Technical Strategic Plan 2018 for the Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.

October 2, 2018

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. ("Fukushima Daiichi NPS") started under the Mid-and-Long-term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi NPS Units 1-4 ("Roadmap"), 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, 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 (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.

Seven years have passed since the Fukushima Daiichi NPS accident, and prospects for short-term measures are becoming clearer, progress has been made at the accident site in the treatment of contaminated water including the construction of the land-side impermeable wall and in removing fuel from the spent fuel pools. In addition, the site work environment has improved. Regarding measures over the mid- and long-term, investigation and R&D have advanced in the areas of fuel debris retrieval and waste management. The Roadmap has also been revised to establish the policy for fuel debris retrieval and the basic concept of solid waste management.

Strategic Plan 2018 provides updates on these developments in decommissioning and the role of NDF and analyzes them closely, and so some areas of the document have been reorganized.

1.1 Enhancement of 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.

To ensure the implementation of the decommissioning financially, a law to partially revise the Nuclear Damage Compensation Facilitation Corporation Act was established in May 2017 and came into effect in October of the same year. Under the Revised NDF Act, NDF has been assigned the new duty of managing the reserve fund for decommissioning. Tokyo Electric Power Company Holdings, Inc. (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" ("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 decommissioning 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 the decommissioning reserve fund system.

Likewise, TEPCO, as the operator of the project, is reinforcing its project management structure with the goal of implementing the ongoing activities steadily while responding to mid- and long-term issues in a strategic manner. TEPCO and NDF have just launched this decommissioning reserve fund system under the project management framework formed to optimize the overall decommissioning plan.

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" ("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).

NDF presented the first of the Policy for Preparation of Withdrawal Plan in January 2018. The first Withdrawal Plan, prepared based on this Policy, was submitted by NDF and TEPCO for approval by the Minister of Economy, Trade and Industry in March the same year. The Plan was successfully approved in April.[1]

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 [IRID] and the Japan Atomic Energy Agency [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.

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1 "Withdrawal Plan for Reserve Fund for Decommissioning FY 2017" approved on April 11, 2018, NDF http://www.ndf.go.jp/oshirase/sonota_20180411.html

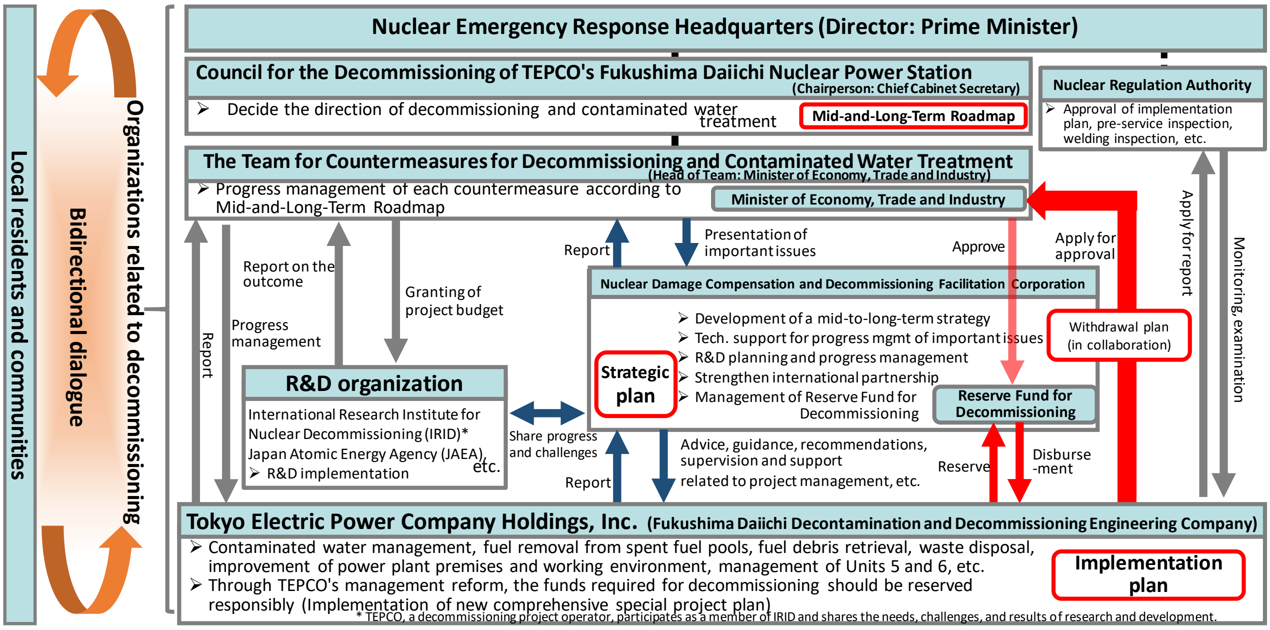


Fig. 1 Division of roles of related organizations in the decommissioning of the Fukushima Daiichi NPS

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 (“Strategic Plan”) every year since 2015 with the goal of providing reliable technological grounds for the government’s Roadmap and contributing to its smooth and steady implementation (Attachment 1).

Strategic Plan 2015, the first edition, provided specific discussions on key decommissioning issues expected over the mid and long term, which had not been sufficiently considered before, and established a policy for the risk reduction strategy. Subsequently, Strategic Plan 2016 was issued as a revision to the first edition to reflect the progress made in field work, technological development and other areas, providing input to the determination of the policy on fuel debris retrieval and the establishment of the basic policies on solid waste management, which are among the milestones (key target processes) set in the Roadmap. Strategic Plan 2017 was released and contributed to these two milestones by presenting strategic proposals based on technological grounds. These strategic proposals were incorporated into the September 2017 revision of the Roadmap, leading to the achievement of the two milestones: the determination of the policy for fuel debris retrieval and the establishment of the basic policies for solid waste.

Thus, the previous Strategic Plans focused on the two issues that NDF should address as part of its decommissioning strategy over the medium and long term—fuel debris retrieval and waste management—and continued deliberations to reach the two milestones. To take concrete action for fuel debris retrieval, future discussions should consider, in addition to these issues, the relationship and consistency with other activities, such as the treatment of contaminated water and the removal of fuel from the spent fuel pools. To address these needs, it was decided that future editions of the Strategic Plan should additionally include the topics of contaminated water management, fuel removal from the spent fuel pools and other associated issues and should propose future directions from mid- and long-term perspectives that examine 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 (see Fig.2).

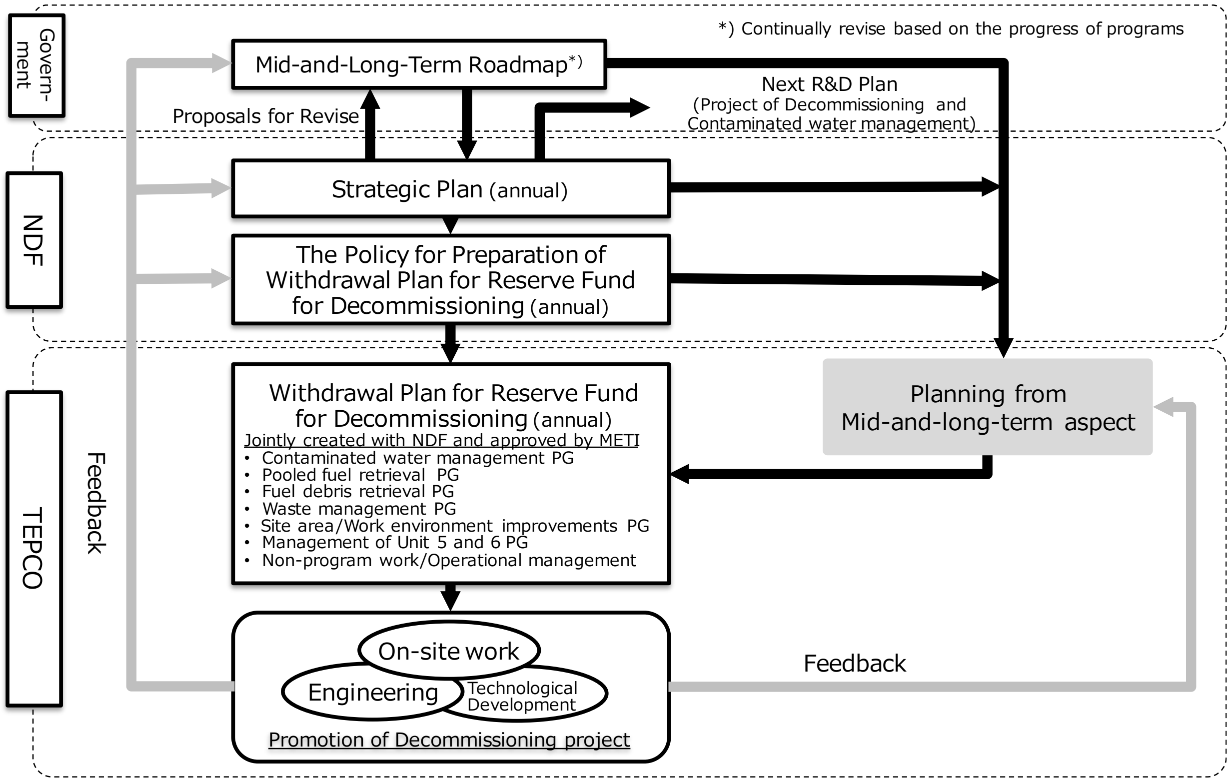


Fig. 2 Positioning of the Strategic Plan based on the system of the Reserve Fund

1.2.2 Overall Structure of Strategic Plan 2018

Strategic Plan 2018 consists of seven chapters.

Chapter 1 (Introduction) states that the decommissioning of the Fukushima Daiichi NPS is moving to a phase where issues over the medium and long term should be addressed from wider perspectives that consider the relationship and consistency among different projects, and that the introduction of the decommissioning reserve fund system has placed greater responsibilities and roles on NDF than before. The chapter also notes that against this background, Strategic Plan 2018 addresses issues that had not been sufficiently covered by previous Strategic Plans, such as contaminated water management and fuel removal from the spent fuel pools, to provide a strategy that would facilitate the smooth implementation of the overall decommissioning project.

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, 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. This chapter also discusses the need to establish an overall plan that helps maintain consistency throughout the decommissioning project by coordinating these concurrent efforts with other specific measures, yet pursues optimized entire planning while supposing interim targets to the extent possible.

In accordance with the fuel debris retrieval policy, Section 3.1 (Fuel debris retrieval) of Chapter 3 states how to proceed with studies to determine the fuel debris retrieval method for the first reactor in FY 2019 and describes the directions and progress of efforts to intensify and accelerate preparatory engineering and technological development for this purpose. The section also proposes example of fuel debris retrieval image and technological issues to be considered in a step-by-step approach.

