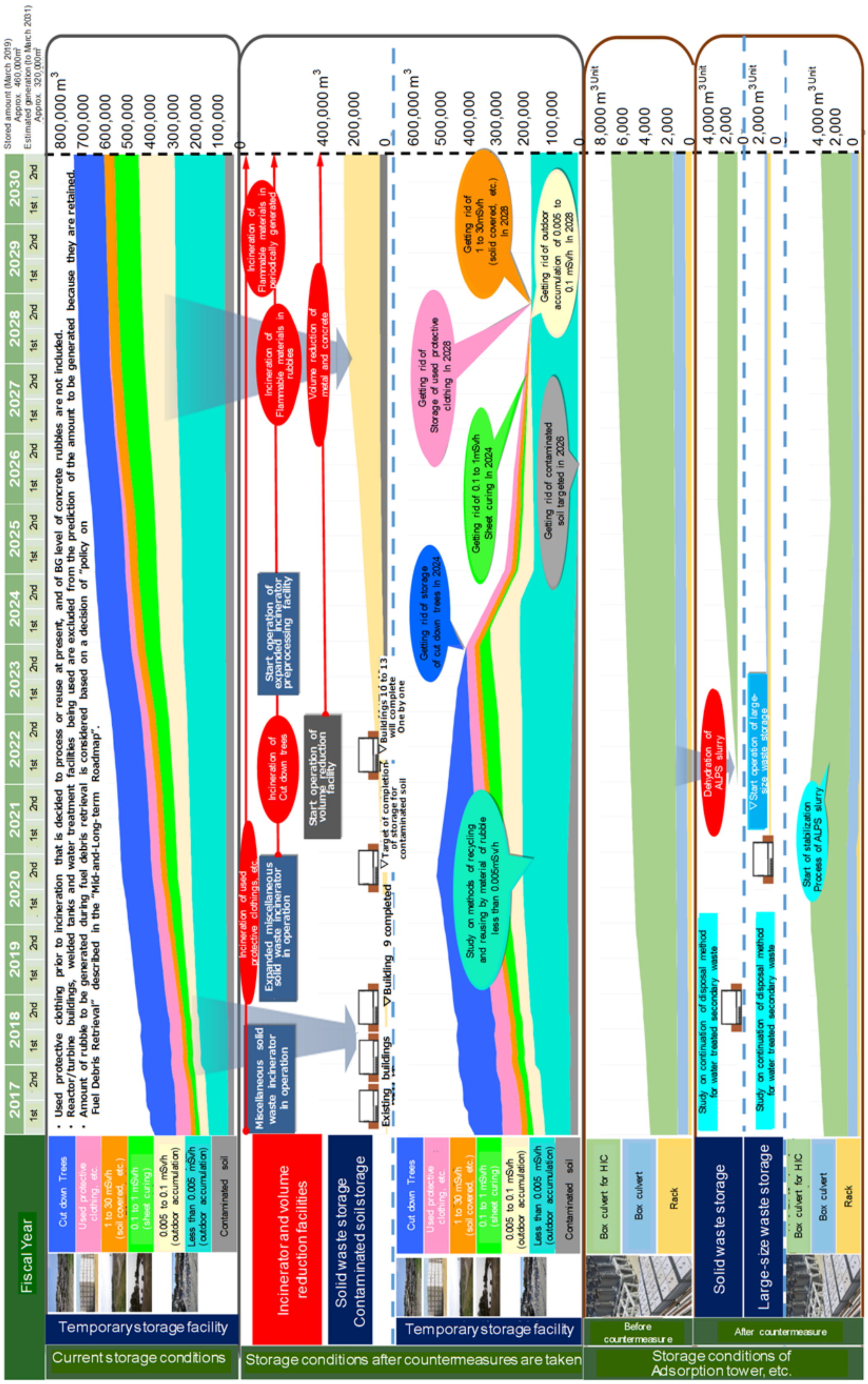
[73] IAEA, Predisposal Management of Radioactive Waste, IAEA Safety Standards Series No. GSR Part 5, (2009). (NSRA, IAEA Safety Standard/Predisposal of Radioactive Waste/General Safety Requirement 5, No. GSR-Part5, July, 2012)

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

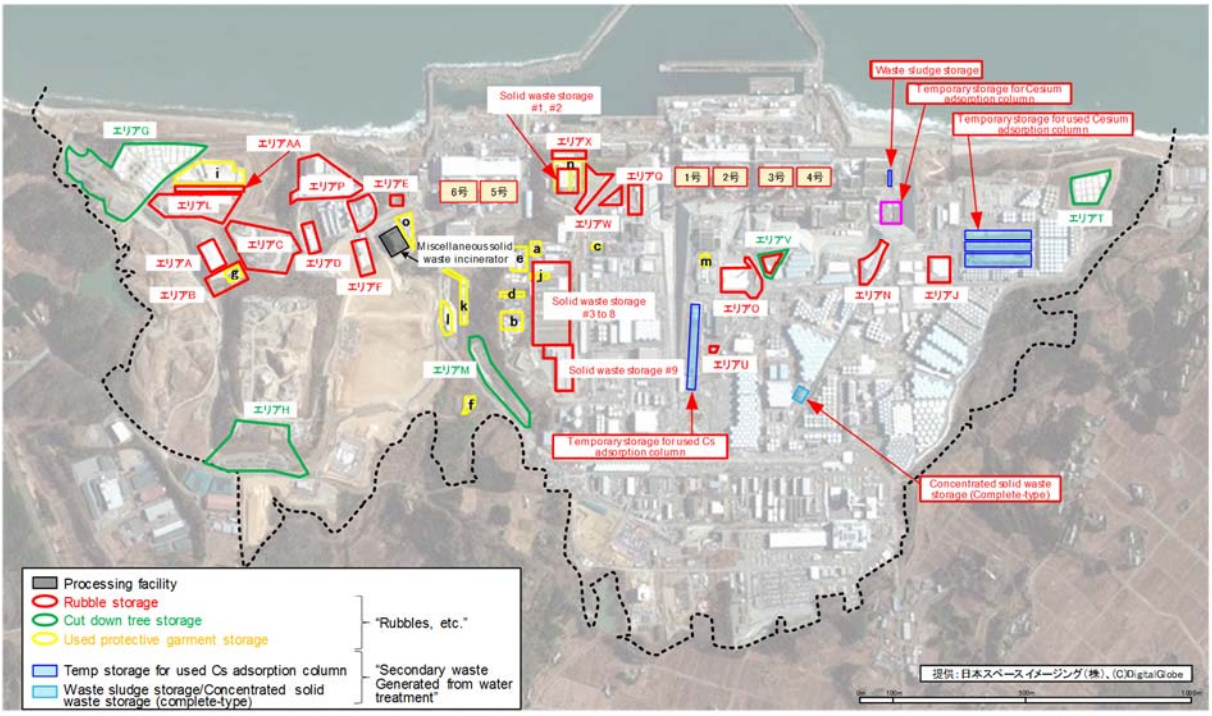
[75] AESJ, The Report of 2013, - Organizing information of radioactive waste and matters to be considered for solving the issues (p.7), March 2014, the Expert Committee, "Processing/disposal of radioactive waste generated by the accident of Fukushima Daiichi NPS"

[76] AESJ, Seiya Nagao and Masafumi Yamamoto, "Introduction to radioactive waste – Management of radioactive waste from operation and decommissioning of nuclear and other facilities (1) Perspective of radioactive waste management", the 56 of (9) of Journal of the Atomic Energy Society of Japan, p.593, (2014).

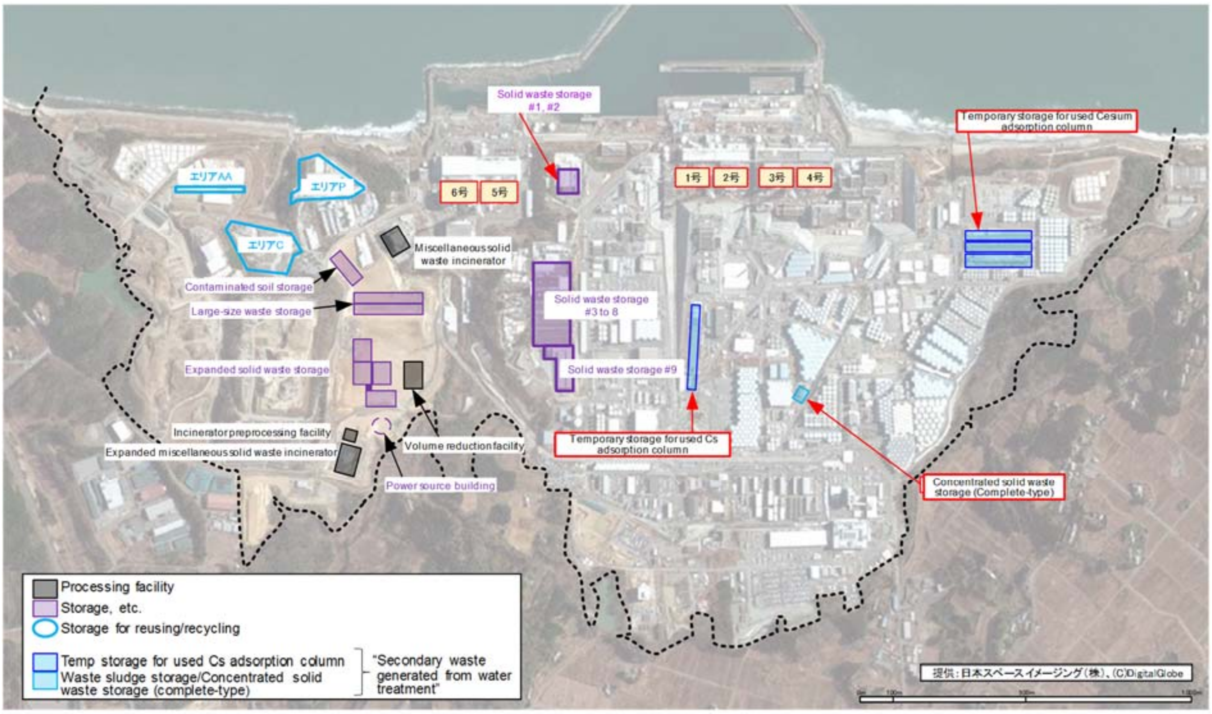
Attachment 12　Overall image of Storage Management Plan for the Fukushima Daiichi NPS[77]



[77] TEPCO, Solid Waste Storage Management Plan for Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc., June 2018 edition (issued in June 28, 2018)



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



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

Fig.A12-1 Present and future storage conditions of "rubble, etc." and "secondary waste generated by water treatment" on site of the Fukushima Daiichi NPS

Attachment 13 Draft of technical map toward human resource development for decommissioning reactors

Stages of Nuclear Industries	Features	Work Process	Field Related to Electrical and Mechanical Engineering	Field Related to Plant Engineering	Field Related to Civil, Geotechnical and Architectural Engineering	Field Related to Chemical and Material Engineering	Field Related to Nuclear Engineering (including Environment and Radiation)	Other Fields
			(Examples of Field) Mechanical Engineering, Electrical and Electronic Engineering, Electronic Material, Instrument Engineering and System Control Engineering, Signal and Image Processing, Information Engineering (Examples of Basic Technology) Electric System Design Engineering (Instrument Engineering and System Control Engineering, Heavy Current and Weak Current Electrical Engineering, Mechanical Engineering), Imaging, Human Interface, VR Technology, Visualization Technology and Recognition Support, Mechanical Crafting (Cutting, Shearing, etc.), Remote-control Systems (Robotics), Resistance to Radiation	(Examples of Field) Chemical Engineering, Industrial Chemistry, Chemical Plant, Plant Engineering, Process Engineering, Water Chemistry (Examples of Basic Technology) Plant Designing, Manufacturing, Construction, Assembly, Piping, Plant Design, Systems Designing, Plant Instrumentation, Boundary Building, Negative Pressure Management, Filter Design, Engineering Flow	(Examples of Field) Civil Engineering, Geotechnical Engineering, Architectural Engineering, Groundwater Engineering, Deep Geological Science, Geohydrology, Soil Science, Solid State Engineering (Concrete, etc.) (Examples of Basic Technology) Architectural Design, Building and Construction Diffusion, Demolishing Technology, Non-destructive Inspection (Concrete, etc.), Structural Soundness, Boring, Underground Diffusion Control and Environment Restoration, Property of Concrete	(Examples of Field) Material Engineering, Solid State Engineering (Metal, etc.), Metal Physics, Metal Corrosion Engineering, Nuclear Fuel Engineering, Actinoid Chemistry, Radiation Chemistry (Examples of Basic Technology) Welding, Corrosion Evaluation, Metal Physics, Nuclear Reactor Material, Fuel Design, Radiolysis, Rust Prevention, Long-term Soundness Evaluation, Volume Reduction and Stabilization and Solidification, Metal Recycling Technology, Property Grasping	(Examples of Field) Nuclear Reactor Physics, Nuclear Reactor Design and Structure, Simulation Engineering, Criticality Control, Maintenance Engineering, Radiation Science, Radiation Effects, Radiation Protection, Environmental Radiation, Kinetics theory (Examples of Basic Technology) Designing, Operation, Subcriticality Monitoring and Control, Analysis Codes and Simulation, Human Factor, Burn-up Analysis, Nuclide Identification, Protection, Environmental Impact Assessment, Exposure Evaluation, Radiation Evaluation, Evaluation of Emission/Scattering and Migration, Future Estimation (Long-term Dynamics), Transfer Behavior	(Examples of Field) Project Management, Legal Affairs, Labor Management, Financial Affairs, PA, Risk Communication, External Relations, Information System, Radiation Management (Examples of Basic Technology) Project Management (Planning, Risk Evaluation and Management, Resource Evaluation, EVM, etc.), Laws and Ordinances, Public Administration Affairs, Accounting, Procurement, Contract, Workforce Estimation, Labor Safety, Management of Records, Documents and Knowledge, Decision Making, Problem Solution, Strategic Thinking, Leadership, Communication Capability, Negotiation and Influence, Presentation Capability, Coaching, Foreign Language Ability, ICT and Systems Engineering, Facility Maintenance and Management, Other sorts of Back-office Operation, Nuclear Material Accounting/Nuclear Material Control/ Safeguards and Inspection Affairs
Nuclear Power Station (from Planning and Construction to Operation)	Sustaining of Criticality/Subcriticality, Existence of Defense in Depth, Remote Controlling in Some Parts, High Temperature and High Pressure, Long-term Operation	Design and Construction, Equipment Design, Manufacturing and Assembly, Power Generation (Turbine, etc.), Operation and Maintenance, Fuel Replacement and Storage	Electrical System (Heavy Current and Weak Current), Instrumentation System, Electricity Generators (Turbine, etc.), Maintenance and Checkup (Electrical Equipment, etc.), Non-destructive Inspection and Analysis (Devices)	Systems Designing (Process Design), Layout Design, Structure Design (Process Equipment, Piping, etc.), Thermal Hydraulics Design, Circulation System for Power Generation (Heat Exchanger, etc.), Confinement System (without α-nuclides), Air Conditioning Design	Geotechnical Evaluation, Seismic Design (Structural Soundness), Large-size Equipment Assembly, Maintenance and Inspection of Buildings, etc.	Reactor Design (Materials), Systems Designing (Materials), Structural Soundness of Structures, Maintenance and Checkup (Structures and Systems)	Core Design, Safety Design, Shielding Design, Thermal Analysis and Cooling Evaluation, Plant Operation, Response to Emergency, Fuel Storage (Dry and Wet)	<Legal Affairs, Finance, and Back-office> Financial Management, Contract Administration, Purchase Administration, Electricity/Gas/Water Supply, Intellectual Property Management, Information System Development and Operation, Security, Management of Records and Documents <Labor, Organization Management, Safety Management> Labor Safety, Response to Emergency and Accident, Fire and Explosion Prevention, Failure Protection Measures, Operation Risk Assessment, Crisis Management, Assessment (Audit), Organization Management, Equipment Management (Operation), Maintaining Motivation, Incentive Design, Technology Succession, Education and Training, HR (human Resource Management and Development Plan) <Project Management> Strategic Vision Formulation, Scenario Study, Overall Plan Formulation, Planning and Application of Decommissioning Plan of the Site, Cost Evaluation and Management, Time Management, Risk Assessment and Management, Process Control, Material Amount Management, Material Procurement, Expenditure Prioritization, QA, Land Planning, Work Space Management, Special Procurement (Planning and Implementation), Redundancy Securing, Construction Management, Quality Control <Engineering> Process Planning, Construction Plan, Maintenance, Operation Instruction, Planning and Training Simulator, (Remote-controlled) Equipment Operation, High-place Work Plan <Matters Common to Nuclear Power Facilities> Site Planning and Regional Relations, Environmental Impact Assessment, (Environmental) Monitoring, Exposure Management and Assessment, Radiation Management Equipment, Anti-terrorism Measures and Nuclear Material Protection, Designating and Canceling Radiation Controlled Areas, Equipment Maintenance, Planning, Managing and Implementing Fuel and Waste Transportation, Compliance with Safety Regulations and Permission and Authorization, Safeguards Administration <Research and Development Environment> Precedent Case and Studies, Environment for Innovation, Development and Maintenance of Foundations for R&D, Strategy for Mock-up Facilities and Testing, Collaboration with Researching Institutions <Social Relations> Securing Consistency with Past Cases, Relations with Stakeholders, Social Impact, Public Relations, Treating Visitors
Nuclear Fuel and Waste (from Front-end to Back-end of Fuel Cycle)	Keep Criticality; Existence of Defense in Depth; High Radiation Field; Basically Remotely Controlled, Long-term Operation; Mechanical Crafting in Some Parts; Emission of Dusts Containing α-nuclides; Numerous Chemical Processes	Design and Construction, Equipment Design, Manufacturing and Assembly, Operation and Maintenance, Transportation of Nuclear Materials and Fuels, Fuel Processing and Manufacturing, Fuel Storage (Dry and Wet), Spent Fuel Reprocessing, Waste Processing and Disposal	Electrical System (Heavy Current and Weak Current) Instrumentation System Nuclear Fuel and Spent Fuel Handling Equipment Remote Crafting and Measuring Instruments Cutting and Dismantlement (Spent Fuel, etc.) Waste Vacuuming and Removal Equipment Decontamination Technology (Device Development)	Systems Designing (Process Design), Layout Design, Structure Design (Process Equipment, Piping, etc.), Confinement System (for α-nuclides) Measures for Scattered Particle Dusts (as System Development), Air Conditioning Design, Spent Fuel Reprocessing, Decontamination of Systems (Using Chemical Methods), Waste Processing (Volume Reduction and Stabilization), Maintenance and Inspection of Systems	Geotechnical Evaluation, Seismic Design (Structural Soundness), Large-size Equipment Assembly, Decontamination Technology (Concrete, etc.), Cement and Asphalt Solidification, Storage Facility and Disposal Site Design (Thermal Design, etc.), Maintenance and Inspection of Buildings, etc.	Fuel Design (Material), Fuel Processing and Manufacturing Systems Designing (Material), Maintenance and Inspection of Systems, Decontamination Technology of Systems, Material Design of Storage Cans, Waste Storage Management (Chemical Stability and Long-term Change Prediction)	Fuel Design (Heat, Neutron), Safety Design, Shielding Design, Thermal Analysis and Cooling Evaluation, Criticality Control, Radiation Measurement, Radiation-resistant Design, Nuclear Material Accounting (Criticality), Measures for Scattered Particle Dusts (Against Exposure) , Heat Calculation of Waste, Waste Shielding Storage and Management (Criticality), Radioactivity and Material Balance Management (Inventory Evaluation)	
Decommissioning of Nuclear Facilities such as Non-accidental nuclear Power Plant	Known Internal Conditions, Gradual Removal of Defense in Depth, Remote Controlling in Some Parts, A lot of Mechanical Crafting, Emission of Dusts, Long-term Project	Retrieval of Spent Fuel, Decontamination of Inside of Buildings, Waste Sampling, Dismantlement of Reactor Area Dismantlement of Buildings, etc., Waste Processing and Disposal, Environment Restoration (Soil Restoration, etc.)	Remote Crafting and Measuring Instruments, Cutting and Dismantlement (Structures), Waste Vacuuming and Removal Equipment, Decontamination Technology (Device Development), Non-destruction Inspection and Analysis (Devices), Waste Sampling Devices, Dismantlement of Steel and Concrete Structures	Confinement System (Without α-nuclides), Decontamination Systems (Using Chemical Methods), Measures for Scattered Particle Dusts (as System Development), Waste Processing (Volume Reduction and Stabilization)	Structural Soundness of Buildings, Decontamination Technology (Concrete, etc.) Recycling of Concrete, etc., Dismantlement of Buildings, etc., Storage Facility and Disposal Site Design (Thermal Design, etc.), Environment Restoration (Soil, etc.)	Decontamination Technology (Structures), Property Grasping of Waste (Radio-chemical Analysis), Waste Storage and Management (Chemical Stability and Long-term Change Prediction)	Radiation Measurement (Handling Operations, etc.), Radiological Protection, Nuclide Identification, Shielding Design, Measures for Scattered Particle Dusts (Exposure Prevention), Heat Calculation of Waste, Waste Storage Management (Criticality, Shielding), Radioactivity and Material Balance Management (Inventory Evaluation), Clearance Level Assessment	
Decommissioning of Fukuoka Daiichi NPS and Other Accident-damaged NPS	Keep Criticality, High Radiation Field, Basically Remotely Controlled, Loss of Defense in Depth, Unclear Internal Conditions, High Uncertainty, A lot of Mechanical Crafting, Emission of Dusts Containing α-nuclides, Long-term Project, Large-scale Project	<Site Stabilization> Countermeasures for Groundwater and Contaminated Water, Securing Cooling Function (Water Circulation), Retrieval of Spent Fuel	Spent Fuel Handling Equipment	Measures for Cooling Water and Contaminated Water (Circulation System)	Measures for Groundwater	Measures for Contaminated Water (Processing)	Thermal Analysis and Cooling Evaluation	• Implementation of all the above actions, keeping in mind Safe, Proven, Efficient, Timely, and Field-oriented work under the environment and uncertainty at 1F that are different from normal environment, with unknown shape, composition, and internal condition (especially, Project Management) • Response to unprecedented regulations and Safeguards • Players well-versed in more than one field are necessary, considering that necessary human resources differ and processes change depending on the period.
		<Improvement of Operation Environment> Decontamination of Inside of Buildings, Structuring Inside PVC	Electrical System (Heavy Current and Weak Current), Instrumentation System, Decontamination Technology (Device Development)	Decontamination of Systems (Using Chemical Methods)	Decontamination Technology (Concrete, etc.)	Unravelling Contamination Mechanism, Decontamination Technology (Structures), Investigating the Chemical Effect of Seawater, Corrosion Prevention (PCV/RPV)	Making Contamination Maps	
		<Investigation and Preparation for Fuel Debris Retrieval> PCV/RPV Internal Investigation, Waste Sampling, Fuel Debris Sampling	Remote Crafting and Measuring Instruments (Investigating Instruments)	Systems Designing (Process Design), Layout Design Structure Design (Process Equipment, Piping, etc.), Confinement System (for α-nuclides) Measures for Scattered Particle Dusts (as a System Development) Air Conditioning Design	Structural Soundness of Buildings, Structural Soundness of Containment Vessels, Water Sealing at Building Borders, Water Sealing at PCV Borders	Systems Designing (Material) Property Grasping of Fuel Debris (Chemical Analysis) Material Design of Storage Cans	Severe Accident Progression Analysis, Property Grasping of Fuel Debris, Thermal Analysis and Cooling Evaluation, Radiation-resistant Design, Measures for Scattered Particle Dusts (Against Exposure)	
		<Fuel Debris Retrieval> Fuel Debris Retrieval, Transportation and Storage of Fuel Debris, Processing and Disposal of Fuel Debris	Radiation Measurement (System Development), On-site Sample Analysis Non-destructive Inspection and Analysis (Devices), Remote Crafting and Measuring Instruments (Retrieving Instruments), Cutting and Dismantlement (Structures), Sampling Devices for Fuel Debris, Retrieving Devices for Fuel Debris, Waste Sampling Devices, Waste Vacuuming and Removal Equipment	Fuel Debris Processing Waste Processing (Volume Reduction and Stabilization)		Radiation Measurement (Development of Components), Aging Characteristics of Fuel Debris, Property Grasping of Waste (Radiochemical Analysis), Waste Storage and Management (Chemical Stability and Long-term Change Prediction)	Radiation Measurement (Handling Operations, etc.), Radiological Protection, Nuclide Identification, Criticality Control, Radioactivity and Material Balance Management (Inventory Evaluation), Fuel Debris Storage and Management (Criticality, Shielding), Heat Calculation of Waste, Waste Storage and Management (Criticality, Shielding)	
		<Dismantlement and Environment Restoration> Reactor Area Dismantlement Dismantlement of Buildings, etc., Waste Processing and Disposal, Environment Restoration (Soil Restoration, etc.)	Remote Crafting and Measuring Instruments (Dismantling Devices) Cutting and Dismantlement (Structures) Waste Sampling Devices Waste Vacuuming and Removal Equipment	Waste Processing (Volume Reduction and Stabilization)	Dismantlement of Buildings, etc., Cement and Asphalt Solidification, Storage Facility and Disposal Site Design (Thermal Design, etc.), Environment Restoration (Soil, etc.)	Property Grasping of Waste (Radiochemical Analysis), Waste Storage and Management (Chemical Stability and Long-term Change Prediction)	Heat Calculation of Waste Waste Storage and Management (Criticality, Shielding) , Clearance Assessment	

(Note) In the section of “Decommissioning of the Fukushima Daiichi NPS and other Accident-damaged NPS”, technical issues that have similar entries in the other stages of nuclear industries are highlighted by yellow color, and other issues that have similar entries as well but have different preconditions or require higher levels of response are highlighted by green color. Technical issues with no similar entries are highlighted by red color. (The corresponding entries in the other stages of nuclear industries are also highlighted by yellow or green colors.)

(Source: Material 2-4-2, 6th Meeting of Decommissioning R&D Partnership Council (December 12, 2017)

Attachment 14 Current Progress of the Government-led R&D program on Decommissioning and Contaminated Water Management

1. Grasping state inside reactor, characterizing of fuel debris, and internal investigation

1-(1) Advancement of comprehensive grasping of state inside reactor (FY 2016 - 2017) (Fig. A14-1-(1))

(Related projects) Advancement of accident progression analysis technology for assessing conditions inside reactor (FY 2011)
Assessing conditions inside reactor by advancement of accident progression analysis technology (FY 2012 - 2013)
Assessing conditions inside reactor through application of severe accident analysis code (FY 2014)
Advancement of grasping conditions inside reactor by accident progression analysis and actual data, etc. (FY 2015)

1-(2) Development of technologies for analyzing and estimating characterization of fuel debris (FY 2019) (Fig. A14-1-(2))

(Related projects) Development of technologies for characterization and processing of fuel debris using mock-up debris (FY 2011 - 2014)
Property analysis of actual debris (FY 2014)
Grasping properties of fuel debris (FY 2015 - 2016)
Development of technologies for grasping and analyzing fuel debris (FY 2017 - 2018)
Construction of material accountancy method related to fuel debris (FY 2011 - 2013)

1-(3) Development of technologies for in-depth investigation of PCV inside (FY 2017 - 2019) (Fig. A14-1-(3))

(Related projects) Development of investigation technology of inside of PCV (FY 2011 - 2013)
Development of investigation technology of inside of PCV (FY 2014 - 2015)
Development of investigation technology of inside of PCV (FY 2016 - 2017)

1-(4) Development of investigation technology inside RPV (FY 2016 - 2019) (Fig. A14-1-(4))

(Related projects) Development of investigation technologies inside RPV (FY 2013 - 2015)

1-(5) Development of sampling technologies for retrieving fuel debris and internal structures (FY 2017 - 2019) (Fig. A14-1-(5))

1-(6) Development of technologies for the detection of fuel debris inside reactors (using muon) (FY 2017 - 2019) (Fig. A14-1-(6))

2. Retrieval of fuel debris

2-(1) Development of technologies for retrieving fuel debris and internal structures (FY2019) (Fig.A14-2-(1))

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

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

2-(2) Advancement of fundamental technologies for retrieval of fuel debris and internal structures (FY 2017 - 2018) (Fig. A14-2-(2))

(Related projects) Development of fundamental technologies for retrieval of fuel debris and internal structures (FY 2015 - 2016)

2-(3) Development of closed circulation systems for water inside PCV (FY 2018 - 2019) (Fig. A14-2-(3))

2-(4)-1 Development of repair methods for leak spots in PCV (FY 2016 - 2017) (Fig. A14-2-(4)-1))

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

2-(4)-2 Full-scale test of repair methods for leak spots in PCV (FY 2016 - 2017) (Fig. A14-2-(4)-2))

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

2-(5) Development of evaluation methods of seismic performances of RPV and PCV and the impacts of the damages (FY 2016 - 2017) (Fig. A14-2-(5))

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

2-(6) Development of corrosion inhibition technology for RPV and PCV (FY 2016) (Fig. A14-2-(6))

2-(7) Development of criticality control technologies of fuel debris (FY 2012 - 2017) (Fig. A14-2-(7))

2-(8) Development of technologies for non-destructive detection of radioactive material deposited in S/C, etc. (FY 2014) (Fig. A14-2-(8))

2-(9) Development of remote decontamination technology in the reactor building (FY 2014 - 2015) (Fig. A14-2-(9))

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

2-(10) Formulation of comprehensive radiation dose reduction plan (FY 2012 - 2013) (Fig. A14-2-(10))

2-(11) Development of technologies for containing, transferring and storing fuel debris (FY 2016 - 2019) (Fig. A14-2-(11))

(Related projects) Development of containing, transferring and storing technologies of fuel debris (FY 2014 - 2015)

3. Waste management

3. Research and development of processing and disposal of solid waste (FY 2017 - 2019) (Fig. A14-3)

(Related projects) Development of technologies for processing/disposal of secondary waste by treatment of contaminated water (FY 2012)

Development of technologies for processing/disposal of radioactive waste (FY 2012)

Research and development of processing/disposal of solid waste (FY 2013 - 2014)

Research and development of processing/disposal of solid waste (FY 2015 - 2016)

4. Spent fuel management

4-(1) Evaluation of long-term integrity of fuel assembly retrieved from spent fuel pool (FY 2015-2016) (Fig. A14-4-(1))

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

4-(2) Investigation of method for processing damaged fuel, etc. removed from spent fuel pool (FY 2013 - 2014) (Fig. A14-4-(2))

5. Contaminated water management

5-(1) Verification tests of tritium separation technologies (FY 2014 - 2015) (Fig. A14-5-(1))

5-(2) Verification of technologies for contaminated water treatment (FY 2014) (Fig. A14-5-(2))

5-(3) Large-scale verification of impermeable walls (frozen wall) (FY 2014) (Fig. A14-5-(3))

5-(4) Development and verification of high-performance multi-nuclide removal equipment (high-performance ALPS) (FY 2014) (Fig. A14-5-(4))

Project objectives

In the decommissioning process of the Fukushima Daiichi NPS, with the aim of confirming the stability of plants and determining methods to retrieve fuel debris, comprehensive analysis and evaluation were performed to precisely comprehend the state of fuel debris and fission products (FPs) in reactors. This project collected and arranged through analysis and evaluation, the data and information required for the assessment of impacts on the integrity of structures, such as PCVs, criticality assessment, and assessment of FP behaviors at the time of fuel debris retrieval, as well as information about the location and distribution of fuel debris and FPs for each unit.