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 and 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 view of the progress 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) proposes the direction of the efforts toward the appropriate storage of spent fuel throughout the Fukushima Daiichi NPS, including Units 5 and 6, and the efforts to determine the future processing and storage methods for spent fuel (e.g. evaluation of the long-term integrity of such fuel), in addition to how fuel removal work should be carried out in each unit according to plan.

Chapter 4 (Handling critical enablers for smooth operation of the project) provides discussions on key issues contributing to the smooth progress of the overall project in wider fields that go beyond the topics addressed in previous editions, such as R&D, international cooperation, and communication with local communities, in addition to technological considerations described in Chapter 3.

Chapter 5 (R&D initiatives) focuses on R&D efforts expected in the future. These include performing even more needs-oriented R&D based on the results of preparatory engineering and incorporating practices such as progress management and implementation evaluations under the project management system. 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 and further enhancement of communication) notes that as fuel debris retrieval work and other key activities move into full gear, the organizations involved should consider and implement ways to ensure closer communication among them. The chapter describes how these organizations should work together toward that end.

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 contained 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 containment 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 exposure of workers to radioactivity (refer to Attachment2).

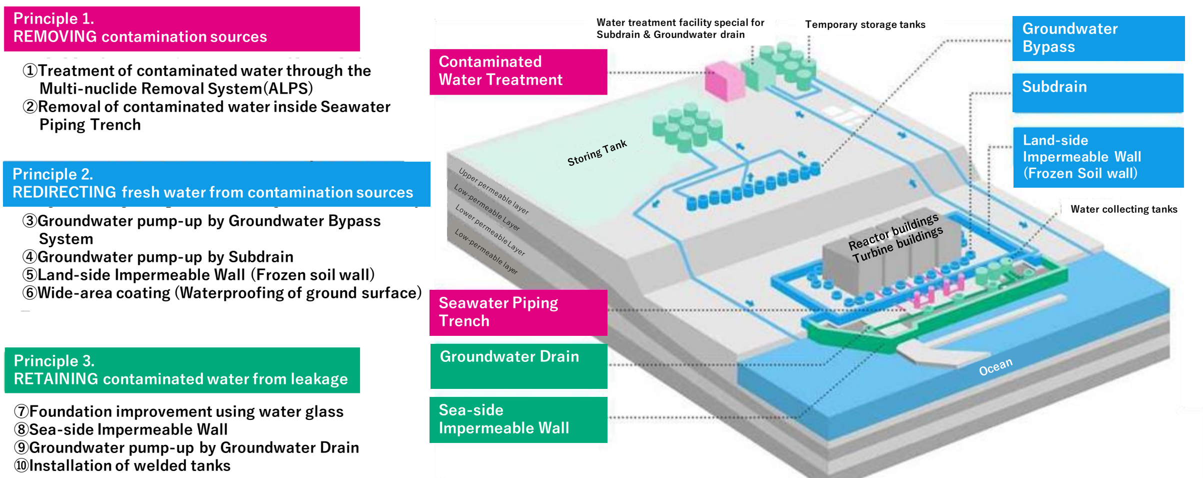
2.2 Progress status of the decommissioning of the Fukushima Daiichi NPS

(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).

As a measure of “Removing” contamination sources, radioactive materials are removed from contaminated water with multi-nuclide removal equipment (advanced liquid processing system:

ALPS). As a measure of “Redirecting” fresh water from contaminated sources, freezing operation of the land-side impermeable walls were proceeded step by step with the approval of NRA, and freezing in all of the areas started by August 2017. In March 2018, the temperature declined to 0℃ or below in almost all areas of the wall, and then water level difference of 4 - 5m was formed between inside and outside of the wall in the mountain side. These indicated the installation of the wall completed except for deep areas. Consequently, the completion of the land-side impermeable wall and reinforcement of the sub-drain system led to the suppression of the groundwater inflow into the buildings, and the sharp decrease in the amount of the water transferred from the groundwater-drains to the buildings. Because of this kind of preventive and multi-layered measures, total generation amount of contaminated water has been decreased to approximately 220m^3 per day in FY2017 from approximately 400m^3 per day in FY2016. In addition, the effect of the land-side impermeable wall is apparent in the decrease the pumping amount both in the sub-drains and groundwater drains. As a result of “Retaining” the contaminated water from leakage, the concentration of radioactive materials in the surrounding sea area is constantly low.



(Courtesy of TEPCO)

Fig. 3 Three principles and measures

In treating stagnant water in the buildings, the amount of stored water has been decreasing steadily by lowering the water level within turbine buildings with the goal of completing the treatment in 2020. The level of stagnant water in the Unit 1 Turbine Building was reduced to the lowest floor level in March 2017. In the Unit 2 - 4 turbine building, the level of the stagnant water lowered to the lowest floor’s intermediate ceiling, which was exposed in December 2017. For the condensers in Unit 1 – 3, where the highly radioactive stagnant water was stored at the time of accident, draining completed by December 2017 and so forth, thereby radioactive materials contained in the stagnant water sharply decreased (approximately a half compared to the end of FY2014). A new circulation system for the contaminated water management started the operation in February 2018 to reduce the concentration of the radioactive materials in the stagnant water. 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's subcommittee on the water treated by the multi-nuclide removal equipment.

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

In Unit 1, to remove fuel from spent fuel pools at the operating floor, rubble removal in the north of the operating floor was started in January 2018.

In Unit 2, as a part of preparation of fuel removal from spent fuel pool, opening to provide access to the operating floor was made, then investigation of the dose and the contamination state in the operating floor was started in using remote robots and heavy machine, etc. from July 2018.

In Unit 3, installation of a cover for fuel removal was completed in the middle of February 2018. Once started the trial operation for fuel handling equipment in March 2018, several troubles have occurred. TEPCO intends to examine and review the start of fuel removal in the spent fuel pool which was scheduled in November 2018.

(3) Fuel debris retrieval

In Unit 2, internal investigation of Primary Containment Vessel ("PCV") was conducted in January 2018, continued from January and February 2017. It was confirmed that deposits, which seemed to be fuel debris, are accumulated in the bottom of pedestal, according to the result of analysis of the images obtained.

In Unit 3, based on results of investigation in July 2017 using a remotely operated underwater survey vehicle ("ROV"), three D shape reconstruction was conducted, to grasp whole image within the pedestal. It was found out that swivel platform came off the track, and partly buried in the deposit, showing relative position of structures.

(4) Waste management

In February 2018, operation of solid waste storage building No. 9, which has about 40% of storage capacity of all the existing solid waste storages (building No.1 – 8), was started. In the storage facility with shielding function, it became possible to store the highly radioactive rubbles arisen from removal in the operating floor of Unit 1 and dismantling of upper part of reactor building of Unit 2. TEPCO formulated Storage Management Plan to store and manage these solid waste properly, it was revised in June 2018 based on the results of prediction of generation of solid waste. (Attachment 9) In addition, sampling and analysis has been progressing for the purpose of characterization.

(5) Other specific measures

The surrounding road of Unit 1 to 4 buildings and part of east side of turbine buildings were determined as “ordinary clothing area”, where the workers are allowed to enter and work in general workwear or in on-site safety workwear with disposable dust-proof mask. As a result, ordinary clothing area expanded to approximately 96% of the Fukushima Daiichi NPS site.

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.

Here the risk level is defined as follows:

Risk Level = Impact × Likelihood
= 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 (see Attachment 3)

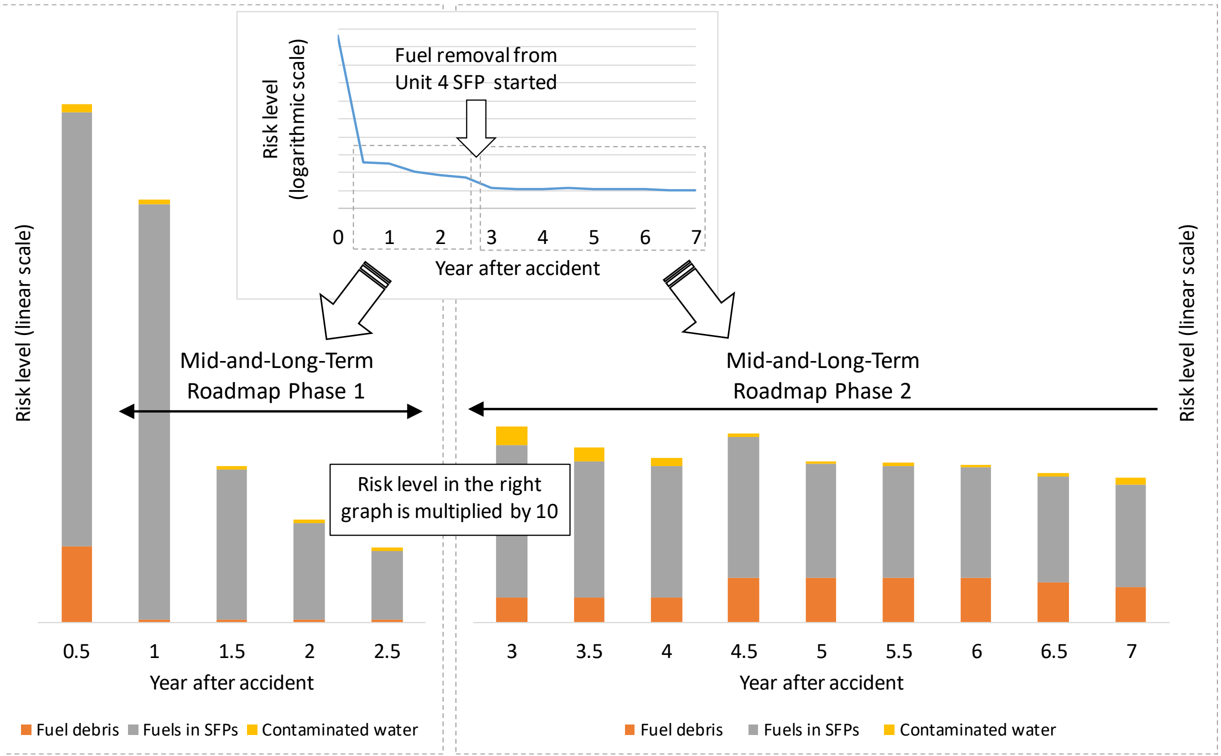
2.3.2 Identification of Risk Source and Risk assessment

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 Roadmap, management of these risk sources is classified into the three broad categories: 1. Highly contaminated water and fuels in the spent fuel pools, etc., relatively high risks given high priority, 2. Fuel debris, etc., immediate risks unlikely, risks may grow in case of dealing with haste, 3. Solid waste, etc. increased risk unlikely in the future, but appropriate decommissioning efforts necessary. Their priorities are set, and appropriate measures are implemented. Risk reduction strategies for each of these sources will be described in Section 3.