1. Project details and progress

The following describes the results this project produced so far based on results from the related projects described in Section 2 below.

(1) Comprehensive analysis/evaluation of conditions inside reactors

Information summary maps which summarizes the various information from the RPV, PCV, and R/B, were created using the assumed conditions inside the RPV/PCV of all units. The information was then comprehensively analyzed and evaluated, and used to provide an estimation diagram of the fuel debris distribution (Fig. 1), an estimation of the FPs distribution, and an estimation of the radiation dose distribution. To effectively advance these efforts toward, a database was developed by comprehensively collecting and arranging, data measured with the Fukushima Daiichi NPS and the results of on-site investigations.

(2) Reduction of uncertainties using analysis methods

Sensitivity and other analysis taking into consideration the boundary conditions and an analysis model for events assumed to have occurred within the reactor were conducted using the accident progression analysis codes (MAAP, SAMPSON), and which then provided expertise that will contribute to the more comprehensive analysis and evaluation. A simulated fuel assembly plasma melting tests (Fig. 2) were performed, which provided expertise leading to reducing the uncertainties of events such as core meltdown and relocation in fuel assembly systems.

(3) Evaluation of FPs chemical properties

In evaluating the FPs chemical properties, and with a focus on Cs, which is largely contributing to the radiation dose level during the decommissioning, a study has commenced upon the distribution of Cs and its chemical properties, including identifying the chemical species that need to be considered in addition to standard chemical species such as CsI and CsOH, and the insoluble Cs particles whose production has been confirmed in the environment around the Fukushima Daiichi NPS , and the possibility of uneven Cs associated with the reactions in the upper structures of the RPVs. In addition, on-site test samples have been analyzed, and a study of the composition and spatial distributions of uranium and FPs conducted from the aspect of identifying the conditions inside the reactor (Fig. 3).

(4) Utilization of domestic/overseas knowledge through international joint research

The international Joint Research, OECD/NEA BSAF Phase 2 Project involves the sharing of accident progress scenarios and plant information with overseas organizations utilizing the database, and the evaluation results of the accident progression and plant/FP distribution by participating organizations being compared to actual measured values and the results of on-site investigations. It was confirmed that the evaluation results of the FP release amounts was consistent with the amounts released into the environment. The estimated accuracy of the fuel debris distribution was improved via more through knowledge of the progression of the accident. The expertise obtained through discussions with overseas organizations were utilized in the comprehensive analysis and evaluations.

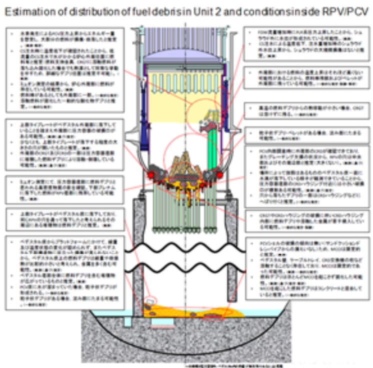


Fig. 1: Example of diagram of estimated fuel debris distribution

Fig. 2 Example of heating test result of simulated fuel assembly plasma

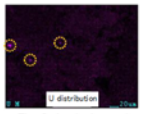


Fig. 3 Analysis result of containment vessel of Unit 1

Implemented by

International Research Institute for Nuclear Decommissioning (IRID) (FY 2013 -), the Institute of Applied Energy

2. Related projects

The following describes the results of previous related projects.

○ Advancement of accident progression analysis technology for assessing conditions inside reactor (FY 2011)
- Plans for future projects have been developed.

○ Assessing conditions inside reactor by advancement of accident progression analysis technology (FY 2012 - 2013)
- To improve severe accident progression analysis codes, significant phenomena for the progression of severe accidents were identified and a phenomena identification and ranking table (PIRT) was complied. Sensitivity analysis results have also been revised.
- Each model of analysis codes (MAAP and SAMPON) has been improved, and the progression of severe accidents has been analyzed.
- Specifically, debris spreading behaviors on the floor of a PCV and the chugging phenomenon in a suppression chamber were evaluated.
- The OECD/NEA BSAF Project was operated by the Institute of Applied Energy as the operating agent. Common analysis conditions were established. Meetings were held, and information was shared with participating organizations.

○ Assessing conditions inside reactor through application of severe accident analysis code (FY 2014)
- To improve severe accident progression analysis codes, based on sensitivity analysis with MAAP, the PIRT was evaluated and the significance ranking was reset.
- Each model of analysis codes (MAAP and SAMPON) has been improved, and the progression of severe accidents was analyzed.
- Specifically, thermal hydraulic analysis related to the spreading of debris and molten core-concrete interaction (MCCI) model has been upgraded.
- Phase 2 has been started after summarization of OECD/NEA BSAF Phase 1 Project.

○ Advancement of grasping conditions inside reactor by accident progression analysis and actual data, etc. (FY 2015)
- To improve severe accident progression analysis codes, each model of analysis codes (MAAP and SAMPSON) has been improved, and severe accident progression analysis and sensitivity analysis were performed.
- An analysis code for the evaluation of MCCI has been developed, and the behavior of fuel debris fallen in PCV was predicted.
- Specifically, melting test of penetrating tubes through RPV was performed at the Korea Atomic Energy Research Institute and data for the verification of analysis results was obtained.
- Comprehensive analysis and evaluations were performed using the results of severe accident progression analysis, internal investigations, and results of other R&Ds, and the distribution of fuel debris was predicted.

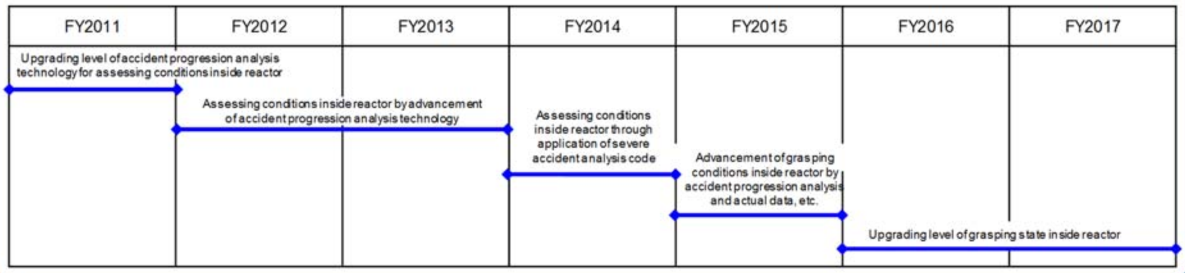


Fig. A14-1-(1) Upgrading level of grasping state inside reactor

Project objectives

In the decommissioning of the Fukushima Daiichi NPS, to contribute to the study of the methods to retrieve fuel debris and internal structures, and development of technology for collection, transfer, and storage of fuel debris, technologies required to analyze and estimate the properties of fuel debris will be developed.

1. Project details and progress

The following describes the results this project produced so far based on results from the related projects described in Section 2 below.

(1) Development of technologies necessary for analysis of fuel debris

- Fuel debris samples and deposits are analyzed at research institutions with hot facilities. The analysis results of the deposits analyzed so far are shown in Fig. 1. Analysis items shared by each hot facility and transportation are examined.
- Based on the analysis results obtained, the "list of fuel debris characteristics" has been upgraded to be used for the development of retrieval methods and the technologies for collection, transfer, and storage, criticality control, and evaluation and analysis in the event of an accident.
- To work on the development of analytical technologies while making use of international knowledge, in the OECD/NEA project, knowledge on fuel debris in each country is collected and the analysis items are reviewed.

(2) Development of the technology for estimating the properties of aging fuel debris

To clarify the impact of aging on fuel debris, tests are conducted to estimate chemical and physical aging characteristics of the molten core-concrete reaction products and the results have been reviewed and evaluated.

(3) Development of the technology for estimating the behavior of fuel debris particulates

In order to investigate the impact of the radioactive particulates generated from fuel debris on the fuel debris retrieval system, tests are conducted on the behavior of generation and dispersion of radioactive fine particles (α-dust) and the relocation behavior in the gas phase, gas-liquid interface and liquid phase and the results were examined and evaluated.

Implemented by

(Comprehensive proposal) International Research Institute for Nuclear Decommissioning (IRID) (FY 2013 -)
(Partial proposal) Estimation of aging properties of fuel debris: TENEX (FY 2017 -)

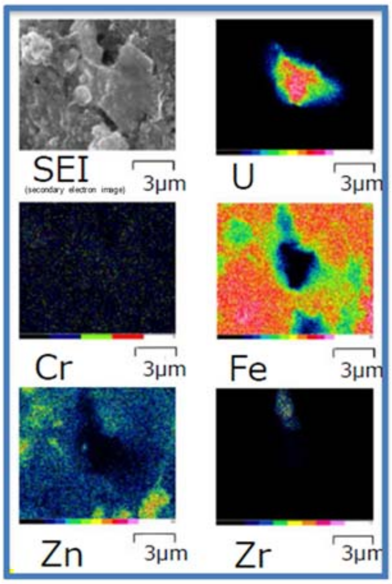


Fig. 1: Element distribution of the deposit collected at Unit 1

2. Related projects

The following describes the results of previous related projects.

○ Development of technologies for characterization and processing of fuel debris using mock-up debris (FY 2011 - 2014)
- Observations of microstructure and measurement of hardness were carried out using TMI-2 debris stored in the JAEA.
- The applicability of the alkaline solution was verified to evaluate analysis technologies.
- In cooperation with the NNC in Kazakhstan, solidified melt bulk was prepared from metals/ceramics with uranium oxide.
- The hydration/drying characteristics were evaluated using porous ceramics.

○ Property analysis of actual debris (FY 2014)
- Using simulated debris, solution, quantitative analysis, simplified quantitative analysis and modification of analyzers (SEM, EDX, and WDX) were examined.
- The applicability of high-sensitive active neutron detection technology was studied as a technology to detect nuclear fuel materials.
- The applicability to nuclide analysis and handling required to accept fuel debris, samples splitting, pre-treatment, analysis and post-treatment were evaluated.

○ Grasping properties of fuel debris (FY 2015 - 2016)
- The properties of fuel debris required to evaluation was identified. Micro-properties, macro-properties and cross-sections of MCCI products were added in the Fuel Debris Characteristics List.
- Data on physical properties required for designing equipment for retrieval, containing, and storage of fuel debris was obtained. Drying properties and changes in characteristics during oxidation reaction were evaluated.
- A multi-element simultaneous analysis using ICP-AES and a multi-nuclide rationalized analysis using ICP-MS were examined. The development of a quantitative porosity evaluation by X-rays CT was continued.
- Data on the hardness and particle size distribution of the solidified melt bulk prepared from metal/ceramics in Kazakhstan was obtained.

○ Development of technologies for grasping and analyzing fuel debris (FY 2017 - 2018)
- To estimate the properties of fuel debris, data on the estimated dose rate of fuel debris surfaces, behavior of particulates, and the properties of deposits inside 1F was collected and assessed.
- Heating tests of fission products in the dry heat treatment were carried out under atmospheric pressure and reduced pressure to evaluate the behavior of the release of fission products.
- As elemental technologies for the analysis of fuel debris, dissolution methods, the analysis technology by X-ray CT, and the analytical method of multi-nuclide rationalization by ICP-MS were developed.
- In an international OECD/NEA project, knowledge on fuel debris was collected, and analysis programs were discussed with international experts.

○ Construction of material accountancy method related to fuel debris (FY 2011 - 2013)
- The amount of fuel materials in the TMI-2, nuclear fuel material measurement technologies used in the Chernobyl NPS and material accountancy procedures were collected and compiled.
- Nuclear fuel materials measurement technologies applicable to the Fukushima Daiichi NPS were evaluated.
- Under the safeguards cooperation agreement between the JAEA and the DOE, a cooperative framework with U.S. national research institutes has been established.

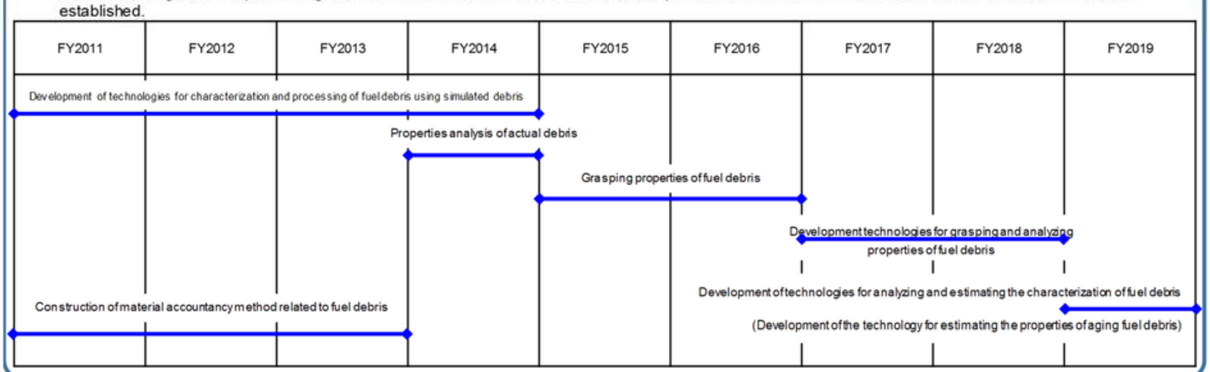


Fig. 14-1-(2) Development of technologies for analyzing and estimating the characterization of fuel debris

Project objectives
To contribute to the determination of methods to remove fuel debris, equipment and more sophisticated investigation technologies will be developed and verified to more accurately and more widely investigate the distribution of fuel debris in PCVs and circumstances in or outside pedestals.

1. Project details and progress
The following describes the results this project produced so far based on results from the related projects described in Section 2 below.

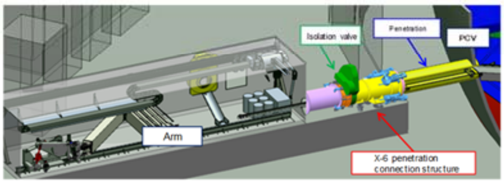
(1) Establishment of surveillance plans and development plans

Surveillance plans and development plans were prepared and updated towards the on-site demonstration of the detailed investigation for Units 1 and 2, based on the results of the latest investigation of the inside the PCVs of Units 1 to 3.

(2) Development of access/surveillance equipment and elemental technologies

[1] Establishing access routes into the inside of the PCV through X-6 penetration, and access/surveillance equipment

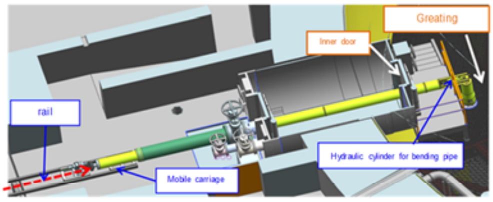
The equipment related to the construction of the access routes into the PCV through the X-6 penetration was designed and manufactured, and the verification in the factory related to the installation of the isolation room and the opening of the hatch, as well as the verification in the factory related to the connection pipe with isolation valves to be connected to the X-6 penetration by remote control were carried out. In addition, the arm-type access equipment was designed and produced with the aim of identifying the range of fuel debris by accessing inside of the PCV through X-6 penetration based on the shape of debris and the distribution of gamma rays.



X-6 penetration connection structure

[2] Establishing access routes into the PCV through X-2 penetration, and access/surveillance equipment

The equipment for establishing the route to access the inside of the PCV through X-2 penetration was designed and manufactured, and verification inside the factory (functional test) was carried out. In addition, an underwater remotely operated vehicle was designed and produced, which is capable of accessing the inside of the PCV through the X-2 penetration and investigating with measuring technology suitable for the objectives of surveillance (distribution and thickness of deposits, fuel debris distribution under the deposits, etc.) considering deposits present in a wide range of basement floors. Surveillance equipment was also designed and produced with the aim of carrying in and out the access equipment through the X-2 penetration in a condition that it is isolated from the inside the PCV, and functional tests were carried out.

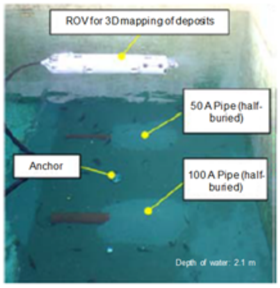


Boring device for X-2 penetration inner door, grating, etc.

[3] Verifying the applicability of elemental technologies

Measuring equipment to be mounted on an access device was designed and produced, and unit testing and the combined testing with the access device were conducted.

X-6 penetration connection structure (connection pipe with isolation valve)



Example of combined test of underwater remotely operated vehicle and measuring equipment

(3) On-site demonstration of the technology for detailed investigation of the inside using X-6 penetration

[1] Establishment of surveillance plans and development plans

Based on the results of surveillance inside the Unit 2 PCV and the results of designing the access and surveillance equipment, the access procedure and the accessible range (the range where measurement is possible) were examined, and the surveillance and development plan for the on-site demonstration was formulated.

[2] On-site demonstration of access/surveillance equipment and surveillance technologies

- Mock-up test considering the on-site situation

  For the mock-up test of the arm-type access equipment, a part of the test equipment was manufactured and a test plan was formulated.

- Work training

  Prior to the work training of the access and surveillance equipment, a virtual reality (VR) system for the operation simulation was created.

- Testing and work training for the construction of access routes into the PCV in the field

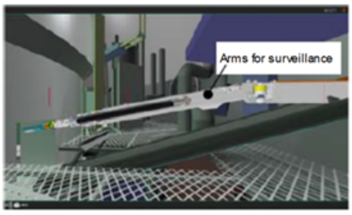
  A mock-up test was carried out on the X-6 penetration connection structure (connection pipe with isolation valve) which is to be connected to the X-6 penetration by remote control, taking the on-site environment into consideration. In addition, a combination test with the isolation room and work training related to the opening of the hatch were conducted.

  Further, a device for removing deposits, etc., inside the X-6 penetration was designed and manufactured.

- The specifications of the neutron detection system were set, and its design and production were started.

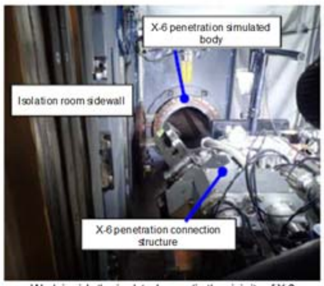
[3] Issues and future plans

In the future, mock-up tests of access and surveillance equipment, combined tests of surveillance technologies, work training and on-site demonstrations will be conducted.



Display screen (access of the arm into the inside of the PCV)

VR system for access and surveillance equipment



Work inside the isolated room (in the vicinity of X-6 penetration)

Status of the combined test

(4) On-site demonstration of the detailed investigation of the inside on the premise of deposit countermeasures

[1] Establishment of surveillance plans and development plans

Towards the detailed investigation of the inside of the Unit 1 PCV, plans were developed for a mock-up test, work training and on-site demonstration using equipment developed related to the establishment of access routes and detailed investigations.

[2] On-site demonstration of access/surveillance equipment and surveillance technologies

• Construction of access routes into the inside of the PCV

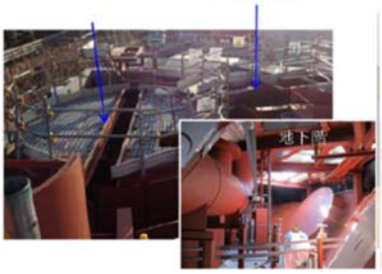
With the equipment and devices related to the construction of the access routes, a mock-up test and work training were conducted for the connection of the new boundary to the X-2 penetration, drilling of the inner and outer doors and grating, the removal of handrails and interference on the underground floor, and installation of guide pipes. Then, preparations for on-site demonstrations in the Unit 1 reactor building were started.

• Detailed investigation of the inside of the PCV

A mock-up test facility was produced, and the mock-up test was started by using the system for detailed investigation and the underwater remotely operated vehicle.

[3] Future plans

The on-site demonstration will be carried out based on the on-site demonstration of the construction of Unit 1 access routes and mock-up test of the detailed investigation.



Mock-up test facility for detailed investigation

Status of mock-up test for establishing access routes

Implemented by
International Research Institute for Nuclear Decommissioning (IRID)

2. Related projects

The following describes the results of previous related projects.

○ Development of investigation technology of inside of PCV (FY 2011 - 2013)

• Targets and items to be investigated and technical challenges were identified, and access routes for the implementation of the investigations were studied.
• In FY 2012, the inside of the Unit 1 PCV was accessed through X-100B penetration and an investigation was carried out with a camera. Based on the results of the investigation, investigation equipment has been developed for prior investigation of the inside of PCVs (collecting videos and data on radiation dose and temperature).
• In FY 2012 and 2013, the inside of the Unit 2 PCV was accessed through X-53 penetration, and investigations were carried out with camera. Since the radiation level around the X-6 penetration was much higher than the estimate, it was necessary to take measures to reduce the radiation level. Therefore, investigations through the X-6 penetration were postponed.
• Design and fabrication of prototypes of equipment to remove Unit 2 X-6 shielding blocks and equipment for investigations through X-6 penetration have been started.

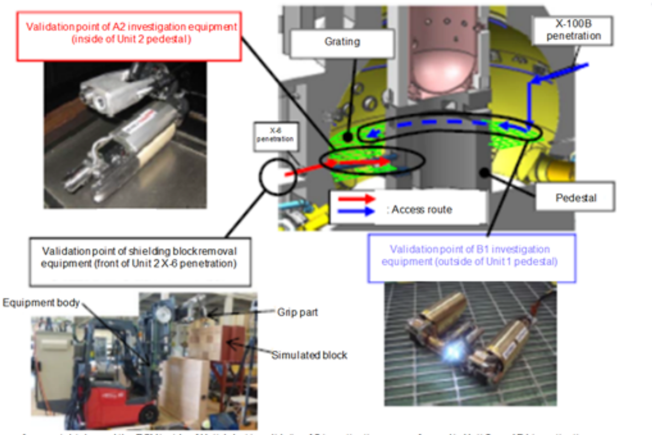
○ Development of investigation technology of inside of PCV (FY 2014 - 2015)

(1) Technologies to access the inside of pedestals
• Verification tests at a plant for investigation equipment for the Unit 2 A2 Investigation (investigation of the situation on the platform in the pedestal) have been completed.
• For further investigation of the inside of the pedestal (A3 Investigation), prototypes of equipment to open the hatch of X-6 penetration were made and tested.

(2) Technologies to remove shielding blocks
• Shielding block removal equipment was developed, and during the period from June through July of 2015, the removal of shielding blocks in front of the Unit 2 X-6 penetration was completed (on-site verification).

(3) Technologies to access the outside of the pedestal
• Verification tests at a plant for investigation equipment for Unit 1 B1 Investigation (investigation, through X-100B penetration, of circumstances on the grating on the first floor in the PCV) have been completed, and on-site verification was performed in April 2015. It was confirmed that there was no significant damage to the existing equipment in the PCV, and data on radiation levels and temperatures in a range about three-fourths of an orbit above the grating on the first floor was obtained.
• Methods for further investigation (B2 Investigation) was drafted.

(4) Fuel debris measuring technologies
• Methods to upgrade measuring technologies were studied for the fuel debris investigations that will start after FY 2017.



The figure of upper-right showed the PCV inside of Unit 1, but in validation A2 investigation was performed in Unit 2, and B1 investigation was performed in Unit 1.

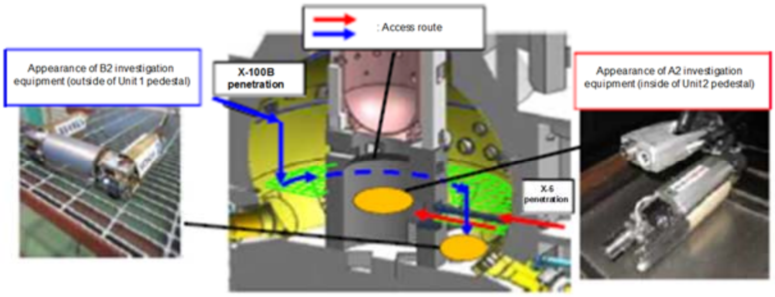
○ Development of investigation technology of inside of PCV (FY 2016 - 2017)

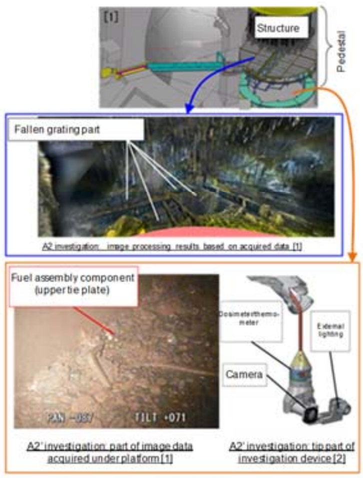
(1) Developing access/investigation equipment and systems for particular parts

- Access/investigation equipment for Unit 1 B2 Investigation (investigation, through X-100 B penetration, of the basement floor outside the pedestal) was developed, and on-site verification was performed in March 2017. It was confirmed that there was no significant damage to the inside wall of the PCV and to existing equipment and that there were deposits on the bottom of the PCV. The radiation level increased as the distance from the surface of the deposits decreased.。
- Access/investigation equipment for Unit 2 A2 Investigation (investigation, through X-6 penetration, of circumstances on the platform in the pedestal) and A2' Investigation (investigation, through X-6 penetration, of circumstances below the platform in the pedestal) has been developed, and A2 Investigation was carried out in January 2017 and A2' Investigation in January 2018. Pieces of gratings that had fallen were found on the platform, and there was a part of fuel assemblies on the bottom of the pedestal. There were also deposits around them, which seemed to be fuel debris.
- Underwater ROV has been developed to access the inside of the PCV through Unit 3 X-53 penetration and to investigate the circumstances inside the pedestal. Then, on-site verification was performed in July 2017. It was confirmed that several structures were damaged and that there were melted objects solidified and clump deposits.
- A concept for how to establish access routes for the next phase of investigations was examined, and elemental tests were performed. As access equipment, conceptual studies and elemental tests were carried out for underwater ROV, floor traveling-type equipment, and arm-type access equipment.

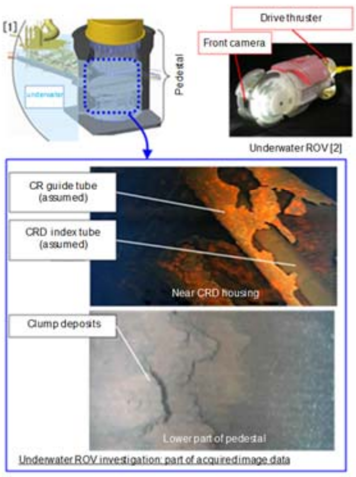
(2) Formulating and updating investigation plans and development plans for next phase investigations

- Conceptual studies and elemental tests were performed for the Unit 1 investigation using underwater ROV that accesses the inside of the PCV through X-2 penetration and for Unit 2 investigation using arm-type access equipment that accesses the inside of the PCV through X-6 penetration.
- Conceptual studies and elemental tests were performed for the following technologies that can be applied in combination with the above access/investigation equipment: technology to measure dimensions, distances, and shapes; visual investigation technologies; and radiation-level measuring technologies (measurement of gamma ray and measurement of radiation released from debris).