Table 1 Major risk sources in the current risk map

Fuel debris		Fuel debris in the RPVs/PCVs in Units 1-3
Spent fuel	Fuel in SFPs	Fuel assemblies stored in the spent fuel pools (SFPs) in Units 1-3
	Fuel in the common pool	Fuel assemblies stored in the common 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 1-4, main process building, and high temperature incinerator building.
	Stored water in flanged tanks	Strontium-treated water, residual concentrated salt water
	Stored water in welded tanks	Strontium-treated water, treated water by ALPS
Secondary waste from water treatment systems	Waste adsorption columns	Storing 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 the multi-nuclide removal equipment stored in high integrity containers (HIC)
	Waste sludge	Precipitation from the decontamination instruments
	Concentrated liquid waste, etc.	Concentrated liquid waste generated by evaporative concentration of concentrated salt water and carbonate slurry collected from concentrated liquid waste
Rubble etc.	Solid waste storage facility	Rubble with high-dose (30mSv/h and above) stored in the solid waste storage facility
	Soil covered temporary storage, etc.	Rubble stored in Soil covered temporary storage facility, Temporary storage tent and Outdoor container storage (1～30mSv/h), and Fallen tree stored in Temporary storage pool
	Outdoor storage, etc.	Rubble stored in Outdoor seat covered storage (0.1～1mSv/h), Rubble stored in Outdoor storage (Under 0.1mSv/h), and Fallen tree stored in Outdoor storage
Contaminated structures, etc. in the buildings		Structures, pipes, components, and other items inside the reactor buildings, PCVs or RPVs that are contaminated with radioactive materials dispersed due to the accident; and activated materials from operation before the accident



※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 The risk level increased from four to four and a half years after the accident because Safety Management of fuel debris became high by dismantling the building cover of Unit 1 in order to prepare spent fuel removal from the pool such as removal of rubbles in the upper area of operating floor. From the viewpoint of risk reduction of the entire site, it was one of the measures needed for spent fuel removal from the pool. When dismantled the cover, measures against dispersion of radioactive material was conducted.

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

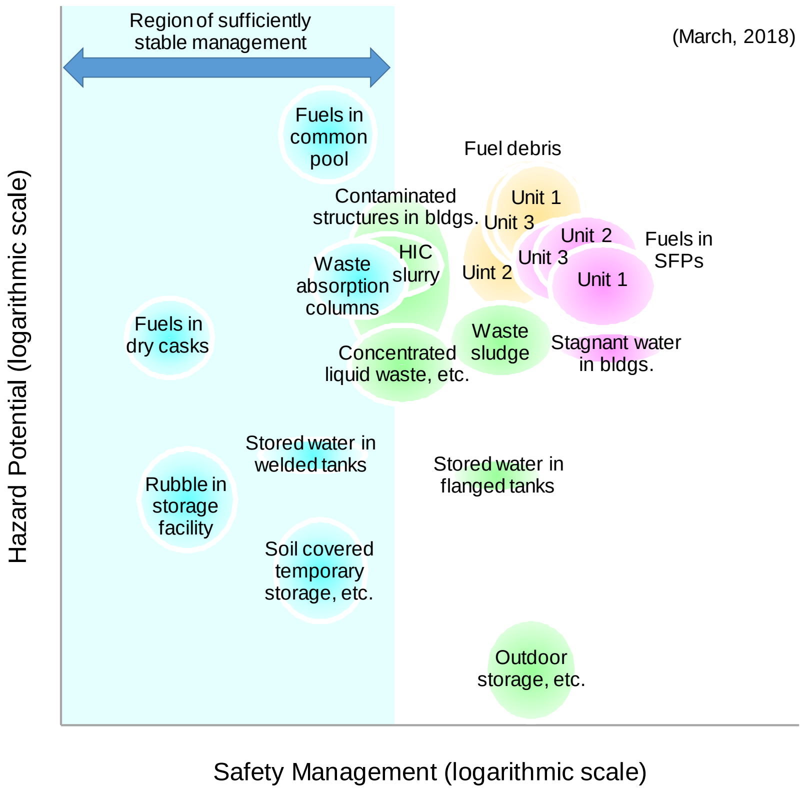


Fig. 5 Examples of Risk Levels of Major Risk Sources at the Fukushima Daiichi NPS

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 the pools to the common 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.

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 Unit 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, 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: containment 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 important to be aware of position of each project and their mutual relationship in their respective fields in managing progress of overall project based on the five guiding principles. 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 example, although the vent stack for Units 1/2 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 the fuels in the spent fuel pool. However, considering fractures and deformation were found at the junctions of the diagonal bracing of the steel tower that supports the vent stack, it is planned to dismantle the upper part of the vent stack with remotely controlled equipment as an environmental improvement ahead of fuel removal from the pool.

In the decommissioning of the Fukushima Daiichi NPS that aspires to a continuous and prompt risk reducing, 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 time axis. 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 just introduced project management mechanism, as described in Section 4.3.

2.3.3.4 **Addressing temporary increase of risk level associated with the decommissioning operations**

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 containment status, and special operations and maintenance performed for the retrieval will increase the exposure of workers involved in these activities.

This possibility of a temporary increase in the risk level and a rise in workers' 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[2].

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 systems, and the development of work plans for the decommissioning work should many constraints such as consider time, cost and worker's 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 4).

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.

[2] 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 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),

3. Technological strategies toward decommissioning of the Fukushima Daiichi NPS

3.1 Fuel debris retrieval work

3.1.1 Sectoral target

The immediate objectives of fuel debris retrieval are as follows (For the objective of fuel debris retrieval refer to Attachment 5).

(1) Retrieve fuel debris safely after thorough 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 policy on fuel debris retrieval.

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 that risk may grow in case of dealing with haste. (refer to section 2.3). Currently, it is 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 goal, fuel debris should be retrieved safely after thorough preparations such as safety measures and bring it to the state of stable storage that is fully managed as soon as possible to achieve a low risk level that is largely acceptable to society. Technical investigations are on to realize this.

Until now, in the Strategic Plan, securing of safety during fuel debris retrieval work and technical requirements that are defined including feasibility of fuel debris retrieval method and stable storage of fuel debris have been considered while organizing the issues logically. In the future, consideration should be made according to these technical requirements to implement fuel debris retrieval work safely when expanding the scale with a step by step approach in accordance with policy on fuel debris retrieval as described in the next chapter.

Furthermore, 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 the upper reactor building. On the other hand, the reactor building of Unit 2 is in a sound state, and the damage level of Reactor Pressure Vessel (“RPV”) is considered small because most of fuel debris are presumed to stay inside 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, many of fuel debris are presumed to stay 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 (“MCCI”) products compared to Units 1 and 3.

3.1.2.2 **Policy on fuel debris retrieval**

The Strategic Plan 2015 and 2016 examined the fuel debris retrieval method option by combining the PCV water level (Submersion method, Partial submersion method) and the fuel debris access direction (Top access, Side access and bottom access). After that the three construction methods were selected (1) The submersion - Top access method, (2) Partial submersion - Top access method, (3) Partial submersion - Side access method) and the study on these methods have been continued.

In the Strategic Plan 2017, with respect to these three fuel debris retrieval methods, in addition to nine technical requirements that need to be satisfied for safe retrieval of fuel debris (1. Containment functions, 2. Cooling functions, 3. Criticality control, 4. Structural integrity, 5. Reduction of radiation exposure, 6. Work safety, 7. Access routes, 8. Development of devices and equipment, 9. System facility and area construction), feasibility evaluation was conducted for each of the three technical requirements (1. Collecting, transferring and storing, 2. Treatment of radioactive waste during fuel debris retrieval work, 3. Safeguard measures) for safe and stable storage of fuel debris. Then, the comprehensive evaluation was implemented based on five guiding principles, and made a strategic proposal (toward the decision and efforts after the decision) for determining the fuel debris retrieval policy. Based on the contents of this strategic proposal in the Roadmap revised in September 2017, the policy on fuel debris retrieval has been determined as follows.

＜Policy on fuel debris retrieval＞

① Step-by-step approach

We will adopt a step-by-step approach wherein we will set the method of fuel debris retrieval to be started first in order to reduce risks at an early stage and will adjust our direction flexibly based on information that comes out as retrieval proceeds.

Fuel debris retrieval, the investigation inside the primary containment vessel, and the investigation inside the reactor pressure vessel will be performed in a coordinated, integrated manner. The fuel debris retrieval starts from a small-scale task and the scale of retrieval will be stepped up as we review our operations flexibly based on new findings obtained from the nature of the fuel debris and working experience.

② Optimization of entire decommissioning work

We will examine fuel debris retrieval as a comprehensive plan aimed at total optimization, from preparation to cleanup through retrieval work, discharge, processing and storage, including coordination with other construction work at the site.

③ Combination of multiple methods

We will combine optimum retrieval methods suitable for the part of each unit where fuel debris is expected to be present, instead of making an assumption that all the fuel debris is to be taken out using a single method.

At present we will examine how to combine methods from an accessibility standpoint, assuming that access is made to the bottom of the primary containment vessel from the side and that access is made to the inside of 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 of the primary containment vessel and expected radiation doses during work, the full submersion method is technically difficult at present, so we will base our efforts 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, we might consider adopting the full submersion method in the future depending on the progress of R&D.

⑤ Prioritizing fuel debris retrieval by access to the bottom of the primary containment vessel from the side

According to an analysis, fuel debris is expected to be present in both the bottom of the primary containment vessel and the inside of the reactor pressure vessel of each unit, although their distribution varies among the units. In view of rapidly mitigating risks from fuel debris while minimizing any increase in risks that might be caused by retrieval, we will prioritize retrieval of fuel debris in the bottom of a primary containment vessel by access from the side by taking the following into account:

○The bottom of the primary containment vessel is most accessible and a certain amount of knowledge about it has already been accumulated through the investigation inside the primary containment vessel;

○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

3.1.2.3 How to proceed discussion toward determination of fuel debris retrieval methods for the first implementation unit

In the Roadmap, it is stated that “regarding the method of fuel debris retrieval for the first implementation 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 choosing this first implementation unit, it is premised that for each of the units 1 to 3, the medium-to-long-term engineering schedule for implementing fuel debris retrieval work are already established. It is only reasonable that the first implementation unit and its retrieval method would be determined after this above is incorporated in the overall plan to ensure consistency. Figure 6 shows the investigating flow (draft plan) to determine the fuel debris retrieval method for the first implementing unit, based on the R&D achievements in the decommissioning and contaminated water management project, results of internal investigation of PCVs, state of the work environment adjustment, and the use plan of the entire site including the plan for fuel removal from the pool and contaminated water management etc. 1: It is necessary to prepare a scenario (operation process plan) during the preliminary engineering work[3] implemented by TEPCO (see next section), based on the consideration on the concept of fuel debris retrieval system for each unit and on the evaluation of its applicability on site. 2: After this, the first implementing unit and the retrieval method will be determined, by considering multiple whole scenarios combining the scenarios of each unit and the plan for surrounding areas and by identifying the whole scenario which is considered to be comprehensively the most reasonable from the viewpoint of the total optimization of the entire site as described in Section 3.6 such as time, safety, consistency in the project as a whole, etc.

At this time, from the viewpoint of evaluation of the applicability of operations to the actual site, ensuring safety during fuel debris retrieval work (containment functions, cooling functions, structural integrity, criticality control, reduction of radiation exposure during work, etc.), feasibility of fuel debris retrieval method (construction of access route, development of devices and equipment, system facility and area construction) and stable storage of fuel debris (examination of collecting, transferring and storing, and safeguard measures) are compatible with the technical requirements described in Section 3.1.3.

In particular, to select the first implementing unit, consideration should be made for the particularity of unprecedented undertaking of fuel debris retrieval work in the environment with many uncertainties, and the benefit of getting experiences and information of handling of fuel debris early, also taking into account the viewpoints of reliability of internal information, work environment such as involvement of necessary preparatory works, the results of the risk assessment of each current unit shown in Fig. 6 and Section 3.1.2.1, and the risk level at the time of assumed fuel debris retrieval work, etc.

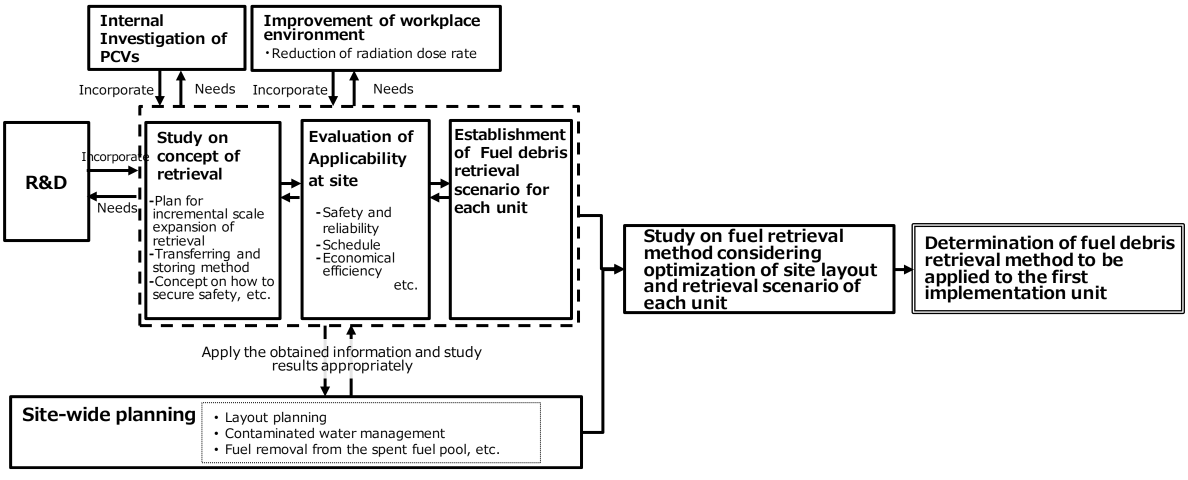


Fig. 6 Investigating flow toward determination of fuel debris retrieval method (draft plan)

[3] Preliminary implementation of engineering related study work to determine feasibility of construction, prior to the basic design to be performed at the time of construction work. Considering on-site applicability of technologies including technologies, devices and equipment including maintenance performance, placement, flow lines etc., fully in consideration with the site situation, will minimize any rework that maybe required post basic design. Therefore, through the results of preliminary engineering work, the construction method will be reviewed as necessary

3.1.2.4 **Proceeding method of preliminary engineering and creation of concrete plan of each task**

In the preliminary engineering work conducted by TEPCO, by confirming the applicability of operations on site in light of the situation of each unit about operations and system concept for each step of fuel debris retrieval proceeded by a step-by-step approach, and it will be specified as a scenario for fuel debris retrieval work for each unit. In particular, details of preliminary engineering work should be fully planned and investigated to obtain the necessary information, aiming at milestones, which is the determination of fuel debris retrieval method of the first implementing unit within FY 2019. From this point of view, considerations meeting the following items are expected to be conducted in the preliminary engineering work:

- The whole related operations ranging from internal investigation in the preliminary stage of fuel debris retrieval work and preparations to the improvement in the surrounding environment to fuel debris storage should be included in the scenario.
- In each step, the information that should be gained in advance should be organized in order to secure safety and engineering reliability on the equipment for retrieval.
- Clarification of prerequisites as well as evaluation on its uncertainties and forecast concerning a development of the scenario should be conducted
- Sufficient safety evaluation should be implemented for the major troubles and others assumed at present.

As a result of these considerations, the following items are expected to be obtained, as the achievement of preliminary engineering work:

- Image of operation process to fuel debris retrieval for each unit and identification of technical issues to solve
- Engineering schedule incorporating the period of solving the technical issues (scenario for each unit)

As a result, it will be possible to create the overall scenario, combining the obtained scenario for each unit and fuel debris retrieval from the pools and contaminated water management. And the candidate of the first implementing unit will be selected according to this overall scenario.

3.1.2.5 **Continued internal investigation and accelerated/prioritized R&D**

It is necessary to draw up a roadmap for solving the technical issues extracted so far and identified in the process of implementing preliminary engineering work, through further internal investigation and accelerated/prioritized R&D.

As the PCV internal investigation conducted so far has obtained various information, further detailed internal investigation is planned to collect data such as the distribution of deposits and fuel debris inside the PCV. Most of these kinds of internal investigations have been conducted till now as field validation of instruments which was developed in decommissioning and contaminated water management project, with only partial of environmental conditions inside PCV being unclear. In the future internal investigation, it should be thoroughly identified what kind of data is necessary as part of assembling the whole project in preparing for retrieving fuel debris, which is progressing with a step by step approach. Then to implement the scenario for the goal of each phase is needed.

In addition, according to the fuel debris retrieval policy based on the partial submersion method, by advancing the side access to the bottom of the PCV, R&D tasks that newly needs have become clear are to be proceeded to extract through preliminary engineering work, as well as accelerating and prioritizing R&D including establishing a containment function (gas phase) on the assumption of the existence of α-nuclides and technology to manage the water level in the PCV. It is also important to take a step-by-step approach to flexibly adjust the direction including the method of retrieving fuel debris, depending on the outcome of R&D and the situation on site to which the scenario is applied.

3.1.3 Technical issues for promoting sectoral strategies and future plans

Fuel debris retrieval work should proceed with a step by step approach according to the fuel debris retrieval policy. After presenting the step-by-step concept in 3.1.3.1, the main issues are described in Section 3.1.3.2 to 3.1.3.5 including the approach to comprehensively understand internal reactor condition, the technical requirements related to safe assurance shown in the Strategic Plan, the technical requirements concerning the fuel debris retrieval method, and the technical requirements on the stable storage of fuel debris, together with further considerations required as the scale grows.

3.1.3.1 Concept of step-by-step approach

In the fuel debris retrieval policy, internal investigation and fuel debris retrieval work will be performed in a coordinated, integrated manner. Starting with small-scale fuel debris retrieval, the scale of retrieval will be gradually expanded, reviewing the work flexibly, based on the nature of fuel debris and new findings obtained from work experience etc.,.

Details of work elements pertaining to fuel debris retrieval for each unit are under consideration (see below and Table 2). Note that these do not necessarily apply to all of Units 1 to 3 across the board.

(1) Internal investigation (Investigation of internal situation and understanding of properties of fuel debris etc.)

For the condition inside of the PCV and damages of the internal structure, investigation and observation are to be made provided that the internal environment has not changed. This will provide information for checking the distribution and accessibility of fuel debris at the bottom of the PCV and information for judging the safety of fuel debris retrieval work, which are used for examining the fuel debris retrieval method.

Furthermore, the nature of fuel debris inside of the PCV, including the shape, existing state, composition, and mechanical/chemical properties, etc. are identified through sampling and analysis.

As fuel debris sampling inevitably involves moving fuel debris, it aims to improve the accuracy of determining the feasibility of the fuel debris retrieval method and to improve the reliability of the protective measures for ensuring safety, by collecting important data that assists evaluation of ensuring safety in the subsequent stage such as information pertaining to the transportation for temporarily storage of retrieved fuel debris and stable storage, information pertaining to the transition state of fuel debris to the gas/liquid phase and potential criticality, etc.

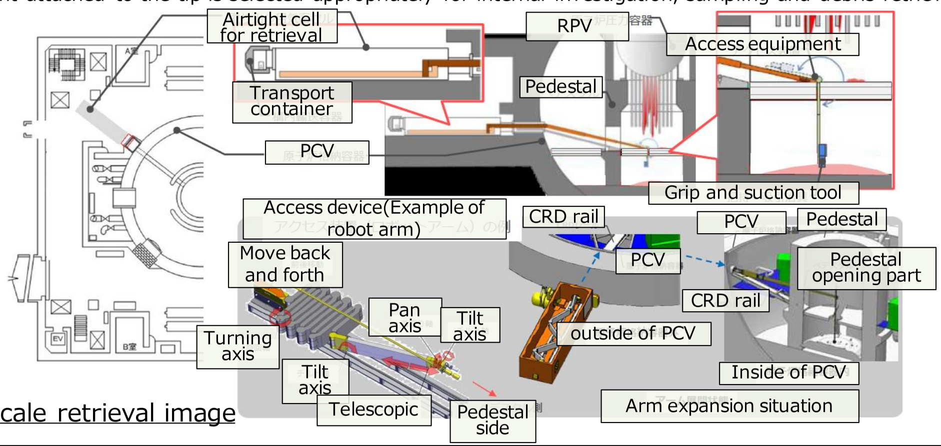
(2) Fuel debris retrieval

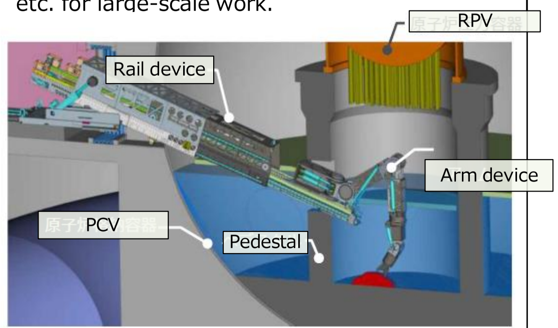
In the initial stage of fuel debris retrieval, fuel debris will be taken out to the extent that the condition of the site is not significantly changed. In order to improve the efficiency of work throughout the fuel debris retrieval period, various kinds of information to identify the work and equipment used for large-scale retrieval scheduled thereafter should be collected and verified, including to confirm the effectiveness and evaluate the work efficiency of the fuel debris retrieval work and equipment, to evaluate the effect on safety when extending the scale of fuel debris retrieval and to check in advance the conditions for collecting, transferring and storing.