Results of investigation inside the Unit 2 pedestal



Results of investigation inside the Unit 3 pedestal

FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019
Development of investigation technology of inside of PCV								
			Development of investigation technology of inside of PCV					
					Development of investigation technology of inside of PCV			
						Development of technologies for in-depth investigation of PCV inside		
							Development of technologies for in-depth investigation of PCV inside (on-site verification)	

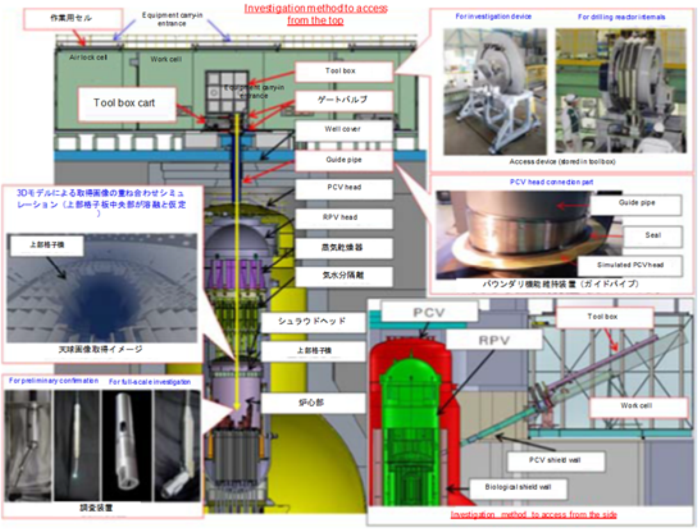
Fig.14-1-(3) Development of technologies for in-depth investigation of PCV inside

Project objectives
To contribute to the studies on the retrieval of fuel debris in RPVs, investigation technologies to identify the state of fuel debris in RPVs will be developed.

Project details and progress
The following describes the results this project produced so far based on results from the related projects described in Section 2 below.
(1) Establishment of surveillance plans, development plans and construction methods
- Information necessary for fuel debris retrieval was organized and updated, and the surveillance and development plan was updated.
- The approach to safety requirements towards the safety assessment during surveillance was organized, and a simplified model using air flow analysis in the primary containment vessel (PCV) was examined in order to assess the impact of radioactive dust during processing.

(2) Study of supplementary systems for surveillance
- Required specifications were identified for supplementary systems necessary for conducting surveillance and safety, such as gas control necessary for maintaining negative pressure in the PCV, nitrogen supply system, dust monitoring, criticality control, and water treatment system.

(3) Development of equipment to access the core
[1] Developing equipment to access from the top (top-hole-drilling method)
- To establish an access route for investigations from the top of the RPV to the core, the position of holes was studied and a work plan was developed. To avoid interference with structures, the removal method of RPV spare top head nozzle was verified through elemental tests.
- The specifications of the work cell in which a negative pressure environment is maintained in order to prevent the expansion of contamination were studied. In addition, the sealing and installation performance of the connection part between the guide pipe and the PCV head was checked through element tests.
- Studies were performed on a processing method to make holes in the reactor internal remotely and in narrow spaces and on its equipment specifications. Then, prototypes of an abrasive water jet (AWJ) tool head and access equipment were made, and their remote operability was checked through elemental tests.
- In response to the above results and remaining issues, equipment specifications were established through desktop studies and partial tests. In addition, an element test plan was formulated to confirm the validity of the equipment specifications, and preparations were made for test specimens and equipment for element tests.



[2] Developing equipment to access from the side (side-hole-drilling method)
- The access route to the core from the side was determined, and a concept of the method was established, including the selection of tools appropriate to the drilling and sealing work and major operation steps. In addition, overall specifications of the equipment were summarized, including the design of maintenance systems for the equipment.
- In response to the above results and remaining issues, equipment specifications were established through desktop studies and partial tests. In addition, an element test plan was formulated to confirm the validity of the equipment specifications, and test specimens and equipment for element tests were prepared.

(4) Development and selection of surveillance method to the core
- Specifications of equipment for prior-checking of access routes and investigation of the core were studied by each investigation step. The visibility, radiation resistance, and operability were checked through elemental tests.

(5) Issues and future plans
- The feasibility of the top-hole-drilling method was confirmed, and the prospect of achieving the side drilling method was obtained. Therefore, exposure assessment necessary for the safety assessment and element tests using partial prototypes of each equipment will be conducted for both surveillance methods. Then, by reflecting the results in equipment designs, specifications for equipment and systems will be developed.
- The work procedures and maintenance methods for surveillance will be organized as well to materialize the surveillance plan.

Implemented by
International Research Institute for Nuclear Decommissioning (IRID)

2. Related projects
The following describes the results of previous related projects.
○ Development of investigation technology inside RPV (FY 2013 - 2015)
- To collect information on temperatures, radiation doses in RPVs and the positions of fuel debris in RPVs, and the damage status of reactor internals, the method of accessing the target of the investigation, the investigation method, and the method to collect samples were studied. Investigation technologies under a high radiation environment (estimated as 1000Gy/h) in RPVs were also sorted out. Then, a technology development plan for the investigation of the inside of RPVs was established.
- The needs of the investigation derived from the field and related projects, such as the fuel debris retrieval project, were sorted out and the feasibility of investigations were assessed.
- To access the inside of RPVs in the early stages, study was conducted on access technologies through existing routes (such as pipes) and through new routes that are to be drilled, as well as the fundamental design of investigation technologies and elemental technologies.
- Elemental tests were conducted to verify the feasibility of RPV top hole drilling method which is one of major technologies for the investigation of the inside of RPVs, systems to maintain the boundary function, and technologies to collect fuel debris samples from the side of PCVs.

FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019
		Development of investigation technology of inside of RPV (FY2013–FY2015)			Development of investigation technology of inside of RPV (FY2016–FY2019)			

Fig.14-1-(4) Development of investigation technology inside RPV

Project objectives

With the purpose of contributing to criticality control, equipment design, and the development and rationalization of work procedures related to the work of fuel debris retrieval, scenarios for sampling actual fuel debris will be developed, and sampling devices including access devices will be studied and developed.

Project details and progress

To contribute to criticality control during fuel debris retrieval and to the design of fuel debris retrieval equipment, the technology needed for the development and updating of the sampling surveillance scenario for the collection of sampling of the access devices, etc., is also being developed. While incorporating the development results of the arm-type access device for detailed investigation of the inside of the Primary Containment Vessel (PCV), the specifications for development of the technologies expected to be applied to the retrieval of fuel debris, such as remote transportation of samples and neutron flux monitoring, are also being materialized through element tests. The activities conducted so far and the results obtained from them are described below.

(1) Extraction of fuel debris, the examination and development sampling scenarios

The entire scenario of fuel debris sampling was decided based on needs and the result of detailed investigation inside the PCV. In addition, a gradual sampling step was reviewed in consideration of the balance between the analysis needs and the response skills of the analysis facility side. Response to a case where it is difficult to access the molten fuel debris due to the interference inside the PCV is being extracted and examined.

Further, a feasible method with a small amount of sampling that does not require special equipment during the detailed investigation inside the PCV was developed.

(2) Design and trial production of systems and equipment for the sampling of fuel debris inside the PCV

[1] Basic design of the fuel debris sampling systems

The structure and specifications were developed for a remote transport system for fuel debris samples, which is expected to be applied to the retrieval of fuel debris, as well as for a neutron monitor for criticality safety when cutting the fuel debris.

[2] Design and trial production of devices accessing to fuel debris

In order to apply the arm-type access device for detailed investigation of the inside the PCV for the collection of fuel debris samples, the measures for enhancing the performance, such as for transportation, containment and avoiding interference was developed.

[3] Design and trial production of fuel debris sample collection devices

Element tests were carried out on attached tools for the collection of sample pebbles and sandy debris, and conceptual designs were carried out. In addition, in consideration of the interface with the sample analysis facility and the arm-type access device, the device specification based on the element test was realized.

(3) Examination on the concept of the sampling system for fuel debris inside the reactor pressure vessel (RPV)

Based on the development of the technology for investigating the inside of the RPV, the system concept to access the inside of the RPV from the top or side was studied and updated.

(4) Issues and future plans

Technologies essential for fuel debris retrieval are being identified, and the verification items, design specifications to be targeted, and development processes are being summarized. In the future, progress will be made to develop the equipment with the aim of early fuel debris sampling.

In addition, in collaboration with the "Development of Technology for Detailed Investigation inside PCV" to be conducted simultaneously, efforts will be made to achieve a small amount of fuel debris sampling.

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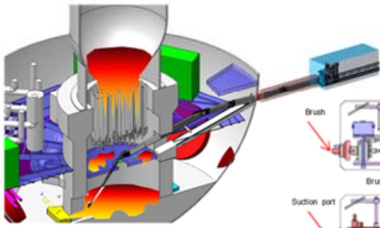
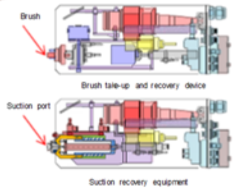
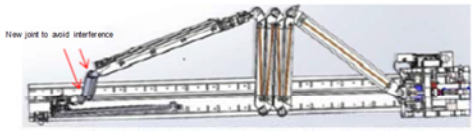


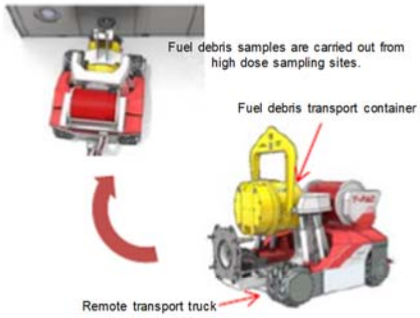
Sampling concept for debris in PCV



Concept of a device for recovering a small amount fuel debris sample



Example of an access device with improved performance in avoiding interference



Fuel debris remote transportation system

FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019
						Development of sampling technologies for retrieving fuel debris and internal structures (FY2017–FY2019)		

Fig.14-1-(5) Development of sampling technologies for retrieving fuel debris and internal structures

Project objectives

In the decommissioning of the Fukushima Daiichi NPS, two technologies have been developed as technologies to detect the distribution of fuel debris in reactors which use cosmic rays, muons: a transmission method and a scattering method. Measurement and evaluation for the transmission method have been completed at Unit 1 of the Fukushima Daiichi NPS, while as for the scattering method, performance tests of a large muon paths detector with a sensitive area of a 7m x 7m have been completed. The applicability of both methods to nuclear power reactor system under high dose level environment has been verified.

Project details and progress

(1) Implementation of small-scale verification tests (resolution of approx. 1 m)

In Unit 1, measurement was performed using a detecting system (transmission method) at three points in total over about 90 days from February to September 2015. Based on the fuel in the spent fuel pool, it was verified that the system had a resolution of 1 m, approximately (Fig. 1). According to the measurement results, there is probably not fuel around the core. By improvement of the muon detector, a small device has been developed that is one-fourth the size of the original with no loss in analysis performance (Fig.2).

(2) Design and manufacturing of detection system (resolution of approx. 30 cm)

Items for improvement to solve the displacement of the detector were identified, and noise reduction technology was added to the identification algorithm. Then, it was verified through simulations that the erroneous detection rate will not drop even if the measuring period is shortened to one-fourth of the original period (Fig. 3).

Transmission tests were performed for reactor components using a large muon paths detector with a sensitive area of 7m x 7m, and it was verified that it could produce images of lead (high-density materials) without being obstructed by concrete.

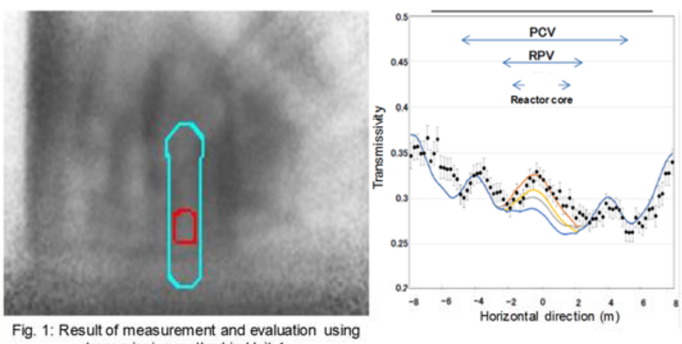


Fig. 1: Result of measurement and evaluation using transmission method in Unit 1

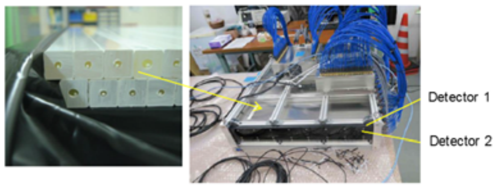


Fig. 2: Small device for transmission method

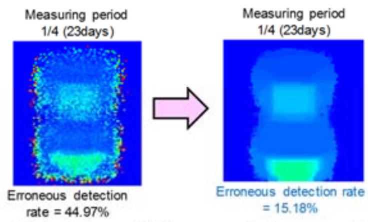


Fig. 3: Simulation result of improvement of erroneous detection rate

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FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018
			Development of technologies for the detection of fuel debris inside reactors (using muon)				

Fig.14-1-(6) Development of technologies for the detection of fuel debris inside reactors (using muon)

Project objectives
Based on the research and development results obtained so far, the necessary elemental technological development and testing will be carried out for the equipment, devices and systems related to the removal of fuel debris and reactor internal structures, as well as technologies for ensuring safety during removal. Mainly, with regard to various technologies required for establishing the access, such as the technology for removing interference existing in the R/B and PCV, and the technology for collecting and recovering fuel debris, technological development will be carried out taking into consideration remote operations under high doses, high contamination, and environmental conditions including uncertain factors, ensuring safety such as maintaining the containment function, and continuous operations during the fuel debris retrieval period. In addition, each elemental technology related to the system for ensuring safety when removing fuel debris and reactor internal structures will be developed.

1. Project details and progress
The following development will be carried out by reflecting and integrating the results of the related projects and the results of the "upgrading of the fundamental technologies for retrieval of fuel debris and internal structures" as bellow section 2:

(1) Development of fuel debris retrieval method

Based on the on-site information, etc., the technology will be developed to construct the access route necessary for the removal of fuel debris existing in the reactor pressure vessel (RPV) and PCV. In particular, with regard to the technology for removing interference that can reduce the fuel debris removal process, the feasibility of the technology for removal is supposed to be confirmed by considering situations of slippage, deformation, damage, etc., based on the results of the investigation of the facilities in the R/B and PCV, and conducting element tests as necessary.

In addition to the technologies for removal of interference, technological development will be carried out for the systems that support the operation of remote equipment, the methods for maintenance of equipment inside the PCV, the technologies for preventing contamination from spreading outside the PCV, and the technologies considered necessary for the construction of access routes that take into account the construction of shields to reduce exposure inside the R/B.

Equipment considered to become interference in each access method are as follows:

[1] Top access method to RPV: Reactor well shield plug, PCV head, RPV head, internal structures, etc.
[2] Side access method to PCV: Equipment, systems and piping inside and outside the pedestal in the R/B (especially around the penetration)

(2) Development of fuel debris handling technology

[1] Development of technologies for the system of collecting and recovering fuel debris dust inside the PCV

a. Development of dust collection system for the dust to be generated during fuel debris processing

For processing such as cutting fuel debris, mechanical methods including core boring, disc saw, chisels, etc., thermal methods such as lasers, etc., and high pressure jet blasting methods have been studied for the application and are being developed in consideration of the requirement of workability according to the characteristics of fuel debris and the impact of dust generated by the processing. In accordance with the characteristics of dust generated by these various processing methods and processing environments, dust collection systems for the area where dust is generated in the air or in liquids will be developed. In addition, a system will be developed to minimize the dispersion of dust inside the PCV as much as possible, which complements the dust collection in the vicinity of the area where dust is generated.

b. Development of methods and systems for recovering and containing according to the condition of fuel debris

In addition to the melt-damaged fuel inside the RPV, there are fuel debris deposits at various locations on the structure, such as the pedestal bottom in the PCV in various states (loose debris, sludge-like debris, fine (powder) debris, debris by processing such as crushing/cutting, etc.). In order to improve the efficiency of fuel debris retrieval, recovery methods and a method of putting debris into the containers and systems according to the state of fuel debris will be developed.

[2] Development of technologies related to purification and treatment of fuel debris and deposits inside the liquid phase

a. Development of technologies to remove soluble nuclides

Regarding the technology for removing dissolved nuclides that are considered to leach into circulating cooling water from fuel debris, elemental tests will be conducted on the alpha nuclides of adsorbents for removing dissolved nuclides to select the most suitable adsorbents, and the conceptual system of the facility for adsorption and removal will be designed.

b. Development of technologies for treating deposits recovered from inside the PCV

When recovering deposits containing fuel debris present at bottom of the inside of the PCV, a recovery liquid containing the deposit will be generated and, when a filter of the circulation cooling water system is backwashed during a fuel debris retrieval operation, a waste liquid containing solid matter or the like will be generated. In handling and storing these, it is necessary to separate the solid components from the liquid from the viewpoint of safety, volume reduction, etc. For the treatment technology to separate the solid matter from the liquid to put it away, a technology considering the efficiency of containing, remote operation, maintenance, etc., will be developed, and a conceptual system of the waste liquid treatment facility will be designed.

[3] Surveillance of technologies for separating fuel debris from waste

The technology, which will be necessary to divide the matter taken out of the inside of the PCV into fuel debris and radioactive waste material, will be studied. Additionally, a method for separation will be examined. Then, the feasibility for the related projects such as “development of technology for containing, transferring and storing fuel debris” as well as “R&D for Treatment and Disposal of Solid Waste” will be assessed.

(Notes)
As for technological development for equipment, devices and systems related to fuel debris retrieval, the following technologies will be developed in consideration of the ease of handling and maintenance methods for systems to be used for remote operation:

- Since the system is installed in high dose areas, maintenance will be conducted by remote operation in principle.
- It is necessary to consider contamination of equipment and required decontamination.
- Work area for maintenance is limited.
- It is necessary to minimize radioactive waste to be generated by maintenance work as much as possible.
- It is necessary to consider the installation and handling of a criticality monitoring system.

(3) Development of technologies related to ensuring safety during fuel debris retrieval work

[1] Development of technologies related to the containment function

a. Development of technologies related to the prediction of dust behavior for the containment function

The containment function is important from the viewpoint of ensuring the safety of the public and workers. Research and development will be carried out for the combination of the airflow analysis inside the PCV and the aerosol behavior analysis technology necessary for the prediction of the behavior of dust containing alpha nuclides to be generated during fuel debris processing inside the PCV. Additionally, the extension of the analytical model for the prediction of the behavior in the R/B will be developed.

b. Development of containment technology for the existing connecting portion in the new large-scale facilities

For large new facilities to be installed in the R/B, such as a working cell for removing fuel debris, the structure, construction method, inspection, maintenance of sealing materials, etc., of the connecting parts, etc., will be examined as technological development to ensure the containment function of the connecting parts with existing structures such as the PCV. Then, the validity of the technology will be confirmed by conducting necessary element tests.

[2] Element technological development related to criticality prevention and monitoring

a. Development of technologies related to criticality monitoring control method

To prevent the occurrence of criticality caused by fuel debris retrieval work, careful removal work is required while monitoring.

The accuracy of subcriticality measurement in a large and complex fuel distribution system simulating the condition of the Fukushima Daiichi NPS will be checked, and the feasibility of subcriticality measurement will be confirmed. Based on the results of the related project "Development of Fundamental Technologies for Retrieval of Fuel Debris and Internal Structures (Development of small neutron detectors)", the applicability of the neutron detector on-site will be checked. In addition, in cooperation with TEPCO's engineering, control procedures including the formulation of criticality proximity monitoring procedures and the setting of control parameters will be drafted, and consideration will be given to the formulation of demonstration plans for on-site application.

b. Development of Criticality Prevention Technology

The operation method for the non-soluble neutron absorber will be studied, including the selection method of the non-soluble neutron absorber according to the condition of the fuel debris at the time of removing the fuel debris and the conceptual design of the device to be introduced. In addition, the effect of debris processing on the non-soluble neutron absorber will be confirmed through element tests, reflected in the examination of operation methods, and the effect of the non-soluble neutron absorber on the structural material in the environment considering the use of rust preventive agents under the radiological impact will be examined.

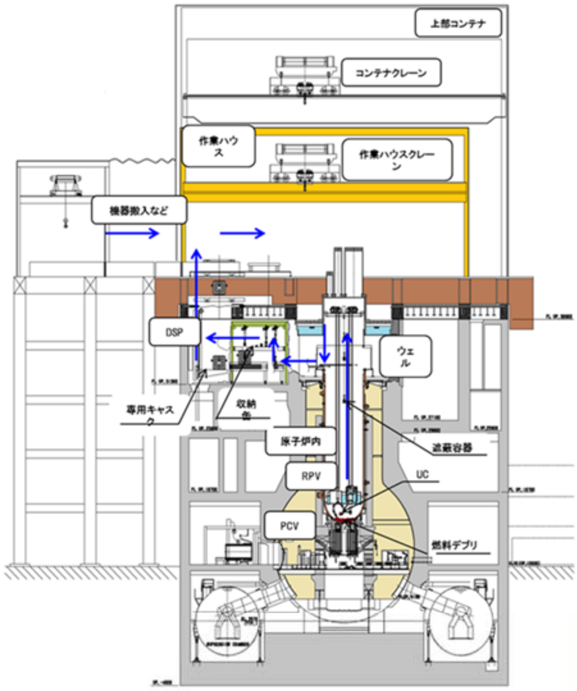

Fig. 1: Concept of partial submersion - top access method (example)

2. Related projects

The following describes the results of previous related projects.

○ Development of technologies for retrieval of fuel debris and internal structures (FY 2014)

(1) To determine the fuel debris retrieval method, plant data and information about the achievements of other development projects were collected and sorted out. Then, three major retrieval methods that are considered to be highly feasible (submersion-top access, partial submersion-top access, and partial submersion-side access) were selected, and issues were identified and summarized.

(2) As regards the identified issues, existing technologies were investigated, countermeasures were considered, and plans for necessary development were established.

(3) Elemental tests were performed for technologies that are considered to be required for the retrieval of fuel debris.

○ Upgrading of approach and system for retrieval of fuel debris and internal structures (FY 2015-2016)

(1) Study on the feasibility of the three major methods

Process flows and operation step charts for the three major methods were examined and developed. Required specifications have been determined and issues have been identified.

(2) Study on the concepts for systems to ensure safety

Safety and functional conditions required for the retrieval of debris were recapped, and configurations of systems to ensure safety were studied.

In addition, the exposure dose was evaluated roughly with the systems that have been studied.

(3) Study on the concept of fuel debris retrieval equipment

The concept of fuel debris retrieval equipment that will be applied to the three major methods (such as the one shown in Fig. 2) was studied.

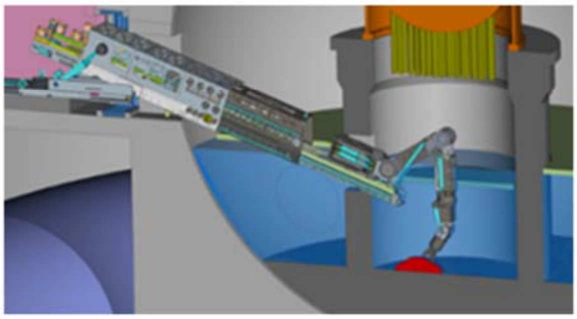

Fig. 2: Concept of fuel debris retrieval equipment in partial submersion - side access method (example)

○ Upgrading of retrieval method and system of fuel debris and internal structures (FY 2017-2018)

(1) Development of technologies related to containment function

- As an element technology (Fig. 3, on right) development for securing the containment function by negative pressure control, technology for securing the containment function by negative pressure control was developed through analysis, elements, and testing.

(2) Development of technologies related to the collection and removal of dust derived from fuel debris

- As for the collection and removal technologies for dust in the gaseous system (Fig. 3 on right) and the collection and removal technologies for soluble nuclides and dust in the liquid system (Fig. 3 on left), existing technologies were investigated and compared, and element tests were conducted for the predominance technology to improve the knowledge.

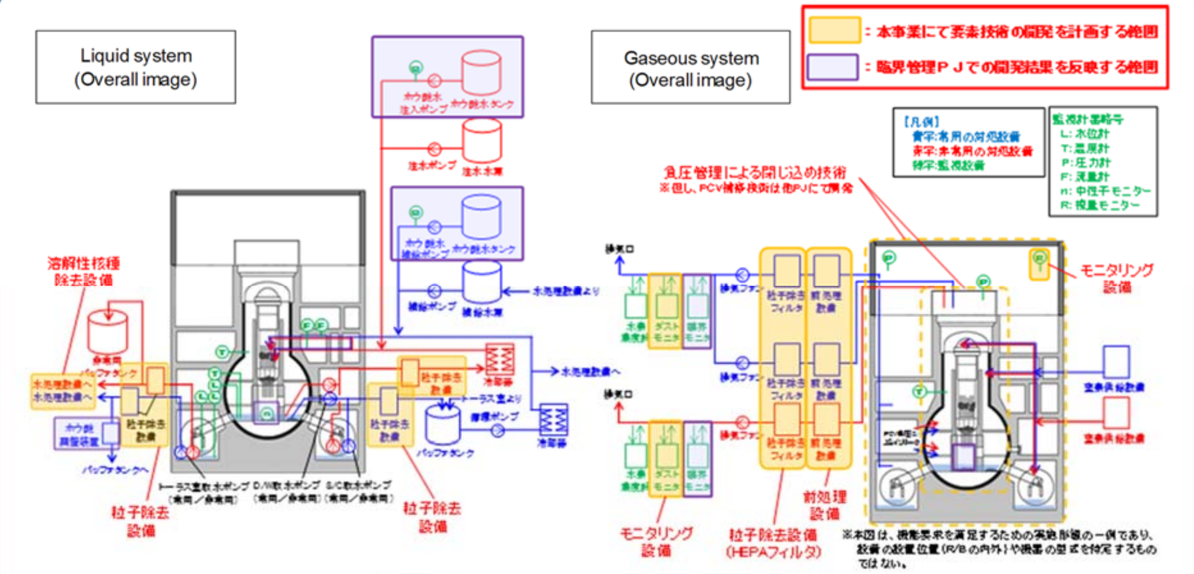

Fig. 3: Scope of element technology development for system formulation

(3) Study on α-nuclides monitoring system required for the retrieval of fuel debris

- An investigation was carried out on the existing monitoring technology of α nuclide during fuel debris retrieval, and problems in the case of practical application were organized.

(4) Study on optimization of ensuring the safety of methods and systems

- As regards construction methods whose applicability to each reactor have been studied with a focus on partial submersion-side access, design conditions were organized and methods to install cells were studied. (Fig. 4)
- The results of the public exposure evaluations at the time of fuel retrieval was reviewed, and worker exposure, which is important, was studied.

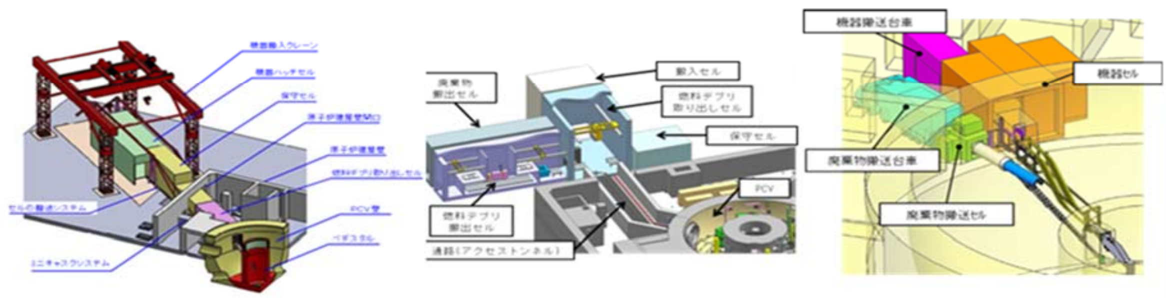

Fig. 4: Installation image of fuel debris retrieval cell

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FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019
	Development of technologies for retrieval of fuel debris and internal structures							
				Upgrading of approach and system for retrieval of fuel debris and internal structures				
						Development of technologies for retrieving fuel debris and internal structures		

Fig. 14-2-(1) Development of technologies for retrieving fuel debris and internal structures

Project objective

Toward the decommissioning of the Fukushima Daiichi NPS, in view of the results of studies that have been performed so far regarding the retrieval method of fuel debris and internal structures, elemental technologies required for retrieval (technologies to prevent fuel debris from scattering, elemental technologies for installing retrieval equipment, technologies to perform remote maintenance of retrieval equipment, and monitoring technologies during retrieval) will be developed, and the feasibility of devices and equipment will be assessed.

1. Project details and progress

The following describes the results this project produced so far based on results from the related projects described in Section 2 below.

(1) Development of technologies to prevent scattering of fuel debris

Fuel debris cutting/dust collecting systems (Figs. 1 and 7) and recovery/transfer systems were developed, and studies were carried out on the concept of the scattering prevention method, a technology to retain fuel debris in the operation area.

(2) Development of elemental technologies for the installation of fuel debris retrieval equipment

Elemental technologies for the installation of operation cells where retrieval equipment will be stored (sealing mechanism (Fig. 2) and remote welding) and technologies to remove materials on access routes that will interfere with the retrieval work (Figs. 3, 4, and 5) were developed.