Based on the data obtained from the operation until the small-scale fuel debris retrieval, installing equipment is to be made that can handle the target amount of fuel debris taken out per day and more efficient fuel debris retrieval will be performed after studying the fuel debris retrieval equipment and the system for ensuring safety.

While entering this large-scale retrieval stage, checking the conditions of the site regularly, the first step should start with a small amount of fuel debris retrieval work. It is necessary to pay attention to the step-by-step approach as the scale gradually expands.

Table 2 Image of fuel debris retrieval by a step-by-step approach (example of Unit 2)

<table>
<tr><th rowspan="2"></th><th colspan="2">Internal investigation etc.</th><th colspan="2">Fuel debris retrieval</th></tr>
<tr><th>Internal investigation (ex.)</th><th>Sampling (ex.)</th><th>Small-scale retrieval (ex.)</th><th>Large-scale retrieval (side-access method) (ex.)</th></tr>
<tr><td>Objectives</td>
<td>• To enforce the previously acquired PCV internal information and analysis results, etc., obtain additional PCV internal information that is the basis for studying fuel debris retrieval methods.
• By contact with fuel debris, confirm whether any debris can be easily sampled .</td>
<td>• Collect fuel debris at various locations in PCV and analyse their properties (shape, existing state, and mechanical/chemical properties).
• Analyse of the effects induced by the sampling work on the surrounding environment and facilities.</td>
<td>• As a preliminary stage for large-scale retrieval, retrieve fuel debris using a small-scale equipment without changing the current states to a great extent, obtain further various information for retrieving fuel debris and verify the plan of large-scale retrieval method.</td>
<td>• Based on information obtained through small-scale retrieval work, review the fuel debris retrieval device, safety related systems, etc. to improve reliability, perform more efficient debris removal.
• Also, depending on the part where fuel debris is present, select an appropriate access and retrieval method.
• Retrieved fuel debris shall be stored in an appropriate storage facility</td></tr>
<tr><td>Contents</td>
<td>• Distribution of fuel debris at the bottom of PCV
• Accessibility information for fuel debris retrieval
• Information that contributes to the evaluation of ensuring safety fuel debris retrieval work,
• Further possibly including
• Information on Pedestal damage
• Information on the possibility of falling objects from the bottom of the RPV during work at the bottom of the PCV</td>
<td>• Transport the collected fuel debris to the analysis facility
• Carefully collect samples while monitoring not to scatter the dust much, Using such methods as suction, gripping, scooping, cutting (or core boring)
• Basically removal of large obstacles in PCV is not planned.</td>
<td>• Removal of obstacles in PCV shall be limited to the minimum necessity within accessible area. Continue the small-scale retrieval work using the methods such as suction, gripping, scooping, small scale cutting, core boring and so on.
• Based on the results of these work, evaluate the effectiveness of the equipment, the influence on safety assurance against expansion of the retrieval scale, and the work efficiency etc.
• Collected debris is to be stored in a temporal storage facility in the building and carry out preliminary confirmation concerning the upgrade to large-scale retrieval, transfer and storage</td>
<td>• In addition to the retrieval work listed left, sludge-like debris and massive debris (collected by large-scale cutting) etc are to be retrieved.
• Retrieval of debris attached to the structure (cutting the structure)
• Removal of interference substances in PCV
• Storage facilities of collected fuel debris are to be prepared for long term storage.</td></tr>
<tr><td>Retrieval Device/Equipment</td>
<td colspan="3">• Use an arm type access device of a size small enough not to expand the X-6 penetration .
• Equipment attached to the tip is selected appropriately for internal investigation, sampling and debris retrieval.


Small-scale retrieval image</td>
<td>• The portion around the X-6 penetration is to be expanded so as to set up an arm with rails etc. for large-scale work.


Large-scale retrieval image of side -access method (ex.)</td></tr>
</table>

Image diagram is excerpted from Material 2-1 of 60th Study group on Monitoring and assessment of specified nuclear facilities, TEPCO (May 18, 2018), Courtesy of IIRID

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

The comprehensive analysis and evaluation results on the distribution of fuel debris of the Unit 1 to 3 and the access route to fuel debris and the situation of the surrounding structure are based on the measured value of plant parameters which are obtained at the time of accident, severe accident progression analysis, information on the actual situation of the site by PCV internal investigation muon measurement, and scientific knowledge obtained by examination 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 the MCCI product. There is a possibility that a part of the fuel debris has spread to the outside of the pedestal through the worker entrance.

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.In the PCV Internal investigation of March 2017 too, no large damage was detected to the structure.

(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 calculated 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, the deposit which appears to be pebbly-like/clay-like shape was 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, damage to the concrete wall in the pedestal, melting of cable tray and steel pillar of the CRD[4] handling machine etc. are not to be observed, so the fuel debris is considered to be containing a lot of metal components such as internal structural material. 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.

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,

[4] Control Rod Drive

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.

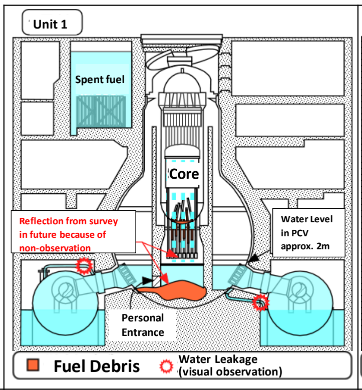
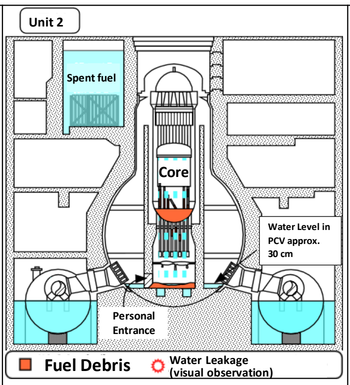
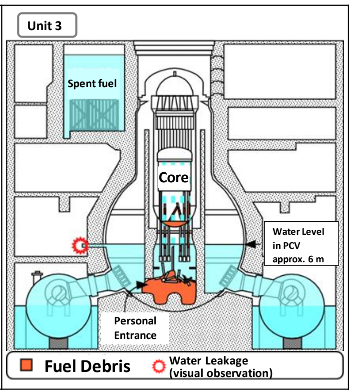
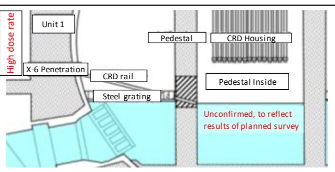
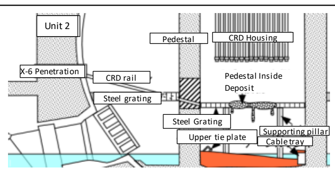
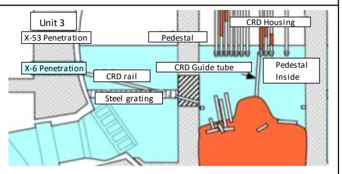
(3) Internal condition of Unit 3

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 poured into the drywell (“D/W”) at the time of the accident, which may have restricted the spread of the fuel debris.

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 structure and fallen substances in the pedestal, missing portions and deformation of CRD housing support 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 in the pedestal inner wall surface.

This information is summarized as in Fig. 7.

	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.
Pedestal Inside	• Most of the fuel debris is present	• A small amount of fuel debris is present	• Amount of fuel debris in Unit 3 is more than that in Unit 2.
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.
			
Information of the access route for fuel debris*	• 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 assembles 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.

- 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 contents observed by previous internal investigation are mentioned as information to judge whether troubles are caused by falling objects on the route.
- In the access route for the fuel debris retrieval in the PCV (large-scale task), an access route through an equipment hatch is planning in the project of retrieval method and system.
- Due to high dose rate around the X-6 penetration of Unit 1, it may use the same access route of the large-scale task, in case it is difficult to improve work environment. Next internal investigation of Unit 1 is scheduled to develop by accessing from X-2 penetration.

(Prepared by Achievement Report 2017 and June 2018 of "Decommissioning and Contaminated Water Management Fund (Advancement of comprehensive grasping of inner reactor)" provided by IRID, The Institute of Applied Energy)

Fig. 7 Estimation of fuel debris distribution of Units 1 to 3, access Route and condition of surrounding structures

Also, as mentioned in Section 3.1.2.5, for future internal investigations, the kind of information required as a part for assembling the whole project is thoroughly examined in the process of step-by-step approach for fuel debris retrieval, and the information that needs to be obtained should be clearly defined as the goal at each stage. In particular, in order to utilize it for creating the scenario of fuel debris retrieval, the following investigation and study[5] for each unit should be considered

[5] "Study status on RPV internal investigation, sampling and analysis" by TEPCO, Handout 3-3, 56th Secretariat meeting/Decommissioning and Contaminated water management team meeting, July 26, 2018

steadily. (Fig. 8)

【Unit 1】

- Grasping distribution of structures and deposits outside the pedestal (including sampling)〔scheduled in the first half of FY2019〕