(3) Development of technologies for remote maintenance of fuel debris retrieval equipment

Maintenance of retrieval equipment installed in a high-radiation area should be performed remotely in principle, so concepts about how to remotely maintain devices and equipment handling fuel debris have been laid out. In accordance with these concepts, studies on maintenance methods, feasibility assessment, and identification of issues was conducted.

(4) Development of monitoring technologies during the retrieval of fuel debris

To monitor the retrieval of fuel debris, an image tube camera (Fig. 6) and a small neutron detector (Fig. 8) that can be used under a high radiation environment were developed.

Fig. 1 Chisel processing test, Fig. 2: Inflatable seal element test

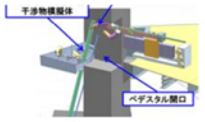


Fig. 3: Element test of removal of interfering objects in pedestal


Fig. 4: Element test of biological shield wall removal


Fig. 5: Combined element test image of Robotic arm and access rail


Fig. 7: Prototype of laser head (ONET Technologies CN)


Fig. 6: Prototype of imaging tube and camera system

Fig. 8: Prototype of neutron detector (RosRAO, FSUE)

Implemented by

(Comprehensive proposal) International Research Institute for Nuclear Decommissioning (IRID)
(Partial proposal) Development of fuel debris cutting/dust collecting system: ONET Technologies CN, Taisei Corporation (FY 2015 - 2016)
Development of monitoring technology during the retrieval of fuel debris: Hamamatsu Photonics K.K.
Development of small neutron detector: International Research Institute for Nuclear Decommissioning (IRID), RosRAO, FSUE, ONET Technologies CN (COMEX NUCLEAR)

2. Related projects

The following describes the results of previous related projects.

○ Development of fundamental technologies for retrieval of fuel debris and internal structures (FY 2015 - 2016)

Focusing on the three access methods (the submersion method, the partial submersion-top access method, and the partial submersion-side access method), plans for elemental tests to identify their feasibility have been established and the following elemental tests were implemented.

(1) Technology to prevent expansion of contamination during the retrieval of large structures
- Scale model tests by operation step

(2) Technology to prevent expansion of contamination during the retrieval of fuel debris from RPVs
- Testing of access equipment to RPVs using the partial submersion-top access method (Fig. 9)

(3) Access technology to fuel debris
- Testing of water hydraulic manipulator
- Testing of access equipment to the inside of RPVs using the submersion method (Fig. 10)
- Testing of access equipment to the inside of pedestal using partial submersion-side access method (Fig. 11)

(4) Remotely operated technologies required for the retrieval of fuel debris
- Testing of flexibly structured arm (Fig. 12)
- Testing of container handling equipment

(5) Technology to prevent expansion of contamination during the retrieval of fuel debris
- Testing of platform/cell for the submersion method
- Welding test for the remote sealing of cells for the partial submersion-side access method

(6) Technology to reduce the exposure dose of workers during fuel debris retrieval work
- Testing of shape-following lightweight shields to be used in the top-access method

(7) Cutting/dust collecting technology required for the retrieval of fuel debris
- Testing of fuel debris cutting/dust collecting performances (Figs. 13, 14, and 15)

(8) Monitoring and measurement technologies during the retrieval of fuel debris
- development high radiation tolerant image camera tube (Fig. 16)

Fig. 9: Seal inside RPV and equipment, lower seal test


Fig. 10: Test of access equipment to RPV

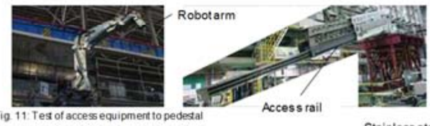


Fig. 11: Test of access equipment to pedestal


Fig. 12: Example of flexibly structured arm for remote operation

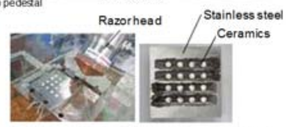


Fig. 13: Performance test of cutting fuel debris


Fig. 14: Boring robot (Taisei Corporation)


Fig. 15: Underwater cutting head (COMEX NUCLEAR)


Fig. 16: Prototype of imaging tube (Hamamatsu Photonics K.K.)

FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018
				Development of fundamental technologies for retrieval of fuel debris and internal structures (FY2015–FY2016)			
						Advancement of fundamental technologies for retrieval of fuel debris and internal structures (FY2017–FY2018)	

Fig. 14-2-(2) Advancement of fundamental technologies for retrieval of fuel debris and internal structures

Project objectives

In order to ensure the safety of fuel debris retrieval work, develop technologies to access and connect to PCV while securing the PCV confinement function which is issue in constructing the necessary closed circulation system for water inside PCV.

Project details and progress

(1) Formulating technical specifications of repair and drafting work and development plan for access and connection to the inside of the PCV

[1] To ensure safety in fuel debris retrieval work, intaking water from the dry well (hereinafter referred to as "D/W"), a suppression chamber (hereinafter referred to as "S/C"), and the torus room were investigated for a water circulation system being studied or developed under the project of "Advancement of Retrieval Method and System of Fuel Debris and Internal Structures".
To intake water from the D/W and the S/C, it is necessary to establish a new access route to the inside of the PCV and water intaking system, while securing the confinement function. In order to realize this, it is necessary to establish a construction technology and a work plan taking into account severe on-site environmental conditions, such as high doses and narrow paths, reliability, inspectability, earthquake resistance, long-term soundness, remote maintainability, and other factors. The required technical specifications and a system establishment work procedure were investigated and development challenges were identified and a development plan was drafted. Required technology development challenges for the following items were identified and the development plan was drafted.

i. Formulating technical specifications considering the on-site environment (example of study on the arrangement of S/C water intake structure: Fig. 2)
ii. Investigating plans for access route construction work and its maintenance (example of study on the construction of access routes from D/W: Fig. 1)
iii. Identifying development challenges and drafting a development plan

[2] Regarding PCV repair technology affecting the construction of closed circulation systems, technical development challenges corresponding to the situation at the on-site work and technical issues corresponding to situations in the field were extracted, and a development plan was drafted.

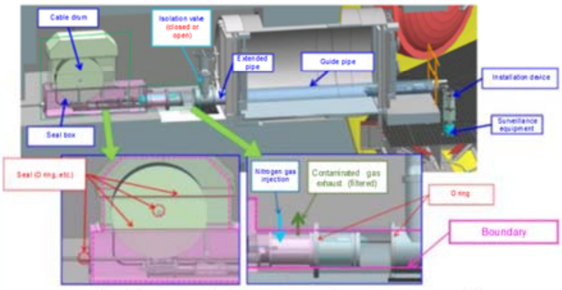


Fig. 1: Examination example on access route establishment from D/W

[Examination results]

A) In Units 1 to 3, more than 8 S/C water intakes can be installed at θ of 66° or more as shown in the drawing.
=> Proceed with development of welding equipment by setting the pertinent angle (θ) to 66° or more.

B) Obstacles in the torus room need to be removed remotely.
=> For the typical obstacles in the torus room (pipes, cable trays, air conditioning duct, and handrail), conceptual examination on removal procedures by repairing the lower PCV (FRM) should be performed.

C) Examination on removing obstacles in the first floor of the R/B should be included in the scope of planned engineering, not in this project, as needed.

D) Though it is necessary to verify the impact of interference in the internal S/C structures (vent tubes, vent header, downcomer) and water intake system, the impact is expected to be small due to flexible hoses.

E) Decontamination is recommended or required.

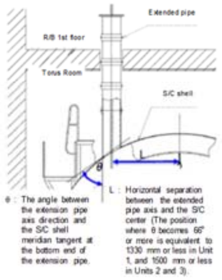


Fig. 2: Example examination on S/C water intake structural layout

(2) Developing and verifying element technologies for access and connection to the PCV

Based on the development plan formulated under (1) above, we are developing and verifying each elemental technology required to access and connect to the PCV. Below are examples of possible elemental technologies.

*Remote construction technology for connections
*Remote access route inspection during service and construction
*Remote repair technology for connections during service and construction

(3) Verifying PCV access and connection technology on a full-scale

Based on the development results of each elemental technology, pilot designing for access/connection to the inside of the D/W and S/C is underway. In light of the results, the following verification of workability in a full-scale, clarification of work requirements and issue identification for actual construction work will be performed by using a full-scale test body for Naraha:

*Confirming the workability by remote control on a full-scale and identifying challenges
*Securing confinement function for actual construction work and the measures to reduce workers' exposure and identifying challenges
*Investigation of the test body after connection work

Implemented by

International Research Institute for Nuclear Decommissioning (IRID)

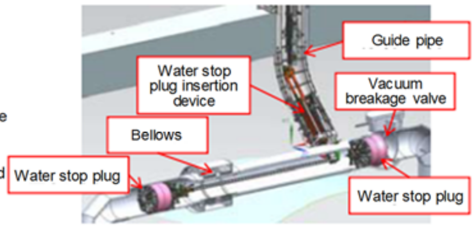
FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019
							Development of technologies to establish closed water circulation systems inside the PCV	

Fig. 14-2-(3) Development of closed circulation systems for water inside PCV

Project objectives
Repair methods for the bottom parts of PCVs have been developed aiming for the establishment of the containment capability of PCVs in order to maintain the prevention of the scattering of radioactive materials, the radiation shielding, the cooling function, and the containment of the contaminated water bearing alpha-emitting nuclides during fuel debris retrieval. In addition, the process of filling the PCV with water has been studied, as well as the concept of environmental improvement methods to enable the practical repair works.

1. Project details and progress
The following describes the results of this project produced so far based on results from the related projects described in Section 2 below.
(1) Study and planning of the process up to the completion of PCV water filling
For each PCV water level that is considered achievable, the target sealing capability to be achieved by leak repair techniques was defined.
(2) Development of repair methods for the bottom parts of PCVs
[1] Reinforcement method for suppression chamber (S/C) supports
Component testing was performed under conditions resembling actual plant conditions to verify the effectiveness of reinforcement based on the evaluation of the strength and fluidity.
[2] Sealing method of pouring grout material into S/C
The feasibility of implementation was evaluated by the series of the tests, namely the grout test with the PCV model with reinforcement rings, the long-distance pumped delivery tests, the component testing under conditions resembling the actual plant conditions, as well as the functional tests of S/C guide pipe implementation.
[3] Sealing method of pouring grout material into the vent pipes
By performing an experiment using a full-scale (1/1) test set using self-compacting concrete as sealant, the implementation feasibility and sealing performance were verified. A heavy slurry based repair material was developed as well.
[4] Sealing method by the plugging of the vacuum breaking line
By performing an experiment on a full-scale (1/1) test set, the implementation feasibility and sealing performance of a seal plug that had been improved for easier implementation were verified.
[5] Repair method for the establishment of boundary for the pipes connected to the PCVs
Sealant was developed, as well as the core technologies for remote implementation equipment, and the feasibility of implementing the proposed methods were verified.
(3) Development of repair methods for the upper parts of PCVs
After studying how it might be possible to improve the leak repair device for application to the equipment hatch sealing, it was concluded that it would probably be possible to increase the ease of implementation.
(4) Sealing method for piping penetrations through the torus chamber walls, etc.
A type of sealant that would allow application by spraying was identified, and test were performed to verify its sealing performance.
(5) Studying the concept of environmental improvement to be achieved to enable the practical application of repair methods
The dose that workers will be exposed to while engaged in PCV bottom repair (sealing) works was assessed, the implementation techniques that may be employed to reduce the exposure dose were reviewed, and challenges were identified.

Vent pipe 1/1 scale test



Drawing of water stop plug for vacuum breakage line

Implemented by
International Research Institute for Nuclear Decommissioning (IRID) (FY 2013 -)

2. Related projects
The following describes the results of previous related projects.
○ Development of identification technology of leaks in PCVs (FY 2011 - 2013)
Devices to be used for locating leaks in the PCVs and torus chamber walls were developed by performing examinations in a high dose, congested, water-filled environment, and their performances were tested using mockups, etc. Some of the devices were put into practical application (to examine the torus chamber rooms in Units 1 and 2, for example), which contributed to the discovery of a leak from the vacuum breaking line bellows in Unit 1.
○ Development of repair method for PCVs (FY 2011 - 2013)
Detailed examination of repair techniques was performed as a step toward the design and fabrication of repair devices that may be used for the establishment of boundary in the vent pipes, S/Cs, etc.
Basic testing was performed for sealing techniques that would contribute to the design and fabrication of devices that may be used in the repair of components at the upper part of PCV, such as hatch flanges and penetration bellows that are likely to have been damaged,
○ Development of repair (water stoppage) technology toward water filling in PCV (FY 2014 - 2015)
(1) Development of PCV repair/sealing methods
- Reinforcement method for S/C supports: The grout material for the reinforcement was improved, and the possibility of practical application was determined through various tests.
- Sealing by grouting inside S/C: The composition of the sealant was determined, and its sealing performance was studied through various tests.
- Sealing by grouting the vent pipes: Deployment testing was performed for the plugging assisting material and the screening of secondary plugging assisting material, and challenges to practical application were identified.
- Sealing by the plugging of the vacuum breaking line: Plug insertion using a flexible guide pipe was tested, and the feasibility of a series of technical procedures was verified.
- Methods for the establishment of boundary for the pips connected to PCVs: The performance required from the sealant was defined, a sealing test was performed, and issues were identified.
- Dry well repair technique: The sealing technique and the test to be performed to verify the applicability of sealant were studied, and the schematic design of the sealing device was completed.
(2) Determining the plan up to the completion of PCV water filling
The work steps up to the completion of PCV water filling at Units 1 and 2 were defined.

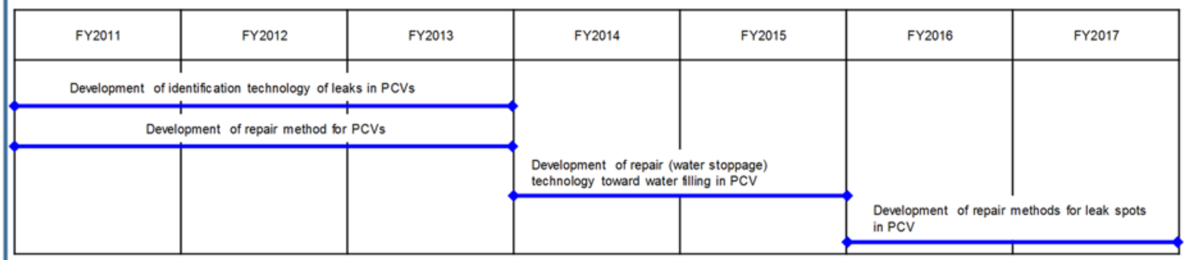


Fig.14-2-(4)-1 Development of repair methods for leak spots in PCV

Project objectives

The repair methods of the bottom part of PCV from the R&D project entitled " Development of repair methods for leak spots in PCV " were tested using a full-scale test set to verify the acceptability of procedures from the viewpoints of actual implementation, the feasibility of implementation by remote control, and the sealing performance. In addition, the effectiveness of simulation using a virtual reality (VR) system for simulator-based operator training for the remote control manipulator was verified.

1. Project details and progress

The following describes the results of this project produced so far based on results from the related projects described in Section 2 below.

(1) Full-scale test of the repair methods of the bottom part of PCV, etc.

The following were tested using the full-scale test set:

[1] Reinforcement method for the suppression chamber (S/C) supports

Experiments were conducted with implementing reinforcement by the injection of highly fluid grout material to the S/C bottom, and the applicability of an implementation procedure developed in consideration of actual plant conditions was verified, as was the feasibility of implementation monitoring, such as the checking of injection height.

[2] Sealing method by grouting the vent pipes

A test was conducted to check the feasibility of an implementation procedure that would involve remote controlled maneuvers to remove obstacles and drill a hole through the vent pipe model, and the feasibility of accessing targets under conditions resembling the actual plant conditions was verified.

[3] Sealing by grouting inside S/C (downcomer plugging)

Experiments were conducted with stopping the leak by grouting highly fluid sealant into S/C, and the applicability of an implementation procedure developed in consideration of actual plant conditions was verified, as was the feasibility of implementation monitoring, such as the checking of injection height.

[4] Preparation for testing, etc.

Maintenance services were administered for water feeding and draining facilities, and regular inspections were performed for this purpose.

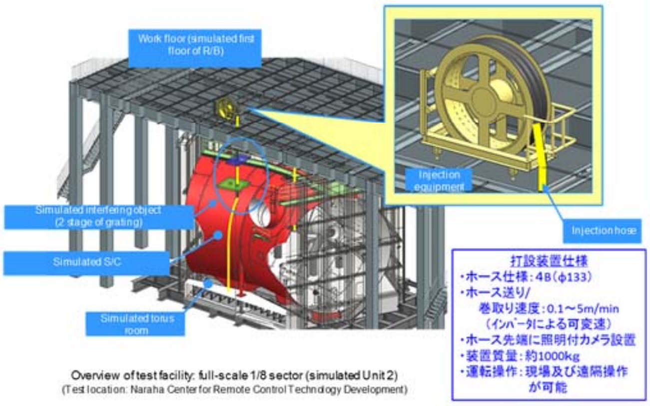


Fig. 1: Overview of the reinforcement test for S/C supports

(2) Preparation of VR data for preliminary simulation experiments

As efforts were being made to prepare an environment that would allow the performing of operator training on a VR system simulating the motions of the manipulator used for plugging the vent pipes, the effectiveness of VR system in operator training was evaluated by capturing manipulator motions using motion capture technology, etc., and comparing the motions simulated by VR system loaded with the motion data and the actual motions made by the manipulator.

Implemented by

International Research Institute for Nuclear Decommissioning (IRID)

2. Related projects

The following describes the results of previous related projects.

○ Full-scale test of repair methods for leak spots in PCV (FY 2014 - 2015)

(1) Testing of PCV bottom repair techniques using a full-scale test set, etc.

The designing and fabrication of a full-scale model reproducing a 1/8 sector portion of PCV bottom at Unit 2 was completed, as was the installation of water feeding and draining facilities required for testing, including the turbid water treatment system.

(2) Preparation of VR data for preliminary simulation experiments

Data on the motions of the remote operated device (manipulator) for loading into the VR system was prepared, and it was verified that the data can be used for simulating motions on the VR system. In addition, research was completed on the knowledge of various institutions inside and outside Japan regarding the functions of remotely operated devices and the systems used to verify operators' skills.

○ Full-scale test of repair methods for leak spots in PCV (FY 2016)

(1) Full-scale test of the repair methods of the bottom part of PCV etc.

[1] Reinforcement method for the suppression chamber (S/C) supports

An implementation procedure verification test was performed, and it was verified that works in a high dose environment, operation by remote control, and the application of devices prepared in the course of PCV repair method development may be accomplished without problems.

[2] Sealing method by grouting the vent pipes

The implementation procedure verification test was initiated.

[3] Preparation for testing, etc.

Pre-testing preparations were completed by transporting the test set, installing buffer materials for S/C supports reinforcement, and ensuring readiness for filling the test set with water.

(2) Preparation of VR data for preliminary simulation experiments

Based on information collected through hearing sessions with remote control system designers and experienced operators, the issues that must be solved in order to achieve necessary improvement in accuracy were identified, and work was conducted toward the realistic simulation of manipulator motions on the operation console and the improvement of remote control system functions.

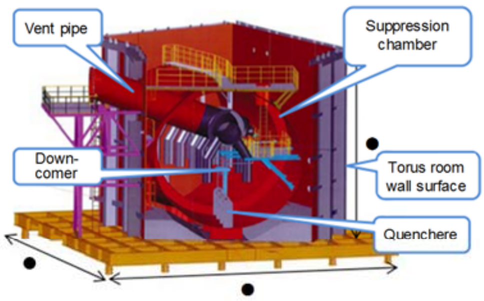


Fig. 2: Full-scale test facility

FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017
			Full-scale test of repair methods for leak spots in PCV			
					Full-scale test of repair methods for leak spots in PCV	

Fig. 14-2-(4)-2 Full-scale test of repair methods for leak spots in PCV

Project objectives

The seismic resistances of RPV, PCV, and other major plant components shall be evaluated through assessment in consideration of effects of the falling of highly heated fuel debris at the time of the accident, the aging degradation accompanying the corrosion of steel, and the water leak repairs performed, and the facilities added prior to fuel debris retrieval. In addition, the effects in the event of damage shall be predicted, and the measures that may be taken to prevent or mitigate the consequences shall be determined. Furthermore, the effectiveness shall also be verified for the safety scenarios developed on the basis of the proposed prevention/mitigation measures.

1. Project details and progress

The following describes the results this project produced so far based on results from the related projects described in Section 2 below.

(1) Producing the scenarios of safety in the event of a severe earthquake

The facility improvement measures to be implemented were determined, as were the emergency action plans to be made ready before the beginning of fuel debris retrieval to address the consequences of damage to large components that may be induced by a severe earthquake, and safety scenarios were developed (each indicating the flow of a series of actions to be taken to maintain safety functions or to restrict effects from the accident).

(2) Development of approaches to evaluating seismic resistance and determining impacts from damage in the process of producing safety scenarios

[1] Development of an approach to evaluating the seismic resistance of suppression chamber (S/C) supports and determining impacts from damage

- By performing the elastic time-history response analyse of vent pipes and S/C system coupled model (Fig. 1), the seismic resistance of the structure after the injection of sealant into S/C was assessed.
- In addition, elastoplastic analyses (by the double gradient method) were also performed for critical components, such as the column supports, to determine the maximum allowable quantity of sealant that may be injected into S/C.

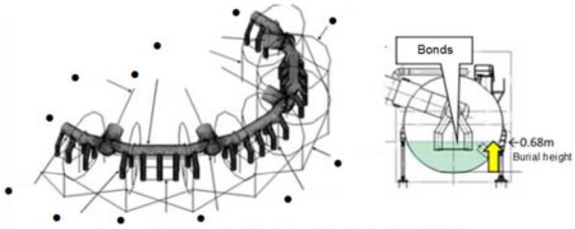


Fig. 1: Vent pipe-S/C system coupled analysis model (Unit 1)

[2] Development of an approach to evaluating the seismic resistance of pedestals and determining impacts from damage

An assessment approach was developed and material data was collected as described below to enable prediction of the distribution of temperature in the pedestal when it was exposed to high temperature and the impact of erosion by fuel debris:

- Performing elastoplastic analyses by three-dimensional finite element method (FEM) (Fig. 2) and evaluating strength and rigidity using a fiber model
- Coupled response analysis method for evaluating how changes in pedestal strength or rigidity may impact the seismic resistance of large components such as PCV and RPV
- Degree of heat-induced corrosion and strength reduction of reinforcement bars that have a history of being exposed to high temperatures

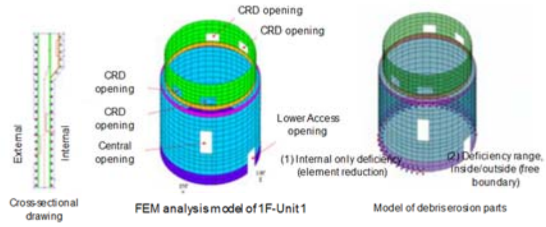


Fig. 2: 3-D FEM elastic-plastic analysis model of RPV pedestal

(3) Supporting the advancement of safety scenarios

In order to support the advancement of assessment approaches mentioned above, the approaches to verification by analyses, tests, etc., were reviewed, and detailed analyses and material tests were performed in connection with the following:

- Assessment of S/C supports at Unit 1 by performing elastoplastic time-history response analyses
- Collection of data from PCV material tests performed to determine the effects of the history of being exposed to high temperature at the time of the accident

Implemented by

International Research Institute for Nuclear Decommissioning (IRID) (FY 2013 -)

2. Related projects

The following describes the results of previous related projects.

○ Development of evaluation methods for the structural integrity of RPV and PCV (FY 2011 - 2013)

(1) Evaluating the seismic resistance of major plant component such as RPV, PCV, and pedestal

Evaluation was conducted on the seismic margins of major plant components at present and at the time of fuel debris retrieval (considering the impacts of thinning by corrosion, the additional load from the weight of fuel debris retrieval devices, etc.). It was concluded that major parts of the components may retain seismic resistances of a satisfactory level, but some components required more detailed analysis of seismic resistance.

(2) Evaluation of the effects that hot debris may have had as they fell inside the pedestal

A literature search, etc., on the molten core-concrete interactions (MCCI) was used to prepare basic data that would contribute to the prediction of erosion suffered by the pedestal.

○ Development of evaluation methods for the structural integrity of RPV and PCV (FY 2014 - 2015)

(1) Evaluating the feasibility of fuel debris retrieval by the subversion method considering the aseismic integrity of PCV/RPV

Based on the results of evaluating the seismic resistance of PCV, RPV and other major plant components under plant conditions at the time of fuel debris retrieval, the feasibilities of fuel debris retrievals by the partial submersion method or the full submersion top access method were studied, and detailed evaluation was performed for the seismic resistance of components and parts that demonstrated small seismic margin in the earlier evaluation.

(2) Simplified evaluation of seismic resistance of components in consideration of PCV repairs and water level increase

The parameters (such as the D/W water level) that would impact seismic response analysis were identified or selected, and then seismic response analysis was performed using different assumptions on the parameter values. Based on the results obtained, it was determined how changes in parameter values would impact seismic response, and a simple method of seismic resistance evaluation was developed. Then, the validity of the simple evaluation method was demonstrated by comparing results from the simple evaluation method with results from the method that is normally used, the dynamic analysis method.

(3) Estimating the impacts of erosion suffered by the pedestal

The knowledge required for estimating or discussing pedestal strength in real units was obtained by collecting concrete strength data from the testing of cylindrical specimens, block specimens, and scaled pedestal specimens, etc., that were heated to high temperature and then left in air or in water as well as reinforcement bar corrosion data.

FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017
Development of evaluation methods for the structural integrity of RPV and PCV (FY2011–FY2013)						
			Development of evaluation methods for the structural integrity of RPV and PCV (FY2014–FY2015)			
					Development of evaluation methods of seismic performances of RPV and PCV and the impacts of the damages (FY2016–FY2017)	

Fig.14-2-(5) Development of evaluation methods of seismic performances of RPV and PCV and the impacts of the damages

Project objectives

To verify the corrosion protection measure and to evaluate its feasibility for practical application so as to maintain the current structural integrity of RPV and PCV through the period of fuel debris retrieval by protecting the progress of corrosion in the structural materials.

1. Project details and progress

The following results were produced from ongoing projects described in described in Section 2 below.

(1) Evaluation of performance of inhibitor for corrosion prevention and its side effects (Figs. 1 and 2)

[1] Evaluation of the local corrosion prevention performance by electrochemical measurement

To evaluate the effectiveness in preventing the local corrosion of carbon steels by the selected inhibitors through a screening process in the previous year, a test procedure was established for electrochemical measurements (repassivation potential for crevice corrosion, open circuit potential, crevice corrosion test at constant electrode potential), and measuring of them was performed under gamma ray irradiation.

[2] Evaluation of the impacts of phosphate-based inhibitor firmly stuck onto high temperature surface areas

Batch type test and test with loop were conducted to evaluate the impacts of a phosphate-based inhibitor firmly stuck onto high temperature surface areas. Another experiment was also conducted to find out the impact on the effectiveness on the corrosion protection of carbon steel when phosphate-based inhibitor is used combined with sterilizing agent.

[3] Evaluating impacts on water treatment systems

The impacts of corrosion inhibitor on water treatment systems were experimentally evaluated. Under various combination of seawater dilution ratio and corrosion inhibitor concentration, experiments were conducted to examine the impacts of corrosion inhibitor on water treatment systems.

(2) Conceptual design of the corrosion prevention system (Fig. 3.)

The conceptual design of the corrosion prevention system was developed to inject the corrosion inhibitor into the actual water circulation system.

Above actions were implemented by International Research Institute for Nuclear Decommissioning (IRID)

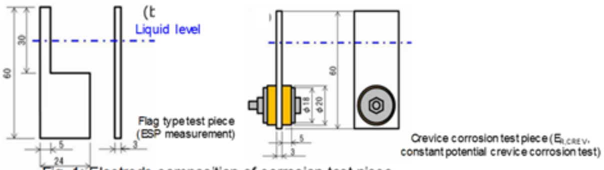


Fig. 1: Electrode composition of corrosion test piece

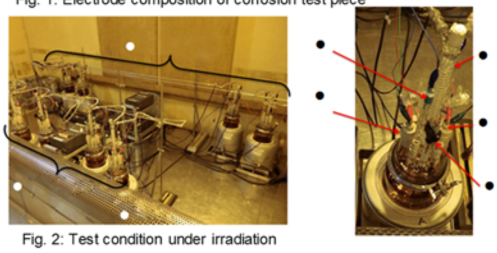


Fig. 2: Test condition under irradiation

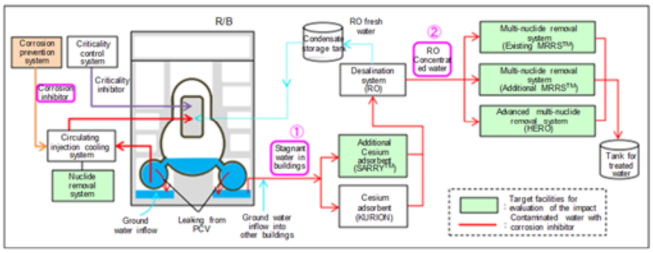


Fig. 3: Example of conceptual design of corrosion control system

2. Related projects

The followings are the results of related previous projects.