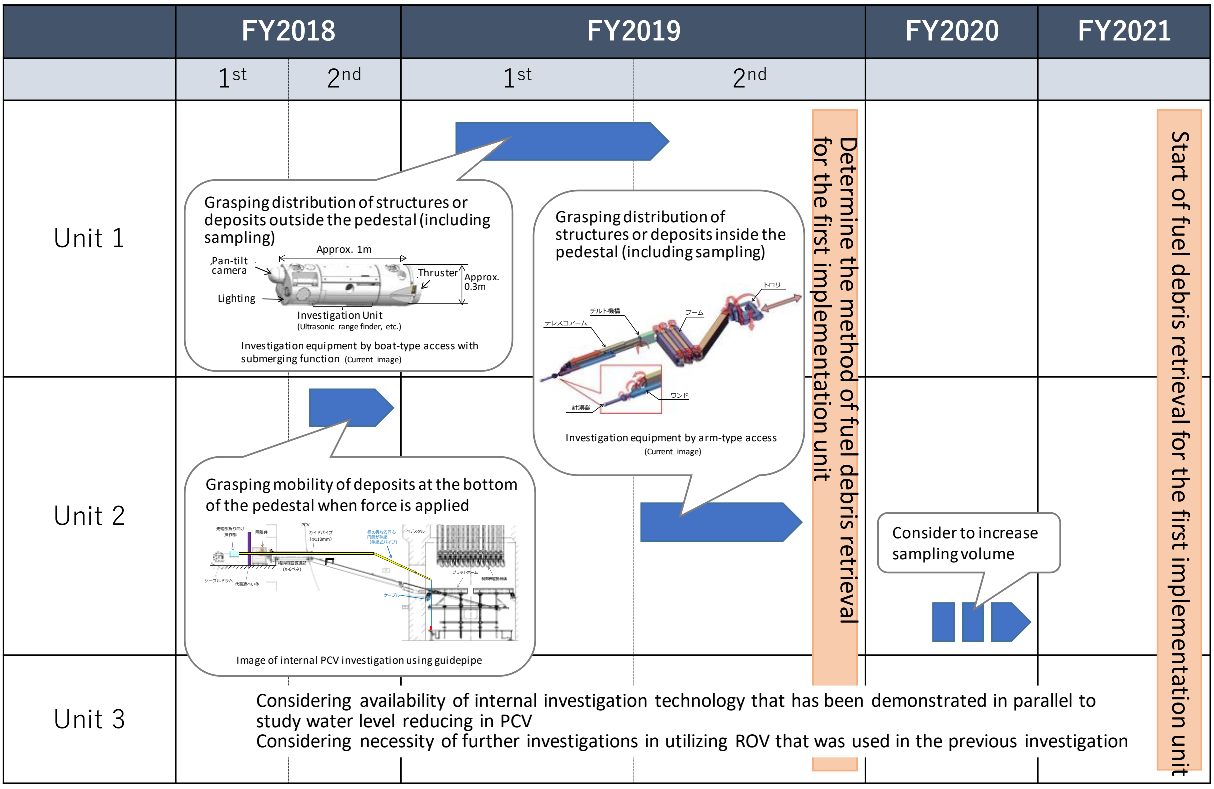
【Unit 2】

- Grasping mobility of deposits at the bottom of the pedestal when force is applied to deposits〔scheduled in the second half of FY2018〕
- Grasping distribution of structures and deposits inside the pedestal (including sampling)〔scheduled in the second half of FY2019〕
- Considering to increase sampling volume〔scheduled in FY2020〕

【Unit 3】

- Considering availability of internal investigation technology developed and demonstrated by the decommissioning and contaminated water management project, in parallel to study water level reducing in PCV
- Considering necessity of further investigation in utilizing underwater ROV used in the previous investigation

Prior to implementing further detailed internal investigation, giving due consideration will be required for continuous ensuring safety, including maintaining containment function and prompt recovery of containment function in the abnormal event as well as measures against exposure and dust management, in consideration of maximum use of existing penetration into internal PCV that has been used in the previous investigations as larger equipment will be used.



Drawings in the balloons were cited from the material from IRID, TEPCO[5]

Fig. 8 Further internal investigation schedule and image of investigation equipment

3.1.3.3 Technical issues for ensuring the safety

3.1.3.3.1 Concept for ensuring safety in 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 Section 4.2) 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 of the PCVs' internal conditions (see Fig. 6).

As the concept of ensuring the safety during the fuel debris retrieval work is being constructed, NDF is focusing on the studies on specifying the technical requirements for ensuring safety during fuel debris retrieval work, as shown in 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 Section 3.5.4.

3.1.3.3.2 Establishing the containment functions (gas-phase)

Dispersion of radioactive material in ordinary operating nuclear power plant is prevented by keeping interior of a reactor building under negative pressure against the ambient air (active containment function by maintaining under negative pressure) and pressure in a PCV is maintained to be equal to that inside of a reactor building (passive containment function). On the other hand, the reactor buildings, PCVs, etc. of the Fukushima Daiichi NPS are partially damaged by the hydrogen explosion and their containment function has been deteriorated. Due to this, establishment of an active containment function by controlling pressure in negative is being considered during fuel debris retrieval work. Moreover, from the viewpoint of prevention of hydrogen explosion due to steadily generated hydrogen by the process of radiolysis of water and of corrosion (inactivation) of structural material due to the presence of oxygen, nitrogen is currently injected into the PCV to maintain it in a nitrogen atmosphere and under slightly positive pressure state. The dispersion of radioactive material has been preventing by the PCV exhaust gas control system which was furnished with filters to remove radioactive material and radioactivity measurement system.[6]

When retrieving the fuel debris in future, the dispersion of radioactive fine particles (α-dust) containing α-nuclides that has a large contribution to dosage during internal exposure derived from fuel debris may occur due to the works such as fuel debris cutting and drilling, and it may create a concern for increasing the concentration of radioactivity in the PCVs gas phase. Therefore, a function for containing the gas phase with protective measures should be provided that suppress the dose impact of workers and public within the allowable value, by minimizing the disperse of α dust from PCV as much as possible taking evaluated dust condition at normal operation as well as abnormal condition into account.

Accordingly, in order to build a reasonable containment function at the each stage as described in Section 3.1.3.1, it is reasonable to upgrade the scale of the retrieval work while verifying the validity of the containment function built in the subsequent stage by grasping the tendency of dust dispersion at the each stage of scale expansion. For example, internal PCV investigations and the small-scale retrieval planned in the near future, α-dust emission can be controlled by reducing the amount to be retrieved, and selecting a retrieval method that does not involve cutting and drilling, while maintaining the current inert atmosphere (slightly positive pressure state due to nitrogen gas charge) inside the PCVs. Based on both the results of monitoring changes in the state of α-dust emission from the retrieval work and the evaluation of effects on the surroundings, it will likely be

[6] Evaluated radiation dose value at the site boundary due to the release of airborne effluent is 0.03mSv/year, on the other hand, the evaluation of additional emission amount from the reactor building is approximately 2.9×10^{-4}mSv/year. (Evaluation value at the time of July, 2018) (Refer to Section 3.5.2.2)

shifted to the larger size of the fuel debris retrieval work gradually, using such as the cutting and drilling equipment. If it is evaluated that the expansion of the retrieval work may induce the effects on the surrounding environment, further study is required for the means to strengthen the containment function by equalization or negative pressurization inside the PCVs as well as constructing a secondary containment function outside the PCVs.

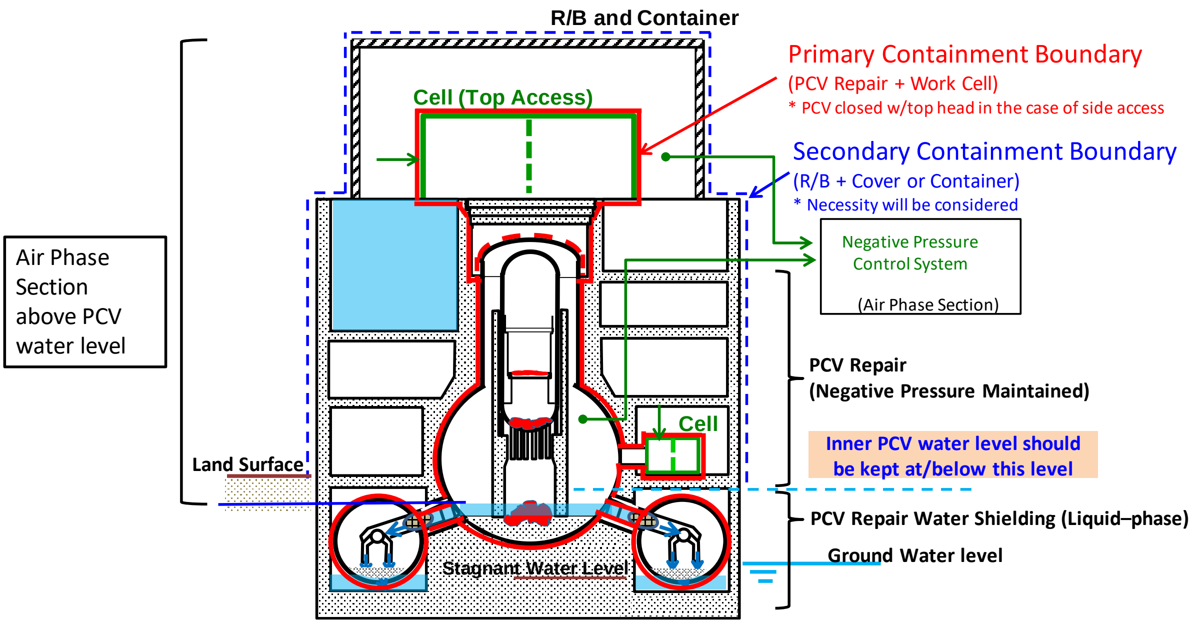


Fig. 9 Example of containment function (gas phase) by negative pressure control

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 data such as α dust dispersion rate and to establish measures to suppress the transition of α-dust gas phase as much as possible based on the collected data.

In order to collect data such as dispersion rate of α dust, it is necessary to plan the dispersion rate measurement during work state of sampling and small-scale of fuel debris retrieval work. Moreover, in order to progress with the technology investigation and R&D activity for 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. R&D for verification of this approximate understanding using simulated debris is currently underway.[7]

In order to suppress the transition of α-dust to the gas phase, it is desirable to submerge the fuel debris and to perform retrieving of it as much as possible under water. However, the water level in the PCV is to be adjusted with other technical requirements such as the building of the

[7] Refer to "(4) Elucidation of Behavior of Radioactive Suspended Particle Behavior Generated in the Decommissioning Process" (including α-dust Measures) in Attachment 12

containment function of the liquid phase described in the next section. Therefore, not all fuel debris can be retrieved under water, and transition of α-dust to gas phase is considered to be mitigated by splashing water on the fuel debris that is not submerged.

(2) Feasibility of negative pressure control in the PCV

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

In order to maintain pressure in the PCV in negative, enough capacity of gas exhaust system is required considering 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 considered as necessary, but there are some difficulties such as remote work or exposure of workers due to work under high dose conditions.

In this way, it is necessary to ascertain the technical feasibility of maintaining the negative pressure in the PCV based on the site conditions as well as the information obtained at each stage described in Section 3.1.3.1.