Note: Activities from FY2011 to FY2015 were pursued as part of the project entitled "Development of RPV/PCV integrity assessment techniques".

○ Development of RPV/PCV integrity assessment techniques (FY 2011 - 2013)

(1) establishment of the model for predicting long term corrosion rate

To develop corrosion rate prediction model, corrosion tests were performed for up to 2,000 hours under various the chloride ion concentration and water temperature.

(2) Development of an corrosion protection measure

Corrosion test was performed using sodium nitrite or sodium tungstate as a corrosion inhibitor, and it was confirmed that corrosion may be protected by injecting such corrosion inhibitors of equal or greater molar concentration to that of chloride ions.

○ Development of RPV/PCV integrity assessment techniques (FY 2014 - 2015)

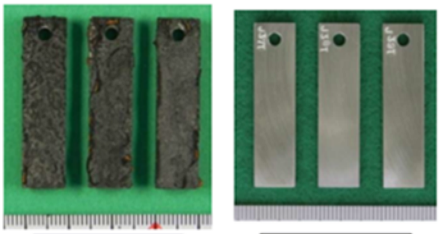
(1) improvement of the model for predicting long term corrosion rate

By performing additional corrosion testing with loop for the extended period (10,000 hours), the model for predicting long term corrosion rate was improved. In addition, study was conducted on influence of substances eluted from fuel debris or concrete on corrosion protection effect of inhibitor.

(2) Establishment of the corrosion protection measure

Selected candidates of corrosion inhibitor in this project (sodium tungstate, sodium pentaborate, etc.) was experimentally confirmed their corrosion protection effect for the carbon steel under anticipated condition including presence of radiation. Based on the test results, applicable inhibitors to the actual units was narrowed down. In addition, experiments were performed to identify the impact of each corrosion inhibitor on water treatment systems, and related technical issues were recognized.

PCV material (carbon steel)
50°C, Artificial seawater diluted 1,000 x (19ppmCl-)
Test time: 500h



General corrosion | No corrosion

No rust-preventive agents | Zinc/sodium molybdic acid mixing phosphate (2,000ppm)

Fig. 1: Development status of anti-corrosion measures

FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017
Development of RPV/PCV integrity assessment techniques (FY2011–FY2013)						
			Development of RPV/PCV integrity assessment techniques (FY2014–FY2015)			
					Development of corrosion protection technology for RPV and PCV (FY2016)	

Fig. 14-2-(6) Development of corrosion inhibition technology for RPV and PCV

Project objectives

To protect on-site workers from radiation exposure and prevent impacts on the surrounding environment, even if re-criticality would occur when fuel debris configurations and water levels may change during fuel debris retrieval work, it is necessary that an impact evaluation method for use with criticality, criticality monitoring technology, including technology for criticality approach detection and re-criticality detection, and criticality prevention technology.

Project details and progress

(1) Studying criticality control method

- Based on the estimated information of each unit on the fuel debris distributions, the points to note in each of the steps up to completing the retrieval of fuel debris were clarified from the perspective of criticality control. These were updated appropriately from the information of evaluations and investigations inside the reactor, for example.
- A behavior evaluation method during criticality was developed, and an evaluation method that will be utilized in studying the procedures to use to mitigate any impact in the case criticality occurs and safety measures to use at facilities in the future.
- Basic policies about criticality control in different methods that may be used for fuel debris retrieval were summarized, and the requirements for the fuel debris retrieval systems were compiled.

(2) Development of criticality control techniques

[1] Development of Criticality Approach Monitoring Method

- Using the reactor noise method that is based on neutron measurements, development of subcriticality measurement technology has been promoted.
  By the measurement operational verification test in a high radiation environment were performed, and by using a reactor core, which simulates the various fuel debris conditions, was configured at KUCA laboratory, and the degree of subcriticality were evaluated. The feasibility of the criticality approach monitoring technology was thus confirmed (Fig. 1).

[2] Development of Re-criticality Detection Technology

- The gas control system used to monitor slight amounts of FP gas concentrations present in the PCV was improved for use in detecting any recriticality in the early stages, and it was verified through a Kr-88 detection performance test at Unit 1 that the system is capable of selectively detecting Kr-88 without interference from the presence of other radioactive nuclides.

[3] Development of Criticality Prevention Technology

- Nuclear characteristic verification tests at the KUCA, dissolution tests with long-term exposure, and performance workability tests took place using candidate materials selected by their fundamental physical properties and radiation resistance performance tests, and a prospect absorbent material candidate obtained (Fig. 2).
- As for the soluble neutron absorbent material (sodium pentaborate), a nuclear characteristic verification test was performed at the KUCA, and the basic specifications of the boron concentration maintenance facility were examined. Herewith, the prospect of boron concentration evaluations and the technical feasibility of the necessary facilities, including the concentration maintenance facility, were obtained.

* Using results from past development activities, in the future, the results will be utilized in studying the optimal practical implementation of a fuel debris retrieval device and relevant systems, and thus ensuring greater safety.

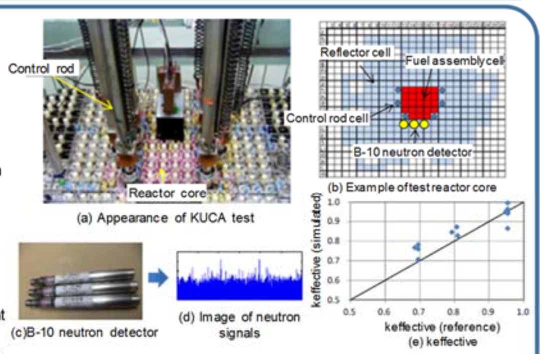


Fig. 1: Criticality approach test at Kyoto University Criticality Assembly (KUCA) laboratory device

Shape	Candidate material
Solid	B_4C sintered metal material
	B/Gd containing glass
	Gd_2O_3 particles
Liquid ➡ Solid (Solidified material)	Granulated cement/Gd_2O_3 powder
	Granulated liquid glass/Gd_2O_3 powder
	Underwater hardening resin/Gd_2O_3 powder

Fig. 2 Candidate materials for insoluble Neutron Absorption and Workability Verification Test of Water Glass Type Absorption Material

Implemented by

Hitachi-GE Nuclear Energy, Ltd., Toshiba Corporation, Mitsubishi Heavy Industries, Ltd., Japan Atomic Energy Agency (FY 2012)
International Research Institute for Nuclear Decommissioning (IRID) (FY 2013 -)

FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018
	Development of criticality control technologies of fuel debris (FY2012–FY2017)						

Fig.14-2-(7) Development of criticality control technologies of fuel debris

Project objectives

For the planning of fuel debris retrieval as a step in the decommissioning of the Fukushima Daiichi NPS, in order to the repair and stop water leakage in the suppression chamber (S/C) located in the PCV lower, it is necessary to obtain information about the presence of radioactive materials (removal of radioactive materials required to repair works). Therefore, the condition of radioactive materials that may precipitate inside the S/C, was predicted and a measurement method was developed.

Project details and progress

(1) Formulation of development plan

Developments and work items required for the detection of radioactive materials believed to be indispensable were present extracted and a development plan was formulated.

(2) Radioactive material migration scenarios

Consideration was given to scenarios involving the migration of radioactive materials into the S/C and torus room. It is thought that the likelihood of an inflow of radioactive materials that exceeded the acceptable limit was low. It can be confirmed that there are no radioactive materials that exceed the acceptable limit by measurements of the lower part of the S/C bottom and the region around the sand cushion drain pipe outlet where there is a relatively high probability of radioactive materials having been precipitated.

(3) Evaluating of the impacts of radioactive substances on water stoppage material

Among the influence factors arising from remaining radioactive materials, there is a concern that even the minimum sediment may heat cement to a temperatures of 80°C. Cement deterioration may be caused by heat generated in water stoppage materials. Based on conservative estimates, the presence of uranium of 13 kg or more was calculated. Therefore, it was concluded that the presence of uranium of 10 kg or more should be detectable by nondestructive measurement.

(4) Development of a technology for detecting of radioactive materials

Nuclides originating from fuel (Eu-154, Cm-244, etc.), background nuclides, and nuclides in shielding material were determined using the ORIGEN code. The mixture ratio of nuclides originating from fuel and structural materials has been set based on the results of a severe accident analysis code (MAAP code). Neutron and gamma rays flux in the area around the S/C bottom were evaluated using a 3-dimensional 1/16 scale model of the S/C and torus room. An assessment of the effect of background gamma radiation (Cs-134 and Cs-137) from stagnant water was conducted. To measure acceptable background radiation level and radio-sensitivity, a B-10 neutron detector and a CdTe gamma rays detectors were selected as the best choice for the task and their responses evaluated at the locations in the S/C and torus room.

Feasibility of non-destructive detection for the S/C bottom with or without radioactive materials was verified technically. Design and production for measurement systems and devices to access are will be decided based on the results of developments of methods to repair and stop water leakage.

Implemented by

International Research Institute for Nuclear Decommissioning (IRID)

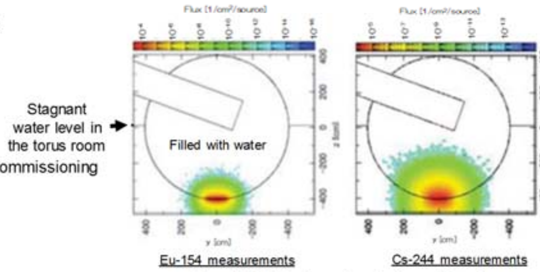


Fig. 1: Distribution of radiation originating from fuel around the S/C (Unit 1)

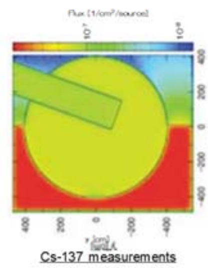


Fig. 2: Background radiation (Unit 1)

FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018
		Development of technologies for non-destructive detection of radioactive material deposited in S/C, etc.					

Fig. 14-2-(8) Development of technologies for non-destructive detection of radioactive material deposited in S/C, etc.

Project objectives
To enable decontamination of the interior of reach reactor building contaminated by the scattering of radioactive materials without causing excessive radiation exposure to workers, studies were performed on different decontamination methods for different decontamination targets (such as concrete, metal, and resin) and for different types of contamination (such as loose contamination, tightly adhering contamination, and penetrating contamination) was examined. Then, apart from the remotely controlled decontamination machine for low locations surfaces that had already demonstrated its performance in the field, development was performed for remote controlled decontamination machines that can be applied to surfaces in high locations or on the second or upper floor levels as machines that are vitally needed to prepare a proper working environment for decommissioning works.

1. Project details and progress
(1) Development of a decontamination machine for surfaces in high locations
In order to use it for decontamination work at the Fukushima Daiichi NPS, decontamination machine for surfaces in high locations meeting the following performance and functional requirements was developed and demonstration tests were conducted.
• Decontamination performance of the target dose rate (3 mSv/h or less for work areas, 5 mSv/h or less for access areas)
• Remote operability , travel performance, and arm operability
• Recovery function in case of failure, toppling prevention, etc.

(2) Development of a decontamination machine for upper floor levels
In addition to the performance and functional requirements, a decontamination machine was developed and tested for use on the upper floors, which must meet the following design requirements for use on the upper floors.
• Capability to use a general-purpose elevator workbench for round trip with for the upper floor
• Capability to round trip from upper floor levels as quickly as possible
• Capability to can operate in the structure of the upper floor, equipment layout

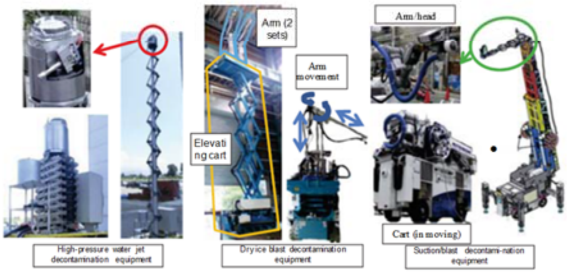


Fig. 1: Decontamination equipment for high places

(3) Examining the concept of decontamination in the basement floor level
If the accumulated water level in the basement decreases because of the retrieval of fuel debris, the implementation of measures concerning contaminated water, or any other reason, the air dose rate may increase due to the scattering of dust and shielding effect by water. Therefore, technical challenges were examined and formulated for attempts toward lowering the air dose ratio in the basement, including the following in the list of items that would require attention.
• Changes in plant conditions (changes in the air dose rate, accumulated water radioactivity concentration, and dust concentration)
• Scenario for environmental improvement including the decontamination of the basement floor
• Combination of different approaches such as decontamination, shielding, and dust collection


Fig. 2: Upper floor decontamination equipment

Implemented by
International Research Institute for Nuclear Decommissioning (IRID) (FY 2013 -)

2. Related projects
The following describes the results of previous related projects.
○ Development of remote decontamination technology in the reactor building (FY 2011 - 2013)
(FY 2011)
• Contamination survey: A field survey plan was produced that involved the determination of survey areas, the preparation of ideas about sampling tools, the listing of analysis targets, and so on.
• Dummy contamination test: A method for preparing a dummy contamination test piece such as a concrete sample was examined.
• Decontamination machine: Technological options were studied by making a public call for technical catalog proposals.
(FY 2012)
• Collection of basic data: By taking measurements on concrete core samples, it was found that there was no penetration of contamination into the concrete interior, it was confirmed that tightly adhering contamination is in scars produced by the aging degradation of epoxy coating on the surface.

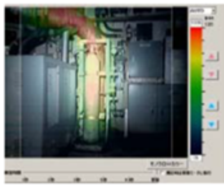


Fig. 1: Investigation result by γ camera in the south side of Unit 1

• Verifying the appropriateness of decontamination techniques: Based on the analysis of the collected basic data and the results of decontamination testing performed on dummy contamination samples, it was found that it would be possible to successfully address different types of contamination on different decontamination targets through high-pressure water jet decontamination, dry ice blast decontamination, or blast suction decontamination, and therefore it was concluded that these decontamination techniques were appropriately selected.
• Demonstration of remote controlled decontamination: By in-factory mock-up testing and demonstration testing, it was concluded that it would probably be possible to successfully put a remotely controlled decontamination machine to practical use, and challenges and necessary improvements were identified.
(FY 2013)
• Collecting basic data on contamination: Surveys were conducted on the dose rate at upper floor levels and in high location surfaces in reactor buildings, the distribution of contamination, internal radiation sources, and the penetration of contamination.
• Organization of decontamination techniques and examining decontamination concepts: A basic policy was established for the decontamination machine for surfaces in high locations and the decontamination machine for upper floor levels.
• Design and fabrication of remotely controlled decontamination machines and demonstrative decontamination testing: Design was performed for the decontamination machine for surfaces in high locations and the decontamination machine for upper floor levels. The decontamination machines that had been fabricated in FY 2012 were modified and put to demonstration testing and performance evaluation.
• Demonstration of the shielding system for practical application: The shielding installation plan for remote controlled was finalized, and the shielding system was put to in-factory demonstration testing and evaluation.


High-pressure water decontamination equipment (Hitachi GE)　Suction/blast decontamination equipment (MHI)　Dry ice blast decontamination equipment (Toshiba)

Fig. 2 Decontamination equipment developed in 2012

FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017
Development of remote decontamination technology in the building						
			Development of remote decontamination technology in the reactor building			

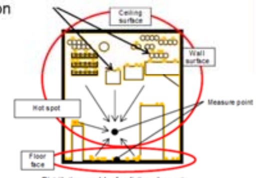
Fig. 14-2-(9) Development of remote decontamination technology in the reactor building

Project objectives

In order to reduce the exposure of workers to radiation in the decommissioning of the Fukushima Daiichi NPS as they engage in work inside reactor buildings, a comprehensive dose reduction strategy was developed combining various dose reduction techniques with remotely controlled decontamination techniques.

Project details and progress

In FY2012,againt the first floor level of Units 1 through 3, the fifth floor level of Unit 2, and the work areas in Units 1 and 3 at floor levels impacted by hydrogen explosions, in FY2013, against areas of relatively high dose rate inside reactor buildings, and the surfaces in high locations at the first floor level in respective reactor buildings, the higher floor levels in respective reactor buildings, the southern part of the first floor level, and access areas in staircases, etc. were addressed. Work was conducted toward establishing a dose reduction strategy that would enable the achievement of the target dose rate (3 mSv/h) using various dose reduction techniques like decontamination. In addition, study was performed and information was collected on dose reduction techniques developed outside Japan, and their effectiveness was examined and a public call was made for technical offers from overseas entities.



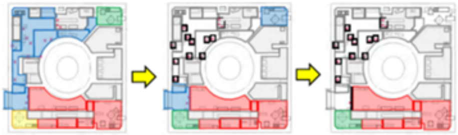
Distribution model of radiation dose rate

(1) Analyzing dose distribution in buildings

Data from dose measurements performed in buildings was compiled as basic data to be used in the development of a dose reduction strategy. The dose rate contributions of radiation sources, such as contaminated floor and wall surfaces, were modeled from the distribution of the dose rate in work areas. In this way, it was found that radiation from floor/wall/ceiling surfaces and also from the ducts and pipes close to the ceiling in spaces devoid of hot spots contributed significantly to the dose rate.

(2) Evaluating and selecting dose reduction techniques from among the decontamination, removal, and shielding options

Conditions were clarified regarding the selection of decontamination, removal, or shielding options for radiation sources such as floor and wall surfaces. The effectiveness of existing techniques was evaluated, and issues were identified.


Current distribution of radiation dose rate / Case of approaching to the facilities of ceiling direction and decontaminating / Case of Shielding partially

(3) Working toward the establishment of dose reduction strategy

Trying to determine the optimal dose reduction technique for floor and wall surfaces, etc., at each reactor building, it was found that radiation from the high location in the building contributed significantly to the dose rate. Based on this finding, a strategy was established to achieve the target dose rate by preparing machines that would enable the remote decontamination, removal, or shielding of target components, particularly the components installed close to the ceiling. That strategy was established by additionally performing detailed surveys to determine the radiation source intensity of contaminants attaching to the target components.

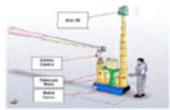
(4) Employment of techniques imported from abroad

To employ techniques owned by overseas entities with sufficient experience in working in high-dose or high-contamination environments, study was performed and information was collected on dose reduction techniques held by the entities mentioned below. It was concluded that these techniques may be effectively applied to solve issues when they are improved or further developed to suit conditions at the Fukushima Daiichi NPS sites.

[1] AREVA (France): 3D contamination distribution capture by remote control in a high-dose environment and dose rate contribution evaluation

[2] Babcock (Britain): Technique for remote contamination analysis in a high-dose environment

[3] CH2MHILL (U.S.): Technique for decontaminating in a high-dose environment (cable trays, ducts, gratings, power boards, instrumentation racks, etc. in high location)


(1) Remote measurement system of radiation dose(AREVA)


(2) Remote sampling tool (Babcock)

In FY 2013, the public offering was conducted for overseas entities on specific solutions that may contribute to the development of dose rate reduction programs, and the proposal was summarized.

Implemented by

ATOX Co., Ltd.

FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018
	Formulation of comprehensive dose rate reduction plan						

Fig. 14-2-(10) Formulation of comprehensive radiation dose reduction plan

Project objectives
To develop the canister necessary for reliably and reasonably containing, transferring and storing the retrieved fuel debris taking its characteristics into account, as well as to establish conceptual idea of the system for containing, transferring and storing of the retrieved fuel debris in conjunction with the ongoing effort by the project "Establishment of the fuel debris retrieval method".

1. Project details and progress
The following results were produced from ongoing projects described in Section 2 below.
(1) Survey on transferring and storing of fuel debris and preparing research plan
In order to contribute to (2) to (4) shown below, develop research plans based on the progress of related projects and on-site status of the Fukushima Daiichi NPS, and update survey/research plans as needed.
(2) Development of storage technologies
Manufacture prototype canisters for fuel debris retrieved from the PCV based on their basic specifications/structures. Implement structural integrity test for confirmation of its required safety functions.
(3) Development of transfer technologies
Perform surveys, analyses and tests to propose a rational method for predicting the amount of hydrogen generation during transferring fuel debris. Based on the results, clarify conditions to transfer fuel debris safely (check items before transfer, measures against hydrogen generation, transfer methods, etc.) Apply predicting method of the amount of hydrogen generation to the treatment system for gas containing hydrogen generated from fuel debris during storage.
(4) Drying technology/system development
Examine drying technologies suitable for fuel debris and deepen review on drying methods/systems by using the pertinent technologies. In addition, proceed with technology development to evaluate necessary treatment before storage such as confirmation of subcritical condition and amount of hydrogen generation.

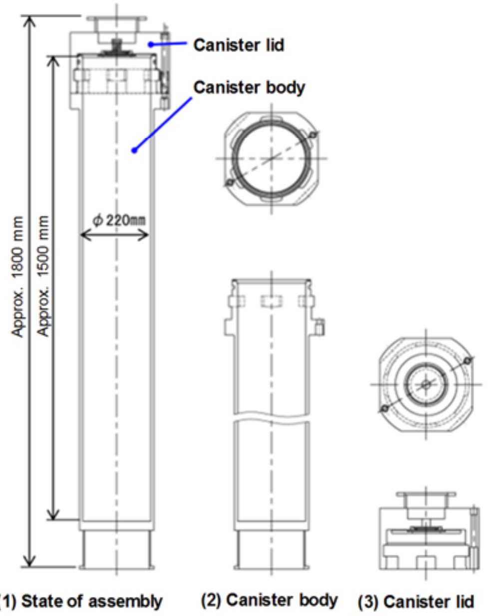


Fig. 1: Proposed basic plan for the canister shape
(Lid with simple mounting structure [lid closure by rotating], inner diameter 220 mm)

Implemented by
International Research Institute for Nuclear Decommissioning (IRID)

2. Related projects
The followings are the results of related previous projects.
○ Development of containing, transferring and storing technology of fuel debris
(1) Survey on the transferring and storing of the damaged fuel (FY 2013 - 2018)
The following overseas experiences that pertain to the transferring and storing damaged fuel were studied.

- Transferring of the fuel debris from TMI-2 (U.S.) to INL, the wet storage of fuel debris, and dry storage of it after drying
- Design and safety assessment capability for canister and drying technology by PNNL (U.S.)
- Study and evaluation of characteristics of MCCI products conducted at ANL (U.S.)
- Transferring and storing of damaged fuel at Paks Unit 2, Hungary
- Transferring of damaged fuel in France
- Radioactive waste disposal technologies performed at Sellafield (Britain)

(2) Study on fuel debris containing method into the canisters (FY 2013 - 2018)
The basic specification and geometry (incl. lid structure and structural buffer) of the canister were established through the definition of the requirement for the canister suitable for work form containing to storing of the fuel debris in coordination with other related projects. Furthermore, a work flow up to transferring and storing of them was proposed and the basic specifications of the canister handling equipment, etc. were established.
(3) Study on safety requirements, specifications for the canister and its storing systems (FY 2013 - 2018)
Preferred scenario was selected regarding the containing of fuel debris into the canisters, transferring, and storing from the viewpoints of safety assurance, work efficiency, etc., and it was reviewed repeatedly taking the latest inputs from related projects into consideration.
(4) Development of an approach to safety assessment and verifying safety (FY 2013 - 2018)
Literature search and survey of overseas cases were performed to investigate more about approaches to the safety assessment of the canister for fuel debris (maintaining sub-criticality, structural integrity, and counter measure against hydrogen generation). Necessary data for safety assessment of the canister was obtained, and a general outlook on safety assessment was confirmed through performing experimental analyses and component tests based on assumed the fuel debris characteristics.

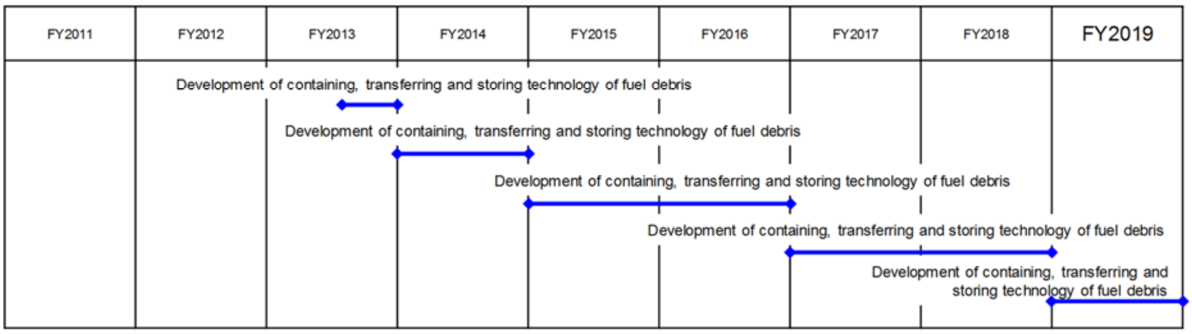


Fig. 14-2-(11) Development of technologies for containing, transferring and storing fuel debris

Project objectives

Aiming to obtain the prospects of a processing/disposal method and technology related to its safety that should be made clear by around FY 2021, the efficiency of solid waste characterization shall be improved with considering features of waste generated by the accident, and research and studies shall be conducted toward establishing processing technologies, disposal concepts, and its safety assessment method on the basis of the characterization results. In addition, technologies necessary to reduce the risks associated with the storage of solid waste shall also be developed.

1. Project details and progress

The following describes the project details based on the results from the related projects, achievements so far and current initiatives as shown in Section 2 below.

(1) Storage and management

[1] Study and evaluation of storage management method

Types and quantities of high-level waste to be generated from fuel debris retrieval will be evaluated, while examining and providing storage methods, containers and containment methods including measures against hydrogen gas.

i) Review on waste information survey, evaluation and storage methods for high-dose waste

[Achievements to date]

- We have investigated the differences in approach to hydrogen gas management, evaluation methods of hydrogen generation, container specifications and measures against hydrogen gas generation between Japan and overseas countries, as well as the reasons, and summarized insights on the pertinent evaluation methods and requirements including venting. In addition, we have examined measures against hydrogen generation in each phase of storage, treatment and disposal of slurry waste and in-core structures (metal waste), and summarized the evaluation methods for hydrogen generation and issues in implementing measures.
- The waste generated from fuel debris retrieval is classified into 4 categories (Objects removed from the 1FL and operating floor, in-core structures, equipment for retrieval, air conditioning/water treatment system waste), and waste information such as the estimated amount and dose has been summarized.

[Current initiatives]

- While summarizing the latest information on types and quantities of high-dose waste depending on the status of examining fuel debris retrieval methods, handling processes of high-dose waste up to storage have been examined based on such information.
- Several anticipated scenarios are under review for the handling process of the representative high-dose waste.

ii) Study on container and storage facility requirements

[Achievements to date]

- For in-core structures, we have summarized a list of safety functions required in each step up to storage, and developed several potential storage/management flows.
- Based on the storage and management flows, examinations have been made on proposed functional requirements for containers and storage buildings.
- The proposed specification outline has been reviewed according to functional requirements for containers and storage buildings.

[Current initiatives]

- The study on rational inner containers accommodating several types of shielding thickness is underway according to dose level.
- We have been summarizing a concept of containers for storage and transfer with filter vents, which are appropriate as measures against gas generation from waste along with fuel debris retrieval works.
- A concept for the drying treatment system, etc., has been summarized, which is appropriate for anti-corrosion measures when storing waste from duel debris retrieval tasks as well as anti-gas measures with anticipation for sealing for disposal.
- Considering priorities and practical applicability of measurement items necessary for storage in storage buildings, a concept of measurement methods and systems has been organized.
- Several anticipated scenarios are under review for the handling process of the representative high-dose waste.

[2] Contamination assessment techniques for segregation of solid waste

To develop a measurement system for α contamination adhered to the surface of building concrete and equipment, design and production of detectors, indication functions and a pan-tilt mechanism, etc., and systematization testing toward practical application. In addition, a measurement technique for the degree of penetration of α-contamination from concrete surface has been developed.

[Achievements to date]

○ Surface α contamination

- Assuming the on-site environment during practical application, parameters that will affect measurement of environmental temperature and dose rate have been summarized. The specifications required for the measuring device (α camera) are defined based on the needs of measuring surface α contamination.
- According to measurement parameters and specifications, we have produced a prototype (Figure 1) with the addition of a larger lens, distance measurement function and temperature adjustment mechanism, and performed element tests to identify issues for practical application.

○ Infiltrated α contamination

- Study on practical applicability as well as investigation on the need for measurement have been performed along with technical investigation for use under expected environmental conditions. Performance of the method to measure the penetration depth of γ nuclides such as Cs-137, which may accompany α-nuclides (Figure 2), has been verified.

[Current initiatives]

- To develop a measurement system for α contamination adhered to the surface of building concrete and equipment, design and production of detectors, indication functions and a pan-tilt mechanism, etc., and systematization testing are underway toward practical application. Then, we plan to conduct mockup testing for α-contaminated equipment on-site to evaluate its performance.

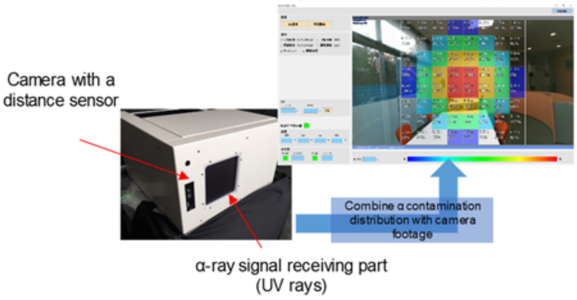


Fig. 1: Measuring equipment for surface α contamination (α camera)

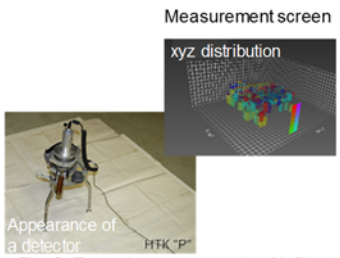


Fig. 2: Example survey results of infiltrated αcontamination measurement technology
Detector appearance and measurement result samples

(2) Establishing processing/disposal concept and development of safety assessment method

[1] Establishment of a selection method of preceding processing

In order to contribute to developing means to select preceding processing methods, we will gain and evaluate necessary data to extract stabilization and immobilization technologies, which have potential to apply them to actual treatment, associated with high and low temperature treatment technologies.

i) High-temperature treatment technology

[Achievements to date]

Applicability of the following 3 elemental technologies has been evaluated through engineering scale tests, etc.

○ In-drum vitrification treatment technology

- In-drum vitrification technology was focused on as a stabilization technology required for pre-disposal management of secondary waste generated by water treatment. Then, simulated solidified waste was produced with the process of simultaneously melting zeolite used for contaminated water treatment together with other simulated secondary waste generated by water treatment (Figure 3). Based on the results of studies on glass composition and crucible melting tests, engineering scale tests were performed to evaluate solidified waste properties, transfer of nuclides to the off-gas system and chemical durability.

Fig. 3: Test equipment for In-drum vitrification treatment technology and solidified waste

○ Vitrification treatment technology using cold crucible induction heating furnace (CCIM)

- Glass composition development
  - For carbonate slurry, iron coprecipitation slurry, zeolite, silicotitanate and ferrocyanide sludge, the glass composition corresponding to the waste has been set to confirm that the vitrification state is good (Fig. 4, 5).
  - We have confirmed that the electrical conductivity of 4 kinds of glass compositions, excluding above ferrocyanide sludge, satisfied the reference values.
- Impact verification by fluctuation in waste composition
  - Based on the analysis results of the actual waste, the fluctuation range of the waste composition of the carbonate slurry and the iron coprecipitation slurry has been defined. It has been confirmed that the vitrification state of the carbonate slurry is good even when the waste composition fluctuates within the prescribed range.
  - In light of suppression of Cs volatilization, the zeolite composition is selected to achieve vitrification under the condition where the melting temperature is lowered from 1200°C to approx. 1025°C (Fig. 6).
- Data acquisition required for full-scale CCIM operability verification and system design (Fig. 7)
  - For verification on the applicability of CCIM, practical-scale tests for CCIM have been performed by using the practical-scale test equipment (approx. 200 to 300 kg in the core) and maintained the calcined layer and bubbling holes at a waste supply rate of 40 to 80 L/h to confirm that the operation can be continued in a practical scale.
- Design and verification of waste gas treatment and supply systems
  - As a conceptual study of waste gas treatment and supply systems suitable for solid waste generated from contaminated water treatment, basic processes of the supply and waste gas treatment systems are established.
  - The radioactive concentration by waste has been defined to calculate the material balance of the radioactive concentration in the waste gas treatment system.
- Review on compliance with domestic regulations
  - To introduce the CCIM system into Japan, relevant laws and regulations in Japan have been listed to summarize issues toward introduction in terms of safety assessments and regulatory requirements in Japan. We have also reviewed articles and other details, screened out and examined issues.

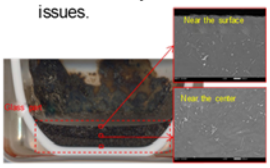


Fig. 4: Vitrification test: Iron coprecipitation slurry
(Waste filling rate of approx. 35 wt%)

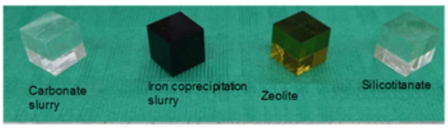


Fig. 5: Example state of vitrification by waste

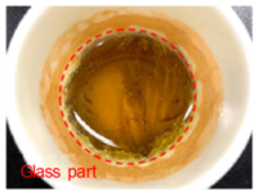


Fig. 6: Vitrification test: Zeolite
Melting temperature of approx. 1025°C
(Waste filling rate of approx. 62 wt%)

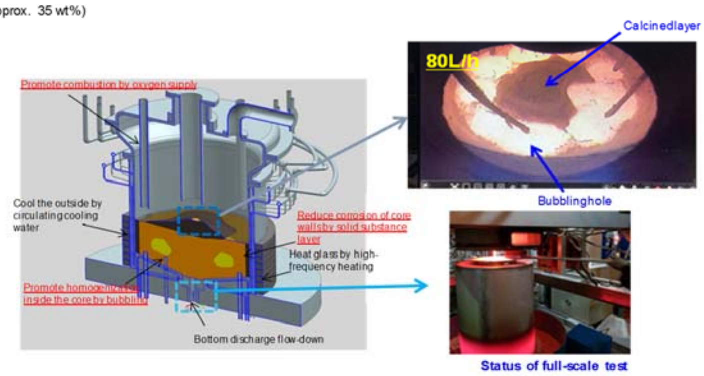


Fig. 7: Overview of cold crucible induction heating furnace (CCIM)

○ In-Can vitrification technology (Fig. 8)

- STEP-1: Scenario examination
  - Collected waste data from the Fukushima Daiichi NPS and created basic database.
  - Performed laboratory-scale test (approx. 100 g) to optimize the scenario (combine several types of waste at a certain ratio and treat them under certain conditions) (Fig. 9).
  - Selected 4 scenarios (scenarios A to D) for bench scale testing first, and then selected the reference scenario for pilot scale testing among scenarios from A to D.
    Scenario A: Mixture of all solid waste and sludge (Moisture content 50%)
    Scenario B: Mixture of all solid waste and dry sludge (Reference scenario)
    Scenario C: Waste with high activity of Cs
    Scenario D: Waste with little Cs and high activity of Sr
- STEP-2: Bench scale test (Fig. 10)
  - Performed bench-scale testing (approx. 1 kg) for each scenario to verify feasibility of the scenario and determine operating parameters.
  - Confirmed that high-density and homogeneous substances could be gained in all the scenarios.
  - Extracted and analyzed vitrified waste samples in the scenarios A, B and C.
  - Analyzed vitrified waste samples in scenario D as in other scenarios.
- STEP-3: Pilot scale test (Fig. 11)
  - Performed pilot-scale testing (approx. 100 kg) on the reference scenario (scenario B) to acquire necessary data for applicability assessment and verify each function/performance in the course of process.
  - Confirmed that high-density and homogeneous substances could be gained.
  - Analyzed vitrified waste samples.
- STEP-4: Applicability assessment
  - Compared and examined plans to treat all waste in bulk or to treat them separately, and studied practical application of the relevant technology.
  - For each treatment plan, examined the number of glass canisters to be required, radioactivity contained in each canister, process flow and evaluated necessary system scale (# of process lines and systems) to treat generated waste within a certain period of time.

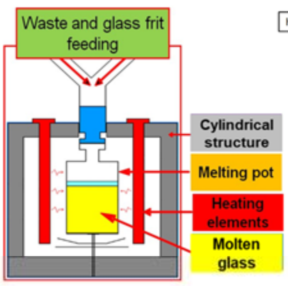


Fig. 8: Conceptual diagram of In-Can vitrification

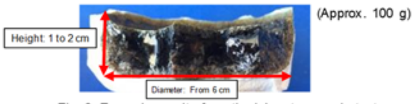


Fig. 9: Example results from the laboratory scale test

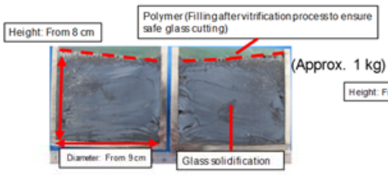


Fig. 10: Example results from the bench scale test

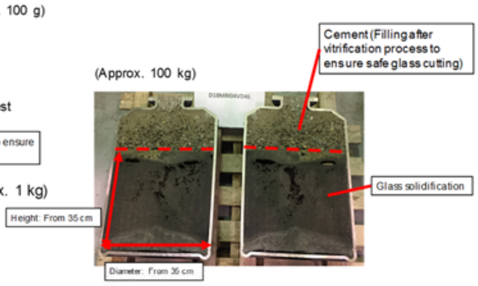


Fig. 11: Vitrified waste produced in the pilot scale test

[Current initiatives]

- With regard to the above 3 elemental technologies, and by using engineering scale test equipment, we also continue to acquire data on evaluation items (Solidification treatment system [Solidification container specification, necessary system], operability, performance of solidified waste, compatibility with disposal, economic efficiency and domestic regulations) essential to extract treatment technologies.
- Studies on the following subjects are ongoing: Impact to waste compositional variation; integrity of heat-affected containers at the time of disposal; economic efficiency of containers; the rate of migration of Cs and other materials to off-gas; the rate of leaching radionuclides from solidified waste; performance of solidified waste when being treated at relatively low temperatures; supply and off-gas treatment systems; waste product specifications; and safety assessment during waste disposal.

ii) Low-temperature treatment technology

[Achievements to date]

- As for data acquisition, which seems to be insufficient for AAM (Alkali Activated Materials) solidification, we have gained data on the relationship between composition rate and fluidity, strength, solubility, hydrogen generation behavior, etc., and reflected it in the summary table in the preceding paragraph. For AAM solidification, moreover, we have confirmed that strength develops early for cement (Fig. 12), the setting time differs by composition (Fig. 13) and it may be superior in dissolution stability compared with cement solidification.

[Current initiatives]

- Since solid waste properties differ, a method to determine a possibility of waste solidification by low-temperature treatment technology is under examination. In addition, we have investigated and tested transformation of solidified waste due to heating, etc., to evaluate the effects.
- Concerning heat generation of solidified waste caused by Cs, etc., we have evaluated the relationship between inventory and temperature to proceed with examinations on the available inventory while maintaining the integrity of the solidified waste.
- Examinations on the sufficiency of thermodynamic data on solidified waste, applicability of equilibrium calculation, as well as summarizing the impact on long-term transformation, are in progress to perform evaluation on transformation behavior of the solidified waste accordingly.

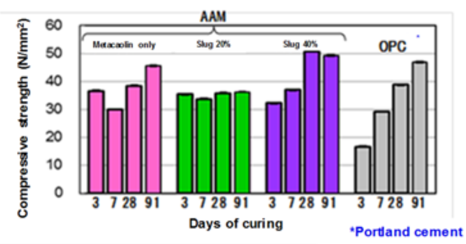


Fig. 12: Relation between compressive strength and elapsed time

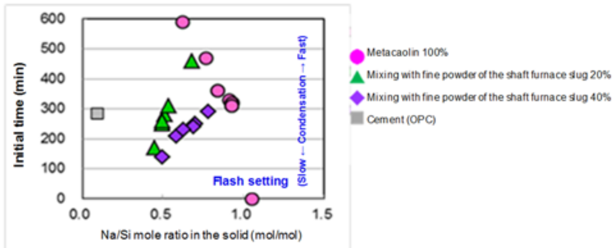


Fig. 13: Relation between composition and setting time

iii) Study on applicability evaluation approach for treatment technologies

In order to extract treatment technologies, we will collect and organize necessary items and information based on the information on solid waste properties for diversified comparison and examinations.

[Achievements to date]

- For each elemental technology of 4 treatment technologies (High-temperature: Vitrification/melting, low-temperature: Cement solidification/AAM solidification), which have been introduced in Japan and overseas countries, we have collected information on maturity, composition/treatment processes, operability, rationality and impact of waste properties (physical, chemical and radiological properties) in a comprehensive manner to identify selection indexes (evaluation axis) for applicable treatment technologies. We have also summarized qualitative and quantitative information on each evaluation axis by elemental technology (Table 1). Based on the organized information, items requiring information acquisition by additional surveillance and testing have been clarified.

[Current initiatives]

- We have been examining the impact of composition/chemical form of the solid waste and solidification composition on solidified waste performance to evaluate the range of solid waste to which each treatment technology is applicable.
- For the evaluation on waste material specifications by treatment technology, we have examined a concept of solidification treatment systems and gained economic data including system configuration and treatment efficiency, maintenance content, types of consumables and frequency of replacement, and types and quantities of secondary waste.
- As volatilization of Cs is an issue in high-temperature treatment technology, volatilization and control mechanisms for Cs are under investigation to evaluate volatilization characteristics of Cs by processing method and operating condition accordingly.

Table 1. Key evaluation axis and summary information (Example: Ultra high-frequency melt-solidification)

(Evaluation axis) (Qualitative/quantitative Information)

Technical achievements		Demonstration test of the small equipment in Japan (30 L/batch)
Profess performance	• Number of processes • Treatment temperature • Treatment capacity • Cs volatilization ratio	14 1450℃ 0.4 t/batch/d Cs 10～70%
Operability	• High-impact parameter • Main process risk	• Waste composition (Ca concentration, impurities), water content of waste, melting temperature • Performance deterioration of vitrified waste due to inner pressure increase and insufficient melting
Economic performance	• Main system configuration • Secondary waste generated	• Dryer, high-frequency power source, water-cooled coil, off-gas system • Bag filter, HEPA filter, residue and scrubber drainage
Solidified waste product	• Solidified waste dimension • Leaching rate • G value	200 L drum 10^{-4}kg/m²/d No hydrogen generation

[2] Proposal of disposal methods and development of safety assessment methods

Several disposal methods will be reviewed in light of the survey results on domestic/overseas disposal concepts, safety assessment methods and information on solid waste properties. Then we will collect and organize necessary items and information to clarify the image of waste based on treatment technologies applicable to solid waste, and to establish disposal and safety assessment methods by disposal method accordingly.

In addition, deterioration behaviors of barrier performance caused by substances that affect safety during disposal should be incorporated into the evaluation.

[Achievements to date]

- We have prepared a list of cases in overseas disposal sites that need to be focused on and summarized applicability to solid waste at 1F and associated issues. The methods to examine a disposal concept with consideration for waste characteristics are also developed (Fig. 14). Through these methods, we have performed pilot analysis on examples of setting several disposal concepts to verify feasibility of methodologies that allow examinations of waste treatment/disposal policies depending on waste characteristics.
- 6 substances (Table 2) are extracted as influential substances that are highly likely to have an impact or need to be verified by nuclide sorption behavior and quantity, etc., while investigating, gaining sorption data on influential substance evaluation, and summarizing evaluation methods. We also have gained sorption data for combinations with less information on interactions between extracted substances and nuclides, and established a method to quantitatively evaluate the level of impact to nuclide sorption behaviors according to the number of data points. Issues are summarized while deriving the tentative sorption reduction coefficient (Fig. 15).

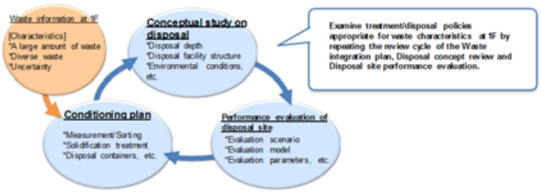


Fig. 14: Disposal concept review process with consideration for waste characteristics

Table 2. 6 extracted materials

Extracted material
Organic matter
Seawater component
Boric acid
Ferrocyanide
Sulfate
Carbonate

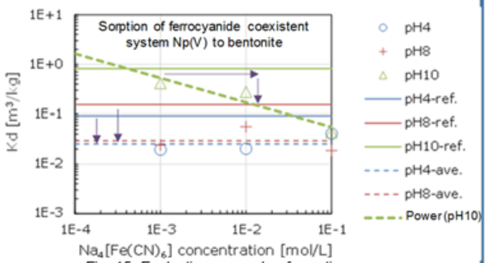


Fig. 15: Evaluation example of sorption reduction coefficient for artificial barriers

[Current initiatives]

- Several disposal methods by solid waste category will be examined in light of the survey results on domestic/overseas disposal concepts, safety assessment methods, and information on solid waste properties. In addition, items requiring review shall be identified and necessary information will be obtained and organized to establish safety assessment methods by disposal method.
- Concerning behaviors related to degradation of barrier performance caused by substances affecting disposal safety, a review is underway so that the evaluation can be performed that incorporates such impact.
- For the disposal methods reviewed, the image of waste by applicable treatment technology depending on solid waste characteristics shall be clarified.

(3) Characterization

[1] Improving the efficiency of waste characterization

Since a large amount of solid waste exists that was affected by the accident, and nuclide composition and activity concentration are diverse, we will proceed with characterization in an efficient manner.

i) Development of characterization method with complimentarily use of data evaluated from nuclide migration model

A method to evaluate the representativeness of analysis data will be examined to allow characterization based on the limited analysis data. As to the statistical inventory estimation method, we also evaluate the adequacy of its application by investigating correlation with analysis data, etc.

[Achievements to date]

- Leveraging the fact that frequency distribution of contamination by radionuclides is log-normal associated with estimation of waste radioactivity, we have examined estimation methods with consideration for analysis data growth (Fig. 16). The radioactive waste inventory is also estimated using an improved assessment method, while developing a calculation tool.

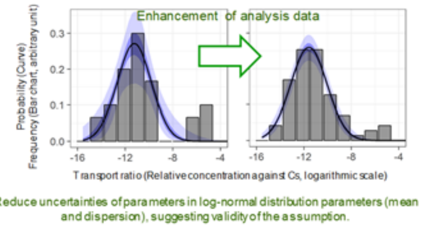


Fig. 16: Example of reduction in uncertainties of distribution parameters along with analysis data growth

[Current initiatives]

- Based on the acquired and published analytical data and relocation behavior of the contaminated nuclides estimated from the analytical results, grasping the contamination mechanism as a relocation model and development of a method to evaluate representativeness of the analytical data are in progress.
- Characteristics of analytical data related to measurement errors, variations, and correlations are investigated and organized to develop a statistical inventory estimation method, while evaluating applicability by examining correlations with analytical data, etc.

ii) Simplification and acceleration of analysis methods

We will make reviews toward technical development for simplification, acceleration, and manual preparation through rationalization, automation of pretreatment of samples, and standardization of analytical methods. In addition, it is planned to gain, assess and manage analytical data in order to contribute to reviewing needs, consistency of the overall waste management including treatment/disposal, nuclides to be analyzed, and optimization of the sample volume for analysis.

[Achievements to date]

- Based on the latest trends for the analytical process, mainly existing radiochemical analysis, we have reviewed and proposed the analytical process that applies ICP-MS to a wide range of nuclides together with the calibration method without using standard samples.
- For the rationalization of the analysis work, the automation technology for 7-step operation processes to measurement (Dissolution, isolation/distribution, reagent addition, filtration, heating/evaporation to dryness, constant volume, ion exchange/solid phase extraction) has been developed to confirm the accuracy equivalent to experienced workers (collection rate, etc.).
- Analysis of rubble, contaminated water and secondary waste generated by water treatment is ongoing for use in R&D on waste storage, treatment, and disposal. Analytical data accumulated so far has been made available online to facilitate decommissioning. The investigation on local distribution of contamination in rubble samples has revealed non-uniform contamination (Fig. 17).
- Conditions inside Tank D in the main process building, where sludge from the decontamination systems is present, were studied, and the actual sludge was sampled (Fig. 18). Through observation with a submerged camera, it was found that the sludge sedimentation layer in the tank had a thickness of about 40 cm, and the volume was estimated to be around 37 m³. To prepare for sludge removal, simulated sludge was produced and tested to obtain basic data on sludge fluidity.

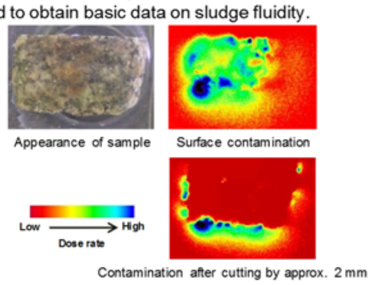


Fig. 17: Locally non-uniform contamination of rubbles (By imaging plate measurement)

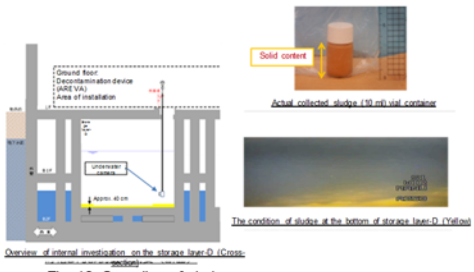


Fig. 18: Sampling of sludge from decontamination equipment

[Current initiatives]

- In order to improve efficiency and rationalization of characterization, we are conducting reviews on technical development for simple and quick analytical methods for target nuclides, as well as manual preparation through rationalization, automation of pretreatment of samples, and standardization of analytical methods.
- As for rubble inside or near the buildings, incinerated ash, secondary waste generated by water treatment and contaminated water accumulated in buildings, we have gained, assessed, and managed analysis data to contribute to understanding the extent of contamination, reviewing needs, consistency of the overall waste management including treatment/disposal, nuclides to be analyzed, and optimization of the sample volume for analysis.

iii) Development of sampling techniques, etc.

Based on the analysis needs for R&D for treatment and disposal of solid waste, a sampling technique for high-dose samples will be developed.

[Achievements to date]

- Concerning sampling of zeolite from the cesium adsorption vessel, we have completed sampling element tests and commenced detailed design of the sampling head, etc. (Fig. 19).

[Current initiatives]

- As for sampling of cesium adsorbent, testing and evaluation on elemental technologies such as drilling holes and the closing of the adsorption vessel necessary for designing mock-up sampling equipment are in progress.

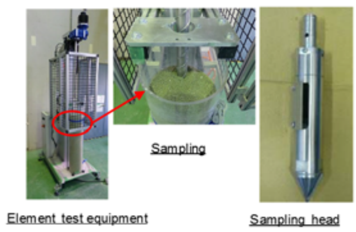


Fig. 19: Sampling test equipment and sampling heads to take used adsorbents from a cesium adsorption vessel

(4) Integration of R&D results

[Achievements to date]

* Regarding the waste stream, latest results derived from previous research are reflected in it, and establishment of methodology to integrate progress, consistency of results, and remaining issues, is made to start. Operational issues are also summarized through trial.

[Current initiatives]

* With incorporation of the results gained from studies, we continue to evaluate progress, consistency in the results, and remaining issues in a comprehensive manner. For this evaluation, issues will be summarized to contribute to further R&D activities.

Implemented by
International Research Institute for Nuclear Decommissioning (IRID) (FY 2013 -)

(Partly proposed by) IHI Corporation (From FY 2018)
Orano ATOX D&D Solutions Co., Ltd. (From FY 2018)
Kurion Japan Co., Ltd. (From FY 2019)

2. Related projects

The following describes the results of previous related projects.

○ Development of technologies for processing/disposal of secondary waste generated by treatment of contaminated water (FY 2012)

(1) Characterization of spent adsorbers, sludge, etc.
- Nuclides in contaminated water and treated water were analyzed, and progress was pursued in the analysis of nuclides that are difficult to measure.
- Work continued in estimating the distribution of cesium adsorbed into the adsorber inside an adsorption tower and in performing tests to characterize the properties, such as the thermal stability of spent zeolite. It was not possible to perform sampling and analysis according to the schedule due to the high dose rate from the sludge itself and in the surrounding area.
- Progress was made in the collection of information regarding the basic properties of secondary waste from newly employed contaminated water treatment systems (cesium adsorption system No. 2 and multi-nuclide removal system).

(2) Studying long-term storage
- Corrosion testing was performed on sludge storage container material and cesium adsorption apparatus material to collect electrochemical data, etc., pertaining to container corrosion that could contribute to the evaluation of long-term storage.
- Based on the results of spent zeolite property characterization, the hydrogen concentration and the temperature inside adsorption towers were estimated as safety-related information.
- Heat flow analysis was performed on sludge under the current storage conditions, and the appropriateness of measures that had been taken to address the issue of heat was verified.
- A literature search was begun on adsorbers used in the multi-nuclide removal system, etc.

(3) Research on the conditioning techniques
- The results of research conducted were compiled on techniques used for conditioning of spent zeolite, sludge, etc.
- By conducting basic experiments on conditioning such as using the cement solidification technique, progress was made in the collection of data required for assessing the implementation feasibility of conditioning techniques.
- Information was obtained about secondary waste from the multi-nuclide removal system (types, predicted quantities, etc.).

○ Development of technologies for processing/disposal of radioactive waste (FY 2012)

(1) Characterization of “rubble, etc.”
- The radioactivity of rubble and felled trees was analyzed to collect analysis data required to know features on the contamination status of waste.

(2) Development of techniques to analyze nuclides that are difficult to measure
- To address nuclides such as Zr-93 and Mo-93 that are difficult to measure and therefore require the development of analysis techniques, literature searches were performed and analysis flows were studied.

(3) Study on the development of infrastructure for R&D on waste processing/disposal
- The study was conducted on the components of R&D as well as those solutions necessary to obtain prospects of a processing/disposal method and technology related to its safety. In addition to that, information was compiled such as needs of users, future possibility of developing a database, and conceptual design was implemented for its setting up.

(4) Establilshing an R&D program on waste processing/disposal techniques
- Referring to a technical development program discussed within the special expert committee of the Atomic Energy Society of Japan, a draft R&D program for waste processing/disposal techniques was produced.

○ Research and development of processing/disposal of solid waste (FY 2013 - 2014)

(1) Characterization
- Rubble, felled trees and secondary waste generated by water treatment were transported to JAEA for radioactivity analysis. A proportional relationship was found between Cs-137 and Sr-90 in rubble and felled trees in terms of radioactivity concentration.
- The radioactivity (i.e. the inventory of radioactive nuclides) in secondary waste generated by water treatment (cesium adsorption apparatus, etc.) was estimated based on the concentration analysis data of treated water.

(2) Studying long-term storage
- The conditions inside cesium adsorption apparatus were estimated based on data from simulation test. It was noticed that corrosion was suppressed by the coexistence of zeolite.
- The technique to be used to stabilize slurry from the multi-nuclide removal system was selected, and test was conducted using simulated samples.

(3) Studies on waste processing
- Experiments were conducted with the solidification of slurry and spent adsorber from the multi-nuclide removal system using solidifiers of various types.
- A catalog of existing waste processing and conditioning techniques was compiled.

(4) Studies on waste disposal
- Assuming the application of existing disposal concepts to the disposal of waste generated by the accident, safety assessment methods (scenarios, etc.) in consideration of the features of waste was provisionally defined.
- In defining analysis cases for the postulated scenarios, provisional assessment was performed for the safety of disposal of different types of waste.

(5) Studying postulate of R&D
- Waste generated by the accident was classified by property, contamination history, etc. And an example of handling flow consisting with storage, processing, and disposal and those may realize safe disposal was defined for each classification of waste.
- The collection of analysis data was expanded or updated with newly obtained data. In addition, the relationships between major development tasks of processing/disposal techniques and various information items were defined to prepare for the development of information management tools.

○ Research and development of processing/disposal of solid waste (FY 2015 - 2016)

(1) Integration of R&D results
- Regarding the waste stream, a technique was developed to narrow down streams that presents multiple options, and case studies were conducted to identify challenges in applying the technique.
- At a study meeting held by OECD/NEA expert group to address issues around waste generated by the Fukushima Daiichi accident, contribution was made to compile a report (published in December 2016).

(2) Characterization
- Rubble, secondary waste generated by water treatment, contaminated water, and so on, were transported to an offsite facility for radioactivity analysis. Data from the analysis of rubble (concrete) from the Unit 1 reactor building (R/B) was found to be consistent with existing data from the analysis of rubble (Fig. 7).
- Work was conducted toward reducing uncertainty in the analytical estimation of inventory, and inventory data sets were produced using the improved estimation technique and made available for use in safety assessment for disposal.

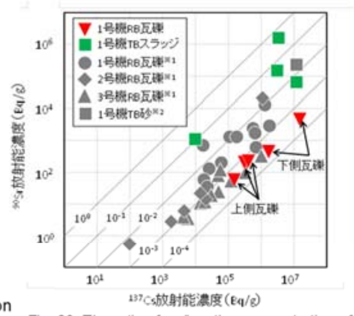
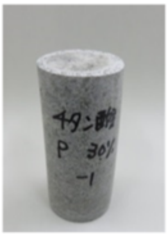


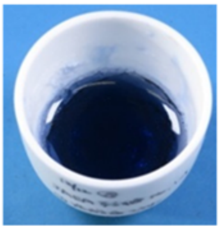
Fig. 20: The ratio of radioactive concentration of Sr-90/Cs-137 in rubble

(3) Studies on waste processing and long-term storage
- A conceptual design was studied for equipment to be used in the stabilization of slurry from the multi-nuclide removal system based on the results of studies on operational aspect of introducing it to the field and verification tests.
- For secondary waste generated by water treatment with which the solidification had not been attempted in the past, basic tests were performed to experiment with solidification through existing techniques (Fig. 8) to determine the feasibility of solidification and collect data on confirmation of the integrity of solidified waste. Comparing the data with the requirements defined for technical assessment, applicable candidate techniques for each type of waste were assessed.
- Accelerated test was performed for residual water evaporation from cesium adsorption apparatus due to heat generation and the evaluation of increase in salt concentration, and a method for the verification of the salt concentration evaluation results was developed.