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

Air flows into the PCV when maintaining pressure in the PCV in negative. Therefore, it is necessary to examine measures of maintaining inactivated condition in the PCV by increasing nitrogen gas supply into the PCV as necessary based on evaluation on occurrence of accidents such as fire and Hydrogen explosion using accumulated information regarding to volume of hydrogen generated by radiolysis of water in the PCV and inflow volume of air (oxygen) into the PCV. Evaluation results on influence of air (oxygen) inflow on corrosion of structural material and its preventive measure are discussed in Section 3.1.3.3.6 for details.

C. Necessity of secondary containment function

As illustrated in Fig. 9, fuel debris is planned to retrieved and collected into the canister which is to be packed into the transfer cask in the working cell which is installed to be connected to the PCV maintained pressure under negative. 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 is considered to 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 at each stage of the fuel debris retrieval scale expansion, 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 pressure in the PCV in negative during the fuel debris retrieval work, it is necessary to consider how to respond deterioration of the primary containment function consisted of the PCV and the attached cell due to earthquakes and aging. This is discussed in detail in Section 3.1.3.3.6.

(3) Study on exhaust gas management

In managing gas exhaust system for maintaining pressure in negative, radioactive material derived from fuel debris in exhaust gas shall be controlled under the level of dose rate limit for public around the site by measuring and controlling release concentration and release amount of the radioactive material. In addition, concentration or amount of the nuclides derived from the fuel debris which releases α or β (γ) 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 section, to lower the dispersion rate of generated α-dust and to mitigate the transition to the gas phase, the fuel debris retrieval work would be performed under water condition by submerging the fuel debris or by pouring water over the fuel debris. In such cases, a great number of α-dust will be mixed in cooling water (liquid phase). To prevent the impact of α-dust in the cooling water on the environment, it may be important to establish a cooling water circulation/purification system as well as a containment function of liquid phase.

The 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 described in 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[8] of the actual scale test, it may be important to explore a retrieval method to minimize leakage with the realization of suitable circulation and purification systems of cooling water (See Attachment 6).

To establish a reasonable containment function of liquid phase at each stage as scale grows described in Section 3.1.3.1, it is rational to monitor the radioactive concentration of the cooling water and verify the validity of the containment function built in the subsequent stage. For example, if the PCVs internal investigations and small-scale retrieval work are performed using the current water circulation system, it may be possible to suppress the increase of the radioactive concentration of cooling water by reducing the retrieved volume and selecting a retrieval method that does not require cutting and drilling, together with the containment function (gas phase). From the viewpoint of investigating the methods to detect the effects induced by the retrieval work on the liquid phase, the circulating water system would be monitored, and based on the confirmation of monitoring results of α-nuclides, the fuel debris retrieval method may gradually be changed to a larger retrieval method using cutting and drilling equipment. If an abnormal event such as a large volume of cooling water outflow from a PCV to the torus room of a 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.

8 IRID, “FY2016/2017 Report of the results on Development of PCV leakage repair technology , Subsidy for Decommissioning and Contaminated water management project by the supplementary budget FY2015”, released in July 2018, http://irid.or.jp/wp-content/uploads/2018/06/20170000_08.pdf ,
IRID, “FY2015 Report of the result (Final Report) on The actual scale test for PCV repair technology, Subsidy for Decommissioning and Contaminated water management project by the supplementary budget FY2015”, released in March 2018, http://irid.or.jp/wp-content/uploads/2018/06/20170000_07.pdf

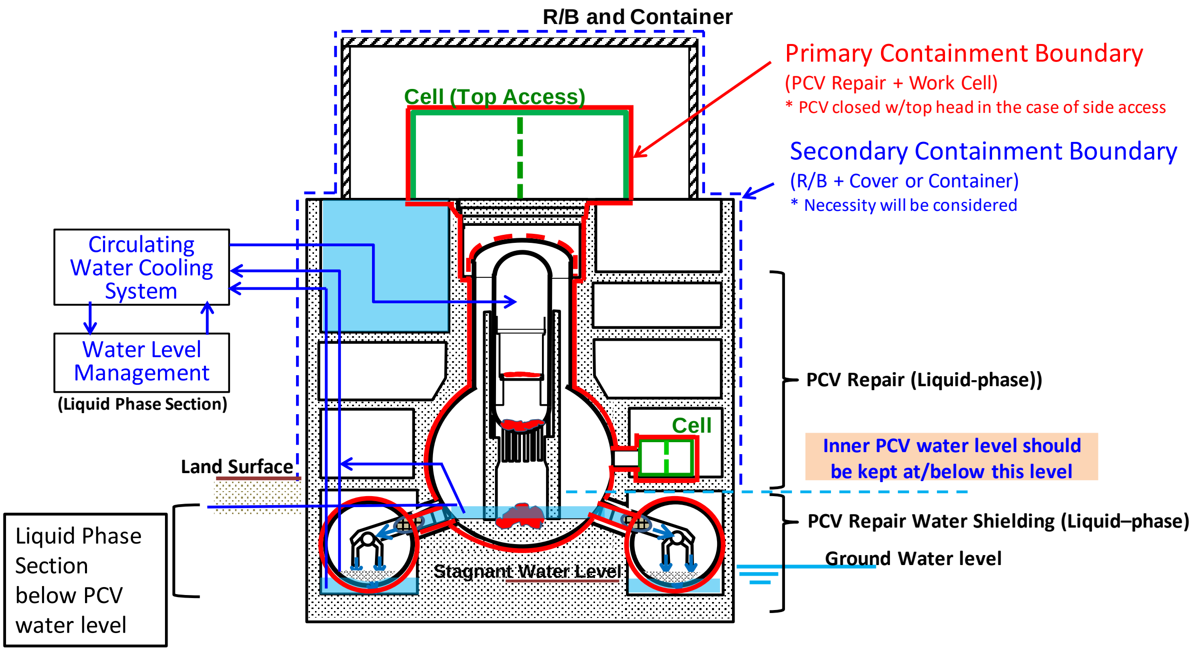


Fig. 10 Build example of containment function (liquid phase)

(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 the sampling or 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. Demonstration and confirmation of its performance are required at the stage of small scale of fuel debris retrieval.

(2) Feasibility of PCV water sealing

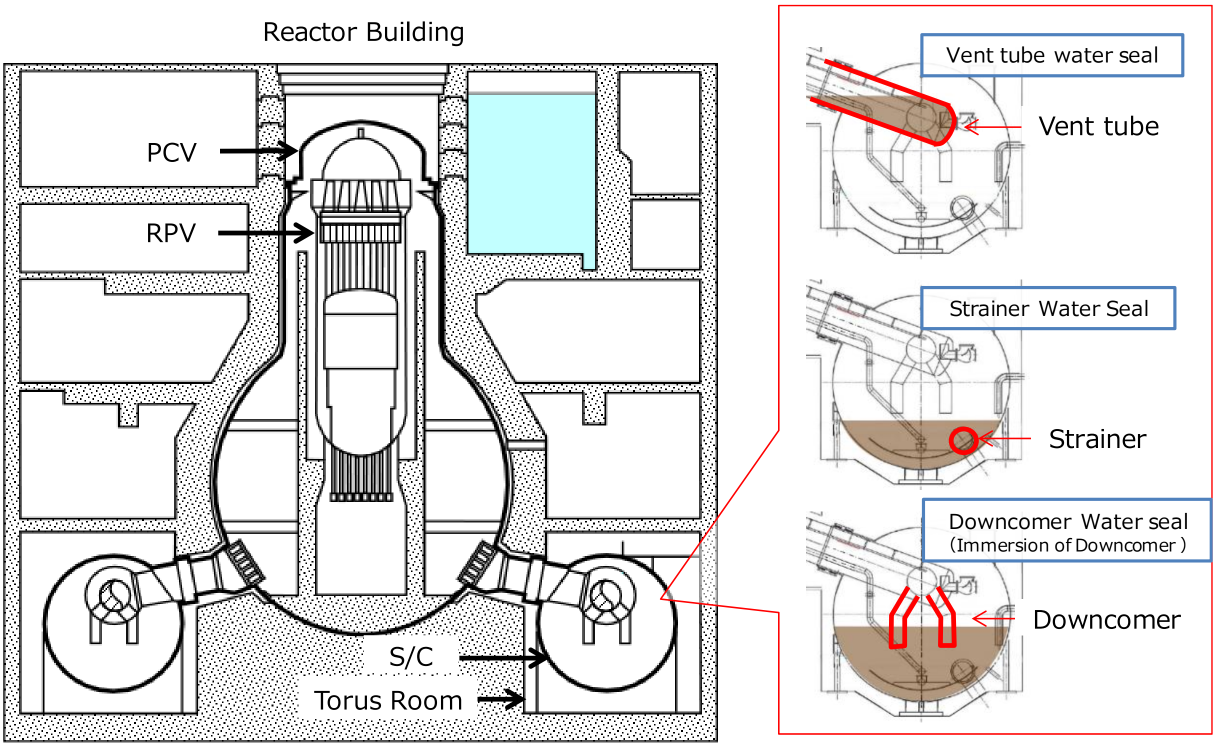
With an aim of improving the containment function of liquid phase at the bottom of the PCV by suppressing leakage of cooling water into the torus room, various PCV water sealing methods including blockage of the vent tubes, burying of the tip of the down-comers and burying the pipe strainers on the S/C wall by concrete have been studied. (Refer to Fig. 10)

Workability and performance of the water sealing technology of blockage of the vent tubes were examined through an actual scale test, using self-filling concrete for blockage of the vent tubes. Drilling holes through 1st floor of the Reactor Building, wall of the S/C and the vent tubes prior to concrete pouring into the vent tubes as well as treatment of these drilled holes after water sealing work completion are also necessary to be performed. Countermeasures for the worker's exposure and reduction of the radiation at the work area are also required for these works. In addition, method/technology with high repeatability for blockage of the vent tubes shall be developed because all sealing work of eight vent tubes need to be completed at the same time. However, current method/technology has not been reached sufficient reliable level.

Rise in concrete temperature during its curing, height of placed concrete need to be studied and repair material for these cracks is required to be developed because some cracks on the placed concrete surface were observed at the full scale test of water sealing by injecting concrete into the Suppression Chamber (S/C) for burying of the tip of the down-comers and the pipe strainers on the S/C wall. The feasibility of S/C guide pipe installation work necessary for concrete injection into the S/C has been experimentally examined. These experiment results show that improvement of the remote construction technology for the guide pipe connecting part, development of the remote examination technology including nondestructive examination at the connection part compiled with Regulatory Requirement and its maintenance method need to be continued. These activities have been carried out as tasks in the Government-led Project of Decommissioning and Contaminated Water Management.