(4) Studies on waste disposal
- Data was compiled including information on the examples of disposal concepts from abroad that may be referenced in the development of disposal concepts, and the features of existing disposal concepts were organized.
- A safety assessment method was developed to evaluate disposal categories with consideration of uncertainty.



Cement solidification


Glass solidification


Compressed solidification


Sintered solidification

Fig. 21: Various type of solidification of simulated waste

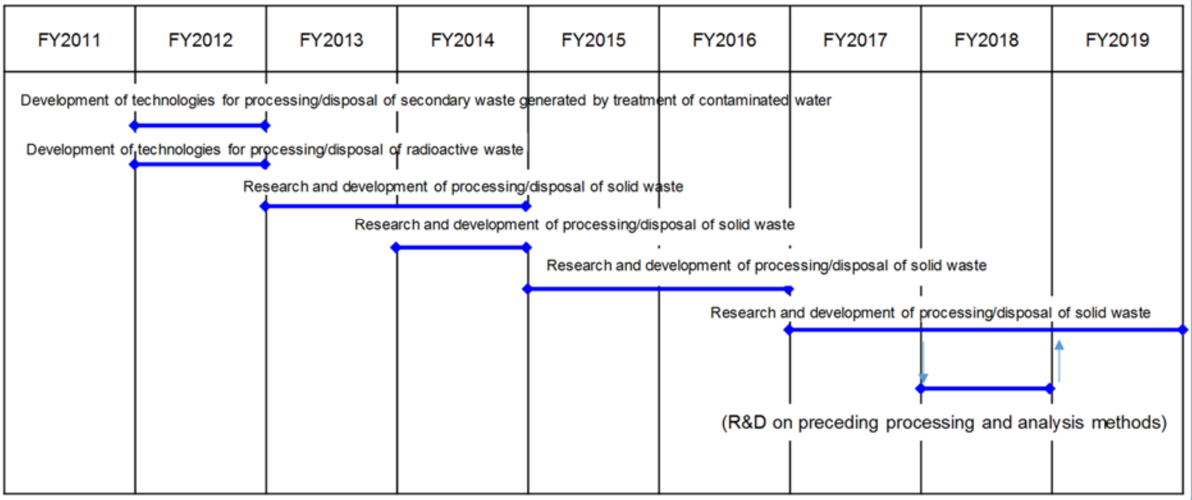


Fig. 14-3 Research and development for processing/disposal of solid waste

Project objectives
In the decommissioning of the Fukushima Daiichi NPS, to safely store the fuel assemblies removed from the spent fuel pool that was affected by the hydrogen explosion and seawater injection in the common pool over the long term as well as to examine the feasibility of future dry storage, technologies have been developed to obtain the necessary data for the examination of decisions on the necessity of the evaluation and management methods for long-term integrity assessment and long-term wet and dry storage.

1. Project details and progress
The following describes the results this project produced so far based on results from the related projects described in Section 2 below.
(1) Development of technologies for assessing the long-term integrity of fuel assemblies
○ Evaluation on the deposits on the surface of the fuel assemblies
Materials of fuel assemblies (lock nuts) of Units 4 at the Fukushima Daiichi NPS stored in the common pool were transported to the post irradiation test facility, and component analysis for white deposits and measurement of corroded crevice re-passivation potential were carried out. Among the constituents of the white deposit, the amount of Mg was the largest, and the amounts of Al and Si were about half of it. The amount of Cl was below the detection limit. Since Mg (OH)2 was separated and Cl was not captured, it is considered that there is no possibility of corrosion (Fig.1). In the electrochemical test, there was no crevice corrosion sensitivity in the area where the chloride ion concentration was lower than 100 ppm, and it was confirmed that there was almost no possibility of corrosion in the common pool of less than or equal to 1 ppm (Fig.2).
○ Evaluation of integrity of fuel in dry storage conditions
Assuming dry storage of the fuel assemblies from the spent fuel pool of 1F, in order to confirm integrity of the fuel assemblies affected by rubble falling and seawater components, which were to be stored in the dry system, a hydride precipitation behavior verification test and a creep test were carried out, and the impact of the factors unique to 1F on material properties was evaluated. It was confirmed that the impact on hydride precipitation behavior and creep behavior was small even in the condition affected by both rubble damages and seawater injection (Fig. 3 and 4).
(2) Basic tests for long-term structural integrity
A test to evaluate seawater components transfer behavior in the crevice structure of fuel components was carried out, and it was found that the seawater components did not concentrate in the crevice structure and it changed according to the salt concentration outside the crevice

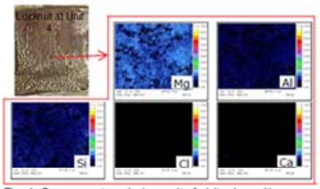


Fig. 1: Component analysis result of white deposition area of locknut at Unit 4

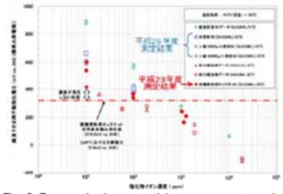


Fig. 2: Re-passivation potential measurement result on corroded crevice of locknut

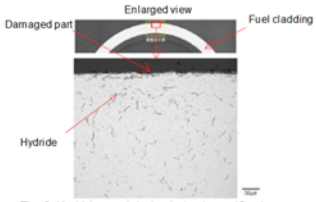


Fig. 3: Hydride precipitation behavior verification test result (Irradiated test piece: 300° C, cooling velocity: 0.04° C/h, stress in a circumferential direction: 70MPa, attached scratches and seawater, fixed rubble)

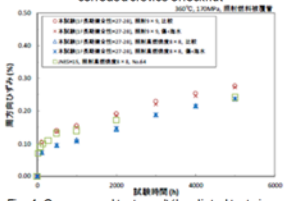
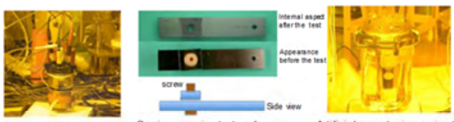


Fig. 4: Creep speed test result (Irradiated test piece: 360° C, stress in a circumferential direction: 170MPa, attached scratches and seawater, fixed rubble)

Implemented by
International Research Institute for Nuclear Decommissioning (IRID) (FY 2013 -)

2. Related projects
The following describes the results of previous related projects.
○ Evaluation of long-term structural integrity of fuel assemblies removed from spent fuel pool (FY 2012 - 2014)
(FY 2012, Fig. 0)
• A corrosion test and a strength test were conducted using the unspent materials collected from irradiated materials. With this, the necessary data was obtained for water quality as well as the impact of irradiation on the examination of the long-term integrity of fuel assemblies.
• The experiment confirmed that the possibility of corrosion, etc. was low under the environment with the actual machine, such as seawater and gamma ray irradiation.
(FY 2013 - 2014)
• Examination of the test conditions for the assessment of long-term integrity : A test plan was developed, including a transportation plan, material matrix, and test manuals for fuel members that had been relocated to the common pool (Fig. 1).
• Development of technology to assess long-term integrity: A corrosion test and a strength test were conducted to evaluate the impact of corrosion, such as debris and stress, with a specimen that simulates the fuel members. It was confirmed that no corrosion or deterioration in strength that could impact the integrity was found on the screw part or in the cladding tubes in the area to be assessed. (Fig. 2).
• Survey of condition of spent fuel stored in the common pool: The appearance of the fuel assemblies that had been relocated from Unit 4 was observed, and the oxide film thickness of cladding tubes was measured. No abnormal corrosion was observed in the spent fuel investigated (Fig. 3).
• Evaluation of integrity of fuel in dry storage: Assessment was conducted for the impact of hydrate separation behavior in cladding tube materials as well as the water content of debris on the integrity of the fuel assemblies during dry storage.
• Evaluation of seawater component transfer behavior on fuel components: Evaluation was conducted for the relocation of seawater component to the clad and the oxide film of cladding tube, etc.
• Evaluation of effect of corrosion derived from seawater or rubble components under radiation environment: An electrochemical corrosion test under the gamma ray environment and a corrosion test were conducted using a specimen with a combination of zircaloy and stainless steel (Fig. 4).



Electrochemical test of irradiated fuel cladding
Crevice corrosion test under gamma ray irradiation using no-irradiated test piece
Artificial seawater immersion test of irradiated fuel cladding
Fig. 0 Tests conducted in 2012

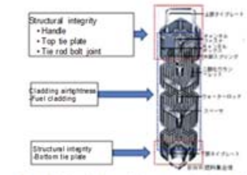


Fig. 1: Evaluation items for long-term integrity of fuel assembly removed from spent fuel pool during wet storage


Test piece of simulated upper part
Fig. 2: Appearance of locknut, etc. after corrosion test


Fig. 3: Appearance of top tie plate of spent fuel of Unit 4

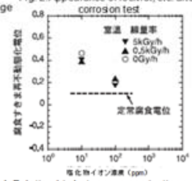


Fig. 4: Relationship between re-passivation potential for crevice corrosion in diluted artificial seawater and chloride ion concentration

FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017
	Evaluation of long-term structural integrity of fuel assemblies removed from the spent fuel pool					
				Evaluation of long-term structural integrity of the fuel assemblies removed from spent fuel pool		

Fig. 14-4-(1) Evaluation of long-term integrity of fuel assembly retrieved from spent fuel pool

Project objectives

It can be thought that the salinity is due to the seawater adhered to the fuel of the spent fuel pool, and there is also the possibility that some of the fuel has been damaged or leaked due to fallen concrete pieces, etc. For this reason, technical issues in the reprocessing of these fuels were investigated and examined, and the development of indicators to decide the necessity of reprocessing was also examined.

Project details and progress

(1) Evaluation of corrosive influence of impure substances on re-processing equipment
Corrosion tests (immersion, electro chemistry) was conducted on materials in high-level concentrated waste liquid storage tanksand high-level liquid waste storage tanks, using simulated high-level liquid waste solutions that took into account impurities and fission products, etc. Under all conditions, results showed that while there was uniform corrosion in the form of intergranular corrosion, pitting was not observed (Fig.1). Furthermore, an increase in chloride ion concentration was accompanied by a decrease in corrosion (Fig.2).

(2) Evaluation of in-process behavior of impurities
The extraction operation of impurity was conducted under the condition of coexistence with FP to check the impact of FP on the extraction of impurity. As a result, the distribution ratio of impurity was as low as 10^{-2} to 10^{-3} order (Fig. 3). In addition, the extraction operation of U and Pu was conducted under the condition of coexistence with an anion, with the possibility of obstructing the extraction of U and Pu, and the impact of the anion on the extraction of U and Pu was checked. As a result, it was confirmed that the distribution ratio of U and Pu would not be influenced by the anion.

(3) Evaluation of the influence of impurities on waste body
To determine the composition of waste solutions, a glass specimen was created from a formulation of powder materials with the major components of seawater and mortar added as impurities, and an evaluation of homogeneity and so on was then performed.
The result was that, under all conditions, there was no phase separation precipitation, and vitrification occurred (Fig.4).

(4) Identifying and outlining of other influences
The influences of the processing of damaged fuel in reprocessing facilities were comprehensively extracted, and the presence or absence of required research elements and the findings obtained in this research were summarized.

(1) RRP simulated waste solution (chloride ion 0g/l)
(2) RRP simulated waste solution + artificial seawater (chloride ion 20g/l)
Observation magnification: x50 (258x257μm)

Fig. 1: Surface observation result of immersion test piece of high-level liquid waste storage tank material

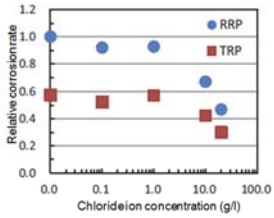
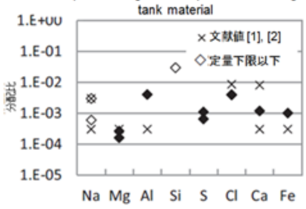


Fig. 2: Corrosion rate of high-level liquid waste storage tank material (relative corrosion rate: corrosion rate of RRP simulated solution containing no impurities is valued as "1")



[1]Data of Inorganic Solvent Extraction (1) JAERI1047
[2]PUREX Technical Manual (1980)

Fig. 3: Distribution ratio of impurity components under the condition of coexistence state with FP

Standard concentration
10x Standard concentration
100x Standard concentration

Fig. 4: Homogeneity results of glass specimens (visual observation)

Implemented by
International Research Institute for Nuclear Decommissioning (IRID)

FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018
		Study of Methods to Process Damaged Fuel Removed from the Spent Fuel Pool					

Fig. 14-4-(2) Investigation of method for processing damaged fuel removed from spent fuel pool

Project objectives

Concerning the contaminated water to be generated at the Fukushima Daiichi NPS, efforts are being made to remove the 62 kinds of nuclides, but tritium remains because it cannot be isolated. Therefore, verification tests on the technologies of isolating tritium were conducted. More specifically, to verify the performance of separation in the water with the tritium generated within the power station (6.3 x 10^6 Bq/L to 4.2 x 10^6 Bq/L (the concentration depends on the timing of sampling)), an arbitrary-scale facility was built and verification tests were conducted to assess the performance of separation, the construction cost and the running cost.

Project details and progress

An arbitrary-scale facility was built, and assessment of the performance of separation and costs, etc. in the actual plant was conducted as Category A (three projects), and assessment of the performance of separation and costs in the laboratory-level tests was conducted as Category B (four projects). In both cases, a variety of issues were found, and it was not possible to find technologies of separation that can be put into practical use immediately.

(1) Category A

[1] Kurion Inc.: Water and hydrogen isotope exchange method (Combined Electrolysis Catalytic Exchange (CECE) method))

- Based on the experimental data obtained from small tests and the building of a 1/10 scale (engineering scale) facility, the performance of separation in the actual plant was verified and the cost was estimated, etc.
- In a design assuming a processing capacity of 400 m^3/day and an separation factor of 284 (H-3 concentration in the effluent: 4.4 Bq/cc), it was estimated that the facility scale was 10,200 m^2, the capital cost was $891,400,000, and the operating cost was $1,157,500,000 (per 800,000 m^2 processing; the same applies hereinafter).
- The following issues were pointed out: there were variations, including instability and reproducibility in the test data; further data must be acquired to assess the performance; the assumed performance level in the design of actual plant is not obtained in the test plant; and the cost estimate related to the construction and demolition of the actual plant is thought to be underestimated.

Fig. 1: Kurion's test equipment

[2] RosRAO: Combination of the water distillation method and the CECE method

- Based on experimental data, etc. obtained from the construction of the actual-scale facility, the performance of separation in the actual plant was verified and the cost was estimated, etc.
- In a design assuming a processing capacity of 480 m^3/day and an separation factor of 500, the construction cost was ¥38,500,000,000, and the operating cost was ¥40,500,000,000.
- The following issues were pointed out: there is a need to clarify evidence data for the performance of separation, etc.; detailed investigation of mass balance including the amount of waste material on the concentration side is required; testing is required for long-term operation and process stability; and the cost estimation is considered to be underestimated.

Fig. 2: RosRAO's test equipment

[3] Sasakura Engineering: Low-temperature vacuum distillation method with catalyst function

- Based on experimental data obtained from the construction of an engineering-scale facility, the performance of separation in the actual plant was verified and the cost was estimated etc.
- In a design assuming a processing capacity of 400 m^3/day and an separation factor of 100, it was estimated that the facility scale was 15,000 m^2, the construction cost was ¥37,100,000,000, and the operating cost was ¥21,200,000,000.
- While it is recognized that the graduation pre-processing test data was properly indicated, issues including the following were pointed out: the test scale was small, an assessment in a one-stage larger test plant is required to upgrade the scale to that of the actual plant, and cost estimation needs to be carefully investigated in a larger-scale test.

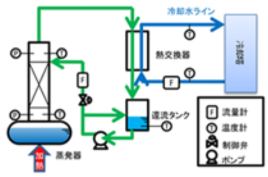


Fig. 3: Sasakura's test equipment

(2) Category B

[1] Sou Innovation: Two-stage gas hydride method

- A laboratory-scale test was conducted for a tritium separation method in solid-liquid separation through the separation of gas hydride crystals that contain only the water with tritium in its structure.
- As a result of examination with laboratory-scale test equipment of a reaction vessel of 500 ml, with tritium from the tritium-containing water in the first-stage separation processing reduction, a reduction in the tritium concentration was achieved with a maximum separation factor of 341. On the other hand, of the tritium separation processing in the two-stage gas hydride, there are still issues concerning the performance of second-stage separation processing, such as that it would theoretically have been difficult to prove the performance in this minimum-scale test equipment.

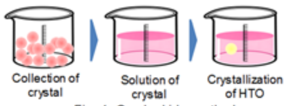


Fig. 4: Gas hydride method

[2] Toshiba Corporation: Multiple-stage crystallization method

- A laboratory-scale test was conducted for a method of incorporating tritium into ice based on the different freezing points of water and the water with tritium and removing the ice with the increased tritium concentration.
- As a result of the test using the tritium liquid, there is a possibility of obtaining 1.02 of tritium separation ratio per one-stage processing by setting the proper ice residence time. It was pointed out, however, that the performance of separation was low, and it cannot be said that this is an advantageous approach compared to existing methods, such as the water distillation and CECE methods.

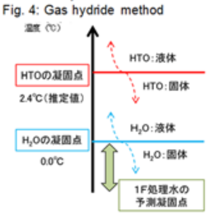


Fig. 5: Crystallization method

[3] Nextide: Multiple electrolytic cell-type electrolytic method

- A laboratory-scale test was carried out for a method of separation based on the differences in the carriage of hydrogen ions during electrolysis due to the different molecule sizes of the normal water that forms a cluster and the water with tritium that is thought to exist alone.
- An electrolysis test was conducted by simple cell with the water with tritium, and the separation factor of 1.015 was obtained. It was pointed out, however, that the uncertainty of data was high and that it is not clear whether tritium was selectively concentrated or depleted.

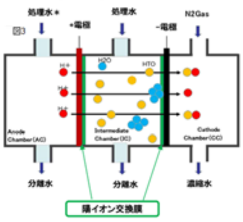


Fig. 6: Electrolytic method

[4] Hokkaido University: Electrolysis recombination method with fuel batteries

- A laboratory-scale test was conducted for the separation method based on the differences arising in the speed of the electrolysis reaction of ion-to-gas due to the mass number difference between light hydrogen and tritium.
- While it has been recognized as acquiring beneficial experimental data for the concentration of tritium in the fuel battery cell, issues including the following were pointed out: this experiment was carried out with heavy water whose concentration is higher than the tritium concentration in the water to be processed, and the applicability to isotope separation in a lower concentration region, such as the water with tritium in the Fukushima Daiichi NPS, has not been confirmed.

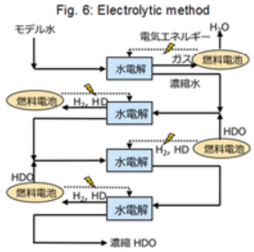


Fig. 7: Electrolysis recombination method with fuel batteries

FY2011	FY2012	FY2013	FY2014	FY2015	FY2016
			Verification tests of tritium separation technologies		

Fig. 14-5-(1) Verification tests of tritium separation technologies

Project objectives

In December 2013, as countermeasures for contaminated water at the Fukushima Daiichi NPS, the Japanese government compiled additional measures for the problems of decommissioning and contaminated water at the Fukushima Daiichi NPS of Tokyo Electric Power Company Holdings, Inc. Although it is stated in the document that the effects of additional measures are expected, in using technologies that require confirmation and verification, technologies with a high level of technical difficulty were verified, including seawater purification technology, technology of capturing radioactive materials in soils, decontamination technology for contaminated water storage tanks, and unmanned boring technology

Project details and progress

(1) Verification of seawater purification technology

- Demonstration tests were conducted to verify the performance of purification technology for the radioactive cesium and radioactive strontium, etc. in the seawater of the port of the Fukushima Daiichi NPS.
- Laboratory tests or tests with actual seawater were conducted for various adsorption methods with inorganic and organic materials (Fig. 1), and a certain level of removal performance was confirmed. It can be thought that the outcome of this project may be used in the case of rising radioactive materials concentration in the seawater of the port.

(2) Verification of the technology for capturing radioactive materials in soils

- Demonstration tests were conducted to verify the performance of the technologies for capturing radioactive materials (mainly radioactive strontium) in soils that is attributed to leakage of contaminated water at the Fukushima Daiichi NPS.
- Two types of permeable reactive walls were examined, and based on analysis, considering the simulation tests, soil quality conditions, and groundwater flow conditions, there is a possibility that the concentration of radioactive strontium in the groundwater can be reduced.

(3) Verification of the decontamination technology for contaminated water storage tanks

- For the spent flange type tank to be generated after the replacement with welded type tanks, demonstration tests were conducted to verify the performance of decontamination methods before demolition (Fig. 2).
- Tests were conducted in three approaches under the concept of neither generating nor increasing liquid waste. This confirmed the remote operability and decontamination performance, and a decontamination work plan was proposed based on the results.

(4) Verification of unmanned boring technology

- For boring, which will be indispensable at the Fukushima Daiichi NPS in the future, demonstration tests were conducted to verify the performance of unmanned boring under a high-dose environment from the viewpoint of reducing the exposure of workers.
- A remote boring system with a satellite communication network was developed and the feasibility of unmanned boring technology was confirmed through actual excavation work. Based on the test, issues during work within the power station premises were identified.

Fig. 1: Adsorption performance test (case of adsorption fiber)

Fig. 2: Decontamination verification test

Implemented by

Mitsubishi Heavy Industries, IBC Advanced Technologies, Inc. Obayashi Corporation, the ATOX and AREVA NC and the AREVA ATOX D& D Solution, JGC Corporation (verification of seawater purification technology)

The ATOX and AREVA NC and the AREVA ATOX D&D Solution, JGC Corporation (verification of the technology for capturing radioactive materials in soils)

IH Corporation, Obayashi Corporation, and Kobe Steel (verification of the decontamination technology for contaminated water storage tanks)

Obayashi Corporation (verification of unmanned boring technology)

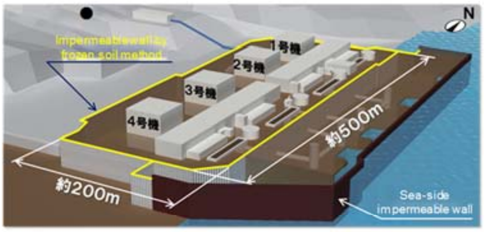
FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018
			Verification of technologies for contaminated water treatment (FY2014–FY2015)				

Fig. 14-5-(2) Verification of technologies for contaminated water treatment

Project objectives

To control the amount of groundwater flowing into the buildings at the Fukushima Daiichi NPS, a technology was established to surround the buildings with large-scale frozen solid impermeable walls (frozen soil walls).

Project details and progress



(1) Implementation period: from October 2013 to March 2021

(2) Project operators: Tokyo Electric Power Company Holdings, Inc. and Kajima Corporation

(3) Objectives of frozen soil walls

• To control increases of the contaminated water due to the inflow of groundwater into the buildings by installing frozen soil walls around the buildings where contaminated water has been stored.

• To control the water levels inside and outside the buildings with recharging (water injection) to prevent from leaking the stagnant water outside the buildings after the installation of frozen soil walls.

• To limit the spread of leakage with the shielding effect of frozen soil walls during the period when the frozen soil walls are sound, even in cases of leaking the stagnant water outside the building.

• For the research period of this project, even after the operation period, it should be possible to maintain the function of facilities through maintenance, replacement, and other responses.

(4) Overview of frozen soil walls

Land-side impermeable walls based on the frozen-soil method can shut out the flow of groundwater with the frozen construction methods, maintaining a high impermeability. More specifically, coolant (brine, about -30° C) that was cooled in refrigerating machines and cooling towers is pressurized and sent in the brine relocation tubes to be circulated through underground frozen tubes, which will freeze the ground in the surrounding area. The total length is about 1,500 m, and the prepared amount of frozen soil is about 70,000 m³, with 1,568 frozen tubes and 359 temperature measurement tubes to be installed.

(5) Water injection system inside the frozen soil wall

As a supplementary system to prevent the contaminated water from the building from flowing underground, 33 holes of water injection wells are arranged on the inner side of frozen soil walls, and water is injected into the ground as needed to keep the groundwater level around the buildings higher (by 80 cm) than the level of water in the buildings. Observatory wells for groundwater level are installed at 82 locations.

(6) Long-term operational system

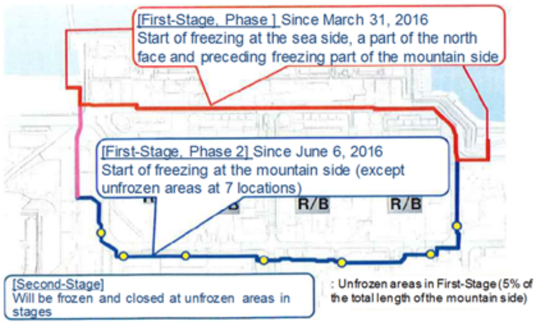
As to the maintenance of the function, it is said that stable operation will be possible for a long time with the replacement of brine (coolant), frozen tubes, and piping as needed. The frozen tubes have a triple-tube structure so that they can be replaced. Leakage detectors were installed inside the protective tubes.

(7) Soil temperature measurement system

Soil temperatures at 359 locations are controlled to maintain the preparation of frozen soil. Instead of conventional platinum thermometers, optical fiber thermometers are used to work out the complication of construction and systems.

(8) Details

June 2, 2014: Start of excavation for frozen tubes
April 30, 2015: Start of test freezing at 18 locations on mountain side
July 17, 2015: Completion of installing all 33 holes for recharge (water injection) wells
July 31, 2015: Approval for the execution of penetration work of buried materials for sea-side frozen tubes.
November 9, 2015: Completion of the positioning of piles of all 1927 frozen tubes and temperature measurement tubes
January 7, 2016: Completion of the installation of brine tubes
February 1, 2016: Completion of the fulfillment of brine for all 1568 frozen tubes
March 31, 2016: First-Stage, Phase 1: Start of freezing at the sea side + part of the north side + the mountain side, where it will be frozen with priority
June 6, 2016: First-Stage, Phase 2, Start of freezing on mountain side (except unfrozen areas at 7 locations)
December 3, 2016: Second-Stage, Start of freezing at 2 unfrozen areas on the mountain side
March 3, 2017: Second-Stage, Start of freezing at 4 unfrozen areas on the mountain side
May 22, 2017: Start of partial maintenance management operation
August 22, 2017: Third-Stage, Start of all freezing
November 13, 2017: Expansion of partial maintenance management operation



(9) Status of preparation of frozen walls (Committee of Contaminated Water Measures, March 17, 2018)

[1] The preparation of frozen walls was completed, except the areas in depth, judging from the status of temperature measurement tubes and the water levels inside and outside.

[2] The impact of unfrozen areas in depth on the control of groundwater level within frozen soil walls seems minor. However, it is reasonable to promote freezing with a supplementary construction approach to take all possible measures for impermeability.

(10) Status of development of frozen soil walls (Committee of Contaminated Water Measures, March 17, 2018)

[1] Although the groundwater levels around the buildings are controlled at higher levels than the water level from the viewpoint of preventing water leakage in the building, they are being managed stably at low levels due to the water-impermeable effect of frozen soil walls. Combined with the effect of sub-drains, it is recognized that inflow into buildings is controlled.

[2] With the control of inflow into the building as well as a large reduction in the amount to be transferred to the building from the area of T.P.2.5m, the amount of contaminated water to be generated was reduced to about one fourth.

[3] In addition, the water-impermeable effect of frozen soil walls is found in the reduction of the amount of sub-drain pumped up and the amount of groundwater pumped up in the area of T.P.2.5m.

2. Related project

(1) Implementation period: From August 2013 to March 2015

(2) Name of project:

FY 2013 infrastructure development project of the decommissioning and safe technology for nuclear reactor power (Feasibility study project for the water-impermeable technology with frozen-soil method to control the inflow of groundwater)

(3) Operator:

Kajima Corporation

(4) Objectives:

• To verify the feasibility of impermeable walls with the frozen-soil method at the Fukushima Daiichi NPS

• To obtain the necessary data for the construction execution plan and the construction execution management on the premise of long-term use

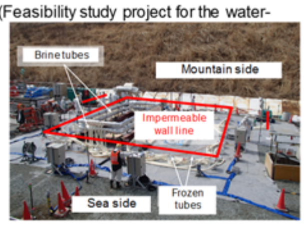


Fig. 14-5-(3) Large-scale verification of impermeable walls (frozen wall)

Project objectives

The conventional Advanced Liquid Processing System (ALPS, reducing the 62 types of nuclides from the contaminated water to less than or equal to the regulatory concentration), in which radioactive materials are removed from the contaminated water in the tank, generated a large amount of slurry waste due to the pre-processing (iron coprecipitation processing and carbonate sedimentation processing) by the injection of liquid reagent. However, development and demonstration was performed for high-performance equipment (high-performance ALPS) that reduces more than 80% of the waste by adsorbing radioactive materials effectively to filters and adsorbents.

Project details and progress

(1). Laboratory test to verify the performance of removal

- With a test tube-scale laboratory test using the actual contaminated water, a filter technology and high-performance adsorbent with longer life were carried out. The results of the laboratory test showed higher removal performance in most parts compared to other existing nuclide removal equipment. In addition, the policy of adsorption tower configuration after the verification test was decided based on the test results.
- With the actual liquid test and a laboratory test, the characteristics of crevice corrosion resistance were assessed for the materials for practical application and several candidate materials. In immersion tests with the actual liquid of about two months, no corrosion was found in the two-phase stainless steel welded specimen, and in the assessment of the corrosion initiation life of the two-phase stainless steel welded part through an accelerated test, it was estimated that even with the water containing 6,000 ppm of chloride ion, if it is neutral, corrosion resistance can be performed 76 years or longer.

(2). Verification of the performance of removal using a test equipment close to the actual device, etc.

- Using a 1/10 scale test equipment of the demonstration plant (Fig. 1), the removal performance of the adsorbent, the validity of the removal process, the amount of waste to be generated, and the properties of waste were verified. As a result, issues including the following were found: (1) the performance cannot be sustained for long in the Cs and Sr adsorbent, and (2) the decontamination factor (DF*) of Cs and Sr adsorbent (after the second tower) was low. It was decided that the factors causing these issues would be analyzed using the demonstration plant because there was no impact of the scale.

*DF: Decontamination Factor)

Fig. 1: Verification test equipment

(3) Confirmation of removal performance with the improved ALPS developed, etc.

- A demonstration plant (500 m^3/day: Fig.1) was designed, manufactured, and installed, and the performance of the removal of nuclides was examined. It is a system consisting of a total of four filters in total (of which three are chloride filters) and 20 adsorption towers, including seven to eight towers of developed Cs and Sr adsorbent materials.
- The following new issues were found in addition to the issues obtained from the verification test: (1) as above, in the Cs and Sr adsorbent, the performance cannot be sustained for long; (2) the Decontamination Factors of the second through fifth towers of the Cs and Sr adsorbent are low; and (3) the Decontamination Factors of the sixth through eighth towers of the Cs and Sr adsorbent are low. In response to this, the analysis of factors through laboratory-scale basic testing, the planning of measures and the verification of measures by a demonstration plant was conducted repeatedly.
- It was revealed that it was possible to sustain the performance in the adsorbent for longer by adjusting the condition of feed liquid (pH) to Cs and SR adsorbent as an appropriate alkali condition. Therefore, for Issue (1), measures were taken by adding alkali after the carbonate ion removal with the addition of acid in the supply tank and before the liquid supplied to the adsorption towers of Cs and Sr adsorbent in the initial stage of the system.
- Actual contaminated water contains a chelate component, forming the complex with a part of Sr, which was considered to be the cause of the low decontamination factor of Sr at the mid-stage adsorption tower in Issue (2). In response to this, countermeasures were taken with the dissociation of the complex by making it acid at the mid-stage of the system.
- The processed water that had once been converted into acid by the countermeasure for Issue (2) is readjusted to alkali or neutral at the latter stage of the system. This was taken as the countermeasure for the declining decontamination factors in Issue (3).
- With the abovementioned measures, within the period of project, the Sr concentration at the exit of the system was less than or equal to the regulatory concentration, and a total of more than 34,000 tons of contaminated water was processed. In addition, it was confirmed based on the life of adsorption tower that more than 80% (at that time) of the amount of waste to be generated could be reduced.

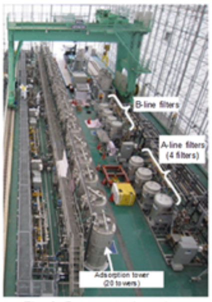


Fig. 2: Demonstration plant

Implemented by

Tokyo Electric Power Company Holdings, Inc., Toshiba Corporation, Hitachi GE Nuclear Energy

FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018
		Development and verification of high-performance multi-nuclide removal equipment (high-performance ALPS					

Fig. 14-5-(4) Development and verification of high-performance multi-nuclide removal equipment (high-performance ALPS)

Attachment 15 Basic Direction of 6 Essential R&D Themes

December 12, 2017

Nuclear Damage Compensation and Decommissioning Facilitation Corporation (NDF)

The Basic Direction of 6 Essential R&D Themes

The Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station (September 26, 2017) specifies enhancement of the activities for matching the R&D required for decommissioning (Needs) with the basic and fundamental R&D (Seeds) and for human resource development. It also specifies enhancement of the functions of Japan Atomic Energy Agency's Collaborative Laboratories for Advanced Decommissioning Science (JAEA/CLADS) and promotion of joint researches with domestic and international universities and researching institutions to establish the international decommissioning research center with concentrated wisdom.

Following the above, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) states in its budget request for FY2018 that they will reform the Center of World Intelligence Project for Nuclear Science and Technology and Human Resource Development ("World Intelligence Project") into a subsidy program intended for JAEA/CLADS and the program will be implemented under the system centered by JAEA/CLADS from the newly adopted proposals from FY2018.

On the occasion of this reform, MEXT showed NDF their intention to discuss how to proceed with the future R&D of the World Intelligence Project. This includes selection of the theme for the call for proposal considering the Essential R&D selected by the task force from the viewpoint of promoting basic and fundamental researches with satisfactory understanding of the Needs.

Therefore, concerning the 6 Essential R&D Themes which are described in the interim report of the Task Force on Research Collaboration (November 30, 2016), the Basic Direction of the 6 Essential R&D Themes was compiled including the background of the issues, the problem consciousness, and the expected research image, with consulting the discussions in the working group for each theme.

Theme	(1) To identity process of characteristic change in fuel debris over time
"Descriptions / Background issues" on the interim report	The fuel debris retrieval is scheduled for 2021 onward, 10 years after the fuel debris production. And since it is anticipated that the retrieval will require a long period of time, the fuel debris will remain inside the reactors over 10 years. In addition, the retrieved debris must be stored safely. Choosing the best possible methods of retrieve/transmission/storage of fuel debris requires predictions of characteristic changes of fuel debris over time.
Basic direction	In relation to the accident of Chernobyl nuclear power plant, detection of particulates of the micron order which contain fuel components from around the fuel debris has been reported and the national report of the Ukrainian government showed concerns about the increase risk of radioactive dust emergence over time through self-decay. One of the possible reasons is that the fuel debris with high radioactivity exposed to rich humidity caused rapid progress of aging which quite slowly proceeds with normal uranium mineral in the geological environment. It

	results in oxidation activated by radioactive dissolution and generate hexavalent uranium compound. On the other hand, because the PCV of the Fukushima Daiichi NPS (hereinafter referred to as "1F") is currently in the nitrogen atmosphere under subtle positive pressure, oxidation is unlikely to proceed immediately. In the future, such an event similar to the above may occur because the air that contains oxygen may flow into the PCV when a negative pressure control is applied to retrieve the fuel debris. Since the radiation level is about one order higher in 1F than that of the fuel debris in the case of the Three Mile Island Unit 2 (TMI-2) accident (occurred in a short time after the operation started), it is under unexperienced condition. In addition, it should be noted that it will take a longer period to complete the retrieval of the fuel debris from the time of accident than in the case of TMI-2. Various factors are involved in the aging of such fuel debris in addition to the oxidation described above. Roughly classifying, those factors may include the chemical mechanism (oxidation-reduction, leaching of included components, changes in the chemical form or the phase state, etc.), physical mechanism (structural or characteristic changes by heat cycle etc., irradiation damage by α-ray), and coupled actions of these factors. Since decay or leaching of fuel debris due to aging lead to emission of FP particles or gas, or effluent of particles that contain α-nuclides that are confined in the fuel debris, they have significant impact on the system design and procedures. It includes the retrieval mechanism, the cooling and circulating system, the containment function, the criticality monitoring system, the PCV gas control system, exposure evaluation, containing, transferring and storing, and processing and disposal. In particular, as for the Mid-and-Long-term Roadmap, while the processing and disposal method of the fuel debris will be decided in the third period (from 2022) after the retrieval of the fuel debris is started, obtaining the aging information of the fuel debris is an urgent issue. While taking into consideration the permission and authorization about the safety regulation, to provide sufficient prediction and explanation of the risk changes resulted from the aging of the fuel debris, it is required to clarify the real situation of what are expected to have critical impacts on the decommissioning works preferentially. Therefore, it is necessary to build a fundamental theory of the aging model by clarifying the aging process while using the current knowledge of the actinoid chemistry. To do so, demonstration test should be performed using real uranium according to the matrix pattern of parameters (temperature, pH, etc.) to collect basic data, and it needs to establish the prediction method of aging. In this case, it is important to maintain the foundations for advancement of the actinoid chemistry, which provides the basis for examination of the physical property of fuel debris. In addition, heat analysis for 1F should be included in the basis of investigation since the temperature distribution of the fuel debris has to be understood by calculating the heat distribution and the impact of regional temperature rise due to the decay heat should also be required to be examined.

Theme	(2) To elucidate corrosion mechanisms under unusual/extreme circumstances
"Descriptions / Background issues" on the interim report	It is required to collect data on corrosion under a variety of circumstances with consideration of the circumstances specific to 1F decommissioning such as high radiation levels and unsteady routes of cooling water in order to prepare for potential corrosion during decommissioning.
Basic direction	A boiling water reactor (BWR) consists of various metallic material. While stainless steel, which is corrosion resistant, is used inside reactor where it is high temperature and high oxidizing environment, carbon steel, which is not corrosion

	resistant, is used for the PCV that is the confinement boundary and is assumed to be used in the normal atmosphere. On the other hand, substantial knowledge has been collected so far about corrosion of structure and piping for commercial electric generation reactors, and especially, data has been collected being focused on the corrosion data in the environment of high radiation, high temperature, and deionized water for the operation of BWR. However, after the accident, 1F has been in a special environment with high radiation, room temperature, suspended solids and deposited materials. The knowledge about such environment is not sufficient. Since water has been injected into PCV to cool the fuel debris, carbon steel is dipped in the water. In addition, it is known that chemical species of oxidation nature such as hydrogen peroxide and various radical species have been generated through radiolysis of water. Currently, since nitrogen has been injected into PCV to prevent hydrogen explosion and the oxygen density has been decreased, the densities of the oxygen and the hydrogen peroxide are considered to be decreased in the water and corrosion of PCV is also considered to be suppressed in some degree. In the future, since the air containing oxygen flows into PCV when a negative pressure control is applied to retrieve the fuel debris, it is important to maintain soundness of the structure and pipes that form the boundary for confinement of radioactive materials and it is also important to prepare countermeasures based on the knowledge on corrosion in such environment. Since the corrosion is essentially a kind of battery reaction, it is likely to happen if the electric conductivity of water raises, pH falls, and the electric potential raises under the condition of declining of surrounding water quality. Although corrosion has been suppressed by nitrogen injection in general, it is still under the condition of potential corrosion. Regional changes of the environmental condition may lead to an increase of corrosion speed at the part. It is quite a special environment surrounded by various factors that promotes corrosion such as a formation of liquid film of dew, a humid environment that repeats wet and dry conditions near the water surface, an irregular flow of cooling water, convection flow, or backwater due to irregular paths created by gaps between various shapes of fallen objects or deposited materials, a progress of corrosion on the anode side between different kinds of metals touching each other, a progress of acid-base reaction by microbes, or any other potential factors. In the future, further changes may occur in the internal environment when the air that contains oxygen flows into the PCV when a negative pressure control is applied to retrieve the fuel debris. Since the corrosion progresses over time during the decommissioning works under the special environmental conditions, estimation of corrosion phenomenon and investigation of countermeasures are required based on the consideration on the environmental changes resulted from the progress of the decommissioning process. Therefore, it is necessary to collect basic data related to the progress of corrosion phenomena and systematically clarify and understand the phenomena in order to provide satisfactory prediction and explanation of the risk changes that follow corrosion of structures taking the permission and authorization of the safety regulation into account with giving priority to the factors of higher needs that may have critical impacts on the decommissioning works from the viewpoint of the probability of occurrence such as the factors above and the impacts on the functionality (parts and severity), the scale and the timing. In this case, in order to examine various approaches including not only the use of existing anti-corrosive agents but also electric protection, it is important to accumulate and maintain the knowledge related to the corrosion phenomena in addition to the electronic state

	of materials in a special environment through principle analysis and clarification of the corrosion progression mechanism.

Theme	(3) Radiation measurement technologies adopting innovative approaches
"Descriptions / Background issues" on the interim report	The radiation levels are still extremely high inside the 1F reactors/buildings due to the accident and the existing measurement devices do not meet the capability/functional requirements to provide accurate figures. It is vital to develop an innovational device adopting brand-new ideas/principles based on 1F needs.
Basic direction	Currently, radiation measurement can be performed following a predefined operation procedure without detail knowledge of measurement since a number of radiation measurement products using various principles or materials including ionization chambers, counting tubes, semiconductor detectors, and scintillation detectors are already offered. However, it is very important to develop the human resources for measurement since it is necessary to understand the principles of the equipment in order to interpret the measurement data and address possible troubles such as the case of the disorder (inversion of data value) between the all β-radioactivity value and the value of Sr-90 because miss-counting has not been taken into account for the resolution time in the analysis of the sampled water at the under-ground water observation hole on 1F. In addition, general radiation measurement products are not able to offer satisfactory performance and functionality to inspect the conditions inside reactors and buildings at the decommissioning site of 1F. The decommissioning works on 1F must be performed by remote operation since the radiation level is extremely higher than the one in the work environment of existing nuclear facilities. It is necessary to develop highly radiation resistant and small sized measurement sensor, electronic circuits, and systems in order to be remotely operated. In addition, it is necessary to research on the basic mechanism related to radiation damages of materials in order to develop highly radiation resistant sensors and circuits. As for the specific examples of sensor development, it is necessary to develop measurement devices of neutron from the viewpoint of criticality prevention, real time measurement of α-ray from the viewpoint of identification of the fuel debris, and γ-ray measurement with high energy resolution for nuclide estimation under the background of high gamma radiation, those what satisfy various needs: radiation resistance, noise resistance, size (small size), counting rate and responsiveness, high radiation resistance, energy discrimination, space resolution (identification of radiation source position), ease of operation, and maintainability. As for the composition of the measurement targets, development of the technology so-called "on-site analysis" is required since there are needs of functions that can be used to analyze the target without transferring a sample to other facility or equipment and obtain rough results used to promptly judge if the target is debris or not, and if the target is debris, the function to judge co-existence of reactor internals and neutron poison is required. In addition, effective support tools for the decommissioning can be provided by developing the technology to visualize the radiation field and the contamination situation and clarify the profile of the fuel debris based on the information of the strength and the direction of the radioactive sources. It is necessary to develop the generic technologies for innovative measurement of radiation using new ideas and principles by considering on-site measurement requirements.

Theme	(4) To clarify behavior of radioactive airborne particle generated during decommissioning (incl. α-dust treatment)
"Descriptions / Background issues" on the interim report	As thermal cutting of the fuel debris via machine or Laser may produce a large amount of α-dust, it requires safety measures and dust confinement solutions. It is necessary to understand physical/chemical properties of α-dust, to predict the amount of dust to be produced for each method, and to consider how to seal the dust according to the results in order to make sure the retrieval will be conducted in a safe and effective manner.
Basic direction	As the fuel debris retrieval work will start, cutting the fuel debris will create a lot of radioactive airborne particles (α-dust) that contain α-nuclide and they will be dispersed within the boundary. When retrieving the fuel debris, since the work will be performed in the confinement boundaries which are the broken buildings, it is important to understand the property of the α-dust for studying how to secure the confinement capability, designing the filtering system, and performing the exposure evaluation of the surrounding environment and workers including the time of accident. With regard to the data about the scattering rate when α-dusts are generated, there is the data obtained at the decommissioning of JAEA's JPDR and the dismantling of glove box of JAEA's Nuclear Fuel Cycle Engineering Laboratories. However, the data has not been collected just for the nuclear fuels but collected for the objects polluted by the nuclear fuels, and the data has been collected for the amount of the radioactive materials and their densities from the viewpoint of radiation exposure control and it is not systematically organized. On the other hand, the radioactive airborne particles in 1F will be generated directly from the fuel debris when retrieving the fuel debris and from the polluted objects in the decommissioning process. The types of radioactive materials are α-nuclides and β (ϒ)-nuclides. While the α-nuclide of which typical element is plutonium is important from the viewpoint of internal exposure, the β(ϒ)-nuclide such as cesium should be well considered as well from the viewpoint of the total exposure evaluation. In order to study on collection of radioactive airborne particles, efficient filtering and purification, criticality prevention, etc., it is necessary to grasp the amount of generated particles, distribution of particle diameters, radioactive diameters, and the physical and chemical property of particles according to the differences of the target objects and the method of cutting. It is also important to understand the behavior of the generated particles in the gas phase, at the air-liquid interface, and in the liquid phase during transportation or transition. For example, it is important to understand the growth of particles through coagulation in the gas phase, evaluation of mist generation from the air-liquid interface, leaching behavior of the components into the water of the liquid phase, transportation behavior such as settling of particles in the water or filtering, etc. With regard to the exposure evaluation of radioactive airborne particles, it is important to evaluate the impact of exposure to radioactive materials derived from the fuel debris, especially the one of α-nuclides. In this case, it is important to decide whether the conventional exposure evaluation methods can be applied by judging if the chemical form and the particle diameter of the radioactive airborne particles represented by plutonium is consistent with the ones that have been used as the criteria of internal exposure evaluation for plutonium.

Theme	(5) To understand fundamentally mechanisms of radioactive contamination
"Descriptions / Background issues" on the interim report	To figure out the mechanism of radioactive contamination towards effective decontamination; it is critical to implement effective approaches of decontamination based on the mechanism of the contamination to radiation sources, and to decrease the volume of radioactive wastes as well.
Basic direction	With regard to reduction of the radiation in the buildings, the target object of decontamination are pipes and ducts, metals in the equipment, resins in cables and so on, paints, and concretes of the walls or floors. The contamination source includes molten high temperature fuels at the time of accident, steams that contain radioactive materials such as Cs leaked in consequence of hydrogen explosion and so on, dusts and contaminated water that contain radioactive materials. Currently, as for radiation reduction in the buildings on 1F, decontamination of floors and walls has only limited effects since there are other contamination sources such as objects remained in pipes, and hidden side behind the pipes located at high inaccessible positions. In the future, when considering each step in the long decommissioning process, it is expected that many situations that require decontamination will arise, therefore, effective and efficient decontamination is considered highly necessary. With regard to decontamination, not only reduction of radiation but also reduction of wastes should be taken into consideration. For decontamination, while engineering approaches are required, including physical methods such as dry ice blast, chemical methods such as chemical decontamination using chemicals such as acid or alkali, and decontamination methods using parting agents, it is indispensable to understand the contamination mechanism of target objects in order to perform such decontamination activities effectively. In the field of researches for clarifying the contamination mechanism, there are a sufficient number of existing researches on the metal materials, which are used in pipes, tanks and so on to confine radioactive materials. However, there is almost no research on the concrete of structures or radiation shields that does not directly touch radioactive materials. The inside the buildings of 1F is widely contaminated by the radioactive materials emitted by the accident. Since most parts of the buildings consist of concrete, it is important to clarify the contamination mechanism of both concrete and radioactive materials in principle in order to reasonably and effectively manage concrete wastes resulting from the decontamination and the process of decommissioning. Therefore, the contamination mechanism must be clarified in principle on the concrete exposed to the accident and the subsequent environment and the process of decommissioning by obtaining the basic data about sorption, penetration, and leaching of the typical nuclide (Cs, Sr, U, Pu, etc.) that should be well considered. In addition, from the mid-and-long-term viewpoint, it is necessary to establish the evaluation method based on the understanding of the contamination mechanism including the changes over time in the contamination state and the penetration behavior in the concrete. Even though a number of researches have been conducted on removal of contamination source in pipes during nuclear fuel reprocessing regarding the contamination mechanism of the metal of the piping and equipment by radioactive materials, few number of researches are found on the contamination mechanism of the metal of the piping and equipment in the environment of the 1F. While it is considered necessary to clarify the contamination mechanism inside PCV or RPV exposed to the high temperature environment at the time of accident, it is not necessary to take into consideration a special contamination mechanism such as penetrate into metals outside PCV. As for the decontamination mechanism of

	resins and paints of cables, it is considered that it not necessary to conduct a special research on decontamination since they can be replaced or removed.

Theme	(6) Environmental fate studies of radioactive materials generated during decommissioning
"Descriptions / Background issues" on the interim report	It is essential to clarify the behavior of radioactive materials such as adsorption, dispersion, moving along with groundwater flow in shallow underground in order to conduct environmental fate studies to ensure they will not affect the environment.
Basic direction	In order to properly evaluate and reduce the risk of future environmental impact caused by radioactive materials in the Fukushima Daiichi NPS site, it is necessary to provide proper evaluation and estimation of the environmental fate of radioactive materials around the site via the shallow underground water and the surface water, or the ports, the marine, and the air, and to provide appropriate environmental countermeasures. Targeted radioactive materials are (1) the radioactive materials that exist in the ground or on the surface of the ground through the contaminated water leaked just after the accident (^{137}Cs, ^{90}Sr, ^{3}H, etc.), (2) the radioactive materials that poured into the ports in past and accumulated on the bottom of the sea (^{137}Cs, ^{90}Sr, etc.), and (3) the radioactive materials that are contained in the contaminated water that will be generated as the result of retrieval of the fuel debris or decommissioning and dismantling of the buildings (including ion such as actinide and suspended solids) that can be the future source term impacting environment. In order to estimate the impact of radioactive materials on the surrounding environment, it is indispensable to understand the existence form and the transport behavior of the radioactive materials as the required basic knowledge. Specifically, the targets include the existence form of the radioactive materials in the underground water, the distribution in the soil, the advection and diffusion behavior in the underground water, the existence form and the advection and diffusion in the surface layer, the existence form and the molten and diffusion behavior of the radioactive materials in the seawater in the port and on the bottom of the sea, and the transportation behavior to the surrounding environment through marine or air. Although all of those depend on the characteristic of the intermedium such as the property of soil and the geological condition, since the measurement work on 1F is limited, it is necessary to aim at establishing the evaluation method in a similar environment. In addition, in order to provide the accurate future estimation of the environmental fate, it is also necessary to develop the monitoring technology to identify the accurate contamination condition and the analysis technology to simulate the transportation behavior of the radioactive materials. As for the monitoring technology, the technology for long term and continuous remote measurement and the mapping and behavior identification technology using the big data are expected. As for the simulation technology, the creation model that can be used to analyze the behavior (influence of unsaturated layer, kinetic evidence, etc.) specific to shallow underground and the estimation technology using the code are expected. It is also important to aim at reducing the risk of the radioactive materials as environmental countermeasure. While a number of technologies can be developed including control of the amount of underwater, soil improvement, stabilizing agent, adsorbent for purification of contaminated materials, and the

	permeable reaction wall, it is necessary to examine the factors that have priority since they may have critical influence on the decommissioning works. In order to provide reasonable environmental fate studies for the radioactive materials, it is important to proceed with considerations on the risk of environmental influence so the development of the evaluation method related to the risk of environmental influence has to be taken into account from this viewpoint.

Attachment 16 Record of collaborative activities with foreign organizations

Activity	Contents	Participating Organization
IAEA Project		
The 4th IAEA Review Mission	・International review was made by accepting IAEA inspection team regarding decommissioning efforts of Fukushima Daiichi NPS (November 2018) ・The received final report was released received in January 2019.	METI NDF TEPCO IRID JAEA
IAEA side event	・Side events are held every year along with the IAEA General Conference and explanation of the latest progress in decommissioning was made in order to gain an understanding of the Fukushima Daiichi decommissioning. ・In the 62nd IAEA General Conference, description videos for the current status of the decommissioning and contaminated water management were presented at the Japan booth while holding the side concerning the present situation of Fukushima Daiichi. (September, 2018) ・In the 63rd IAEA General Conference, description videos for the current status is planned at the Japan booth and the side event on Fukushima reconstruction and food safety of Fukushima Daiichi will be held. (September 2018)	METI NDF TEPCO IRID (for data provision)
DAROD	・Knowledge and experience obtained from the efforts on challenges of decommissioning and recovery of damaged nuclear power facilities (regulations, technologies, systems, and strategies) are shared among the relevant countries.	NDF
CRP T13015	・Sharing information regard to the management of severely damaged spent fuel and corium	IRID JAEA
OECD/NEA Project		
Symposium on Decommissioning and Food Safety of Fukushima Daiichi NPS	・This symposium was held for the purpose of sharing the efforts of safety management on food in regions affected by radioactive materials including Fukushima as well as cultivating a better understanding of current decommissioning status and food safety of Fukushima Daiichi NPS for food safety experts from each country, (March, 2019) ・A reception making use of ingredients produced in Fukushima was also held after the symposium.	METI MAFF TEPCO
Dialogue with government on industrial clusters by ORCD	・From the point of view of whether it may contribute to promoting industrial cluster in Fukushima, a dialogue with government was made concerning industrial clusters. A side event is scheduled to be held with the attendance of invited the local officials by utilizing network of OECD and collecting referential examples. (The 1st event held in February 2019, The 2nd event in September 2019).	METI
BSAF	・Research organizations and governmental organizations from eleven countries joined to conduct benchmark study using severe accident analysis codes developed by these organizations to find out how the accident in the Fukushima Daiichi NPS	JAEA IRID TEPCO

	progressed and how the fuel debris and FPs spread inside the reactors. Knowledge and findings related to the modeling of phenomenological issues obtained by member countries' organizations are being utilized. ・Data measured during the accident and information database regarding the post-accident radiation levels are shared.	
PreADES	・Sharing characteristics information that helps to understand properties of fuel debris such as its phase state and composition. ・Enhancing "Fuel debris Analytical Chart" that summarizes needs and priority of fuel debris analysis. ・Maintenance of tasks after analysis and analysis facility information	METI NRA IR JAEA IRID NDF TEPCO
WGAMA-LTMNPP	・Regulations and standards in various countries and operators' efforts are shared and summarized on how to ensure safe and stable status in the nuclear power plants in which fuel remains after severe accidents.	NRA NDF TEPCO
TCOFF	・In reference to the accident progression of the Fukushima Daiichi NPS, (1F) advancing molten core and molten fuel models, FP migration behavior model and thermodynamic database as their basis. Based on the material scientific knowhow, evaluating details of molten core and fuel on condition of 1F accident, and characteristics of fuel debris and its producing mechanism. Then, providing material scientific knowhow and result of detail evaluations to international cooperation project including PreADES, ARC-F, TAF-ID, and domestic decommissioning project like IRID. ・Project budget for 2017 to 2019 was contributed from MEXT.	MEXT JAEA IR Tokyo Institute of Technology
EGFWMD	・Expansion of knowledge for waste management and decommissioning at the Fukushima Daiichi NPS ・Advice to Japan's R&Ds regarding waste in the Fukushima Daiichi NPS	NDF
NEST	・Establishing international network among universities, researching institutions and industries in each country through executing projects which young researchers and engineers participate in. ・Practical education on interdisciplinary science technology that focused on advanced remote operation technology by inviting young researchers and engineers.	JAEA The University of Tokyo
EGCUL	・Discussing on characterization method for waste from unknown derivation	METI NDF JAEA TEPCO
TAF-ID (reference)	・Maintenance and enhancement of thermodynamics on Atomic Fuel database (TAF-ID) for advanced fuel and damaged fuel and its application ・TCOFF is used for analysis as a major user of TAF-ID Database. Conversely, knowhow from TCOFF is used for advancement of TAF-IS Database.	JAEA IR

Inviting International Expert		
International Special Advisors (NDF)	・To integrate and utilize a wide range of wisdom and knowhow, NDF invites the experts in strategy development, R&D, program/project management and safety regulation as the International Special Advisors from UK, US, France, and Spain. ・ISA participates in the Decommissioning Strategy Committees and makes advises based on their experiences in other countries.	NDF
International Expert Group (TEPCO)	・To obtain advice to contribute to the safer and more efficient decommissioning of the Fukushima Daiichi and its R&D, TEPCO invites experts with international expertise and experience from UK, US, France, and Ukraine.	TEPCO
International Advisors (IRID)	・To gain the evaluation on the implementation status of the R & D design review being undertaken, enhancement of information dissemination and communication, and acquire knowledge including failure experience, IRID invites the prominent experts from the UK, US, and Spain.	IRID
Activities by each organizations		
Cooperation with overseas organizations at the stage of IRID's practical application research	・Development of internal investigation technologies（UK, France, Russia） ・Development of fuel debris and structural component retrieval technologies（US,UK） ・Development of fuel debris criticality control technology (US, UK, France） ・Development of Solid waste processing and disposal technology (US, France)	IRID
INSIDER Project participation	・In order to optimize waste management, this project aims at establishing common method applicable to the specific cases by evaluating cost effective analysis and measurement methods for nuclear R&D facility and damaged reactor, etc. ・Participating in the kick-off meeting of this project, and gathering the information. ・Participating in the workshop held in Spain in May, 2019.	NDF
TOAL DECOM participation	・Participating in meetings of nuclear and non-nuclear companies related to decommissioning, held mainly by British companies, and gathering information on efforts of each company. (April, 2018)	METI NDF
ATOMEXPO participation	・Participating in a forum where nuclear power companies related mainly to Russia and Europe, held mainly by ROSATOM, and exchanging views with local stakeholders. (May, 2018 and April, 2019)	METI JAEA TEPCO
The 4th Fukushima/ Chernobyl/ Three Mile Island International Symposium	・Based on the lessons and cases learned from the accidents of Three Mile Island and Chernobyl Nuclear Power Plant, studies have been made for controlling the accident of the Fukushima Daiichi NPS. (May, 2019)	NDF JAEA TEPCO