In addition for establishing the water tightness at the penetration of piping through PCV shell and torus room wall, material for water sealing and the remote placing equipment have been developed, and the feasibility of the water sealing work using them has been confirmed. However, it is difficult to access to such place of actual units for water sealing work because of high radiation field. It is also presumed that there are water leakage through unknown paths such as small cracks or gaps were observed in unit 5 and 6 even after the water sealing work. Therefore, complete water sealing is considered to be difficult at units 1 to 3.

As mentioned above, technical issues still remain to be continuously resolved in order to improve the performance of PCV water sealing, as well as current level of water sealing technology is found not to be able to achieve complete water sealing. Even in case of practical water sealing work of blockage of the vent tubes, it is necessary to install the PCV cooling water circulation 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 preliminary engineering work. Finally, the applicability of these water sealing technologies to actual unit should be judged based on these results.



Enlarged views in the right are material from IRID[8] that was partly modified.

Fig. 11 PCV lower area water sealing (Examination example)

(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, cooling of fuel debris, radioactive dust dispersion and location of taking water from the D/W need to be examined, as well as the water level in the PCV, S/C, torus room and groundwater are required to be monitored and controlled during fuel retrieval work.

Attachment 7 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℃ 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 stage of retrieval scale expansion d described in Section 3.1.3.1, 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 system. Based on the data obtained for each stage of retrieval scale expansion, it may be necessary to examine the circulation cooling system to be required in the subsequent stage while evaluating the reasonable circulation flow rate necessary 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 as follows.

(1) Establishment of a temperature target during operation and countermeasures to an abnormal conditions

It is necessary to establish the PCV internal temperature target at which each operation of fuel debris retrieval work is able to continue. Also, countermeasures against the unanticipated abnormal condition need to be studied. 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 preliminary engineering work, in order to carefully proceed 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 ("FP") of short half-life, has shown no sign of criticality as it does not exceed 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 extremely 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. Further, the fuel debris is presumed to scatter in a wide range, instead of remaining in the core, as results of the accident progression. Even if criticality should occur, it may be pointed out that the effect of re-criticality is presumed to be small because the fuel debris widely scatters.

To keep the subcritical condition more reliably, it is important to store the retrieved fuel debris stably, controlling the shape and size of retrieved fuel debris, for instance, by storing the debris in storage cans. To prevent fuel debris from reaching criticality during the fuel debris retrieval work, it is necessary to investigate what kind of conditions during the work would lead to criticality, including the shape of the fuel debris or the water volume changes, and establish an appropriate management method with combined functions of prevention, detection, and termination of criticality.

To realize the management method to avoid re-criticality, it is necessary to carefully expand the scale of fuel debris retrieval while inspecting the character/composition etc. of fuel debris at each stage described in Section 3.1.3.1. In the early stage of the retrieval work, the fuel debris should be retrieved in a way that does not significantly change the shape of fuel debris. Then, the composition and characteristics of fuel debris and the fluctuation of the neutron signal in the vicinity of fuel debris handled during the work should be checked to evaluate the possibility of the criticality of the fuel debris. The volume of fuel debris retrieval at one time can be increased based on the measurement of subcritical conditions or taking measures such as placing neutron absorbers. However, in case the confidence level is not enough by just limiting the retrieval amount of fuel debris additional measures such as measuring the degree of criticality before retrieval operation and/or inputting neutron absorbing materials may be considered.

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

(1) Establishment of criticality evaluation method

As described in Section 3.1.3.1, it is necessary to refine the information on the conditions for reaching re-criticality of the fuel debris based on obtained information in each step of the fuel debris retrieval work. In this regard, the evaluation method have been developed to estimate the conditions for sub-criticality and the degree of influence of criticality if it should happen. In conducting these evaluations, it is necessary to plan so that the information on the critical parameters can be obtained through the process of progressing internal investigations.

(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 the criticality monitoring are, (1) ability to survive accumulated dose (Gy) according to the operation period and (2) installability in assumed equipment (size/weight, cable diameter). Accordingly, it is important to select an optimal detector based on the information on PCV 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.

(3) Feasibility study of measuring the degree of sub-criticality

When measuring the degree of sub-criticality, 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 gamma ray environment. From the examination to date, the equipment mountability (size/weight) of detectors is a key issue[9] mainly due to the necessity of shielding the lead under a high gamma ray environment (assuming 1000 Gy/h). In the future, the neutron detector has been selected and optimized, reflecting the constraints introduced by the study results of the project of the fuel debris retrieval method and system. Meanwhile, efforts have to be put into ascertaining the gamma ray dose rate and neutron count rate around the fuel debris and downsizing the detector as well.

In addition, in order to verify the applicability of the measurement system of sub-criticality for the actual retrieval work of the fuel debris, where various mix of the compositions and characteristics of the fuel debris are expected, it is necessary to formulate a plan for verification of the technology reflecting the actual circumstances.

(4) Feasibility study of neutron absorber

Based on the information obtained at each stage described in Section 3.1.3.1, the feasibility of constant use of sodium pentaborate as a neutron absorber has been studied, investigating the necessary boron concentration and the installability of the equipment, in case it turns out that the criticality of fuel debris is relatively high[9]. While examining the influence on 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 operation.

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

In addition, the development of a non-soluble absorbing material which can locally restrain the influence on the PCV circulation cooling system, has been performed as well. B_4C metal sintered material or B/Gd-containing glass or Gd_2O_3 particles and water glass /Gd_2O_3 granulated powder have been proposed as candidates so far by conducting fundamental physical property test and radiation resistance performance test. For the candidate materials, further studies are underway on methods of obtaining data by long-term exposure test for the storage of the fuel debris, and methods of dispersion to fuel debris and confirming the effect after spraying as adaptability

[9] IRID, Final Report of “Development of Criticality management technology for fuel debris” Subsidy for Decommissioning and Contaminated water management project by the supplementary budget FY2015, released in March 2018, http://irid.or.jp/wp-content/uploads/2018/06/20170000_05.pdf

corresponding to debris processing[9].

(5) Detection of criticality by PCV gas management installations

The current PCV gas management equipment is to be maintained as criticality monitoring in order to detect re-criticality due to the fall of fuel debris and/or accumulation of debris of fine particles in location other than the cutting area.

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[9]. However, the applicability to the actual plants is to be examined in the future.

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, taking into account the effects mentioned above against the possible occurrence of a severe earthquake. In addition, the deterioration of containment function of PCVs and reactor buildings due to corrosion have to be suppressed during the retrieval work. Furthermore, it may be required to prepare for the mitigation measures in advance, evaluating the impact on human beings and the environment induced by the postulated damage to important functions due to a large earthquake.

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 (600Gal), taking into account the damage caused by the accident, the degradation over 40 years and the increased weight of new facilities required for the fuel debris retrieval work.

In these evaluations, while taking into account major damage caused by hydrogen explosions in the reactor buildings of Unit 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 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[10]. 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.

For the evaluation of pedestals, conservative conditions have been set taking into account the influences of exposure to the high-temperature environment[11], 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 a detailed analytical models. The results shows that the S/C supports may have a certain level of safety margin against the design basis earthquake ground motion[11] 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.

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.

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

As described in 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 progresses due to inflow of

10 e.g. Contents from Measurement to the Fukushima Daiichi NPS accident/, Reservation and status of implementation on interviews with regulated person, etc. dated on July 24th, 2014, “The result of periodic inspection (the 9th) for confirming integrity of the reactor buildings of Unit 4 of the Fukushima Daiichi NPS”, released in July 2014 on NRA web, http://www.nsr.go.jp/data/000054381.pdf

11 IRID, “Development status of integrity assessment technology for PCV/RPV” Subsidy for Decommissioning and Contaminated Water Management project by the supplementary budget FY2013, released in November 2015, http://irid.or.jp/_pdf/201509to10_09.pdf

atmospheric air during fuel debris retrieval work. The evaluations of earthquake resistance described in (1) have been done considering the impact of corrosion progress. It has been evaluated such that they have relatively large seismic safety margin against a design-basis seismic ground motion Ss(600Gal) 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 one of the subsidized R&D projects of 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, 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[12]. 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[12]. 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 fuel debris retrieval are high dose areas such as inside the reactor buildings. Also, in the new stage of fuel debris retrieval, there comes a need handling of nuclear fuel materials containing α-nuclides derived from fuel debris with a large internal dose impact. Accordingly, the strict control of not only for external exposure but also for internal exposure is essential.

Specifically, it is important to prevent excessive exposure to workers through appropriate radiation protection schemes depending on the working environment (target nuclide, dose equivalent ratio, air 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 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

[12] IRID, “The report of the result on Development of corrosion inhibition technology for PCV/RPV”, Subsidy for Decommissioning and Contaminated Water Management project, released in July 2017, http://irid.or.jp/wp-content/uploads/2017/06/20160000_10.pdf

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 dose for overall work.
- 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 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 reduction of radiation dose.

Regarding the protection from internal exposure, measures such as suppressing dispersion of radioactive dust and prevention of contamination expansion are being taken and appropriate protective measures are to be selected depending on the target nuclides, concentration in air and surface contamination density in the work area, to prevent inhalation ingestion and body pollution. In addition, 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 know-how/technology transfer.

In particular, concerning the reduction of exposure of workers in the reactor building, it is important to set up a dosage reduction plan in consideration of the contamination condition in order to secure the necessary operation environment for the operation target area by the appropriate dosage reduction technique (decontamination, removal, shielding). The target dose rate of the operation target area is set to be lower than the exposure dose limit (50 mSv/year and 100 mSv/5 years) specified by laws and regulations, it is necessary 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 and utilize it on-site.

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

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 equipment and devices used for fuel debris retrieval work, and transporting fuel debris and waste, an access route should be established by removing obstacles and reducing the 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, from the perspective of a containment (the air phase) function described in Section 3.1.3.3.2, it should be kept in mind to suppressing the release of radioactive materials from the PCV and RPV and maintaining the integrity of existing structures.

According to the fuel debris retrieval policy based on the partial submersion method that extends the side access to the bottom of the PCV, TEPCO is now conducting the preliminary engineering work. Based on the results of R&D of decommissioning and contaminated water management, an access route from the PCV side opening to the fuel debris is to be constructed. Then, it will be drawn up a plan in which a side wall opening is made on the reactor building and the side wall opening on the PCV is enlarged as required. In 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 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 stage of the internal investigation etc. described in Section 3.1.3.1.

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. At present, it is considered on the premise of accessing from the top to the inside of the RPV.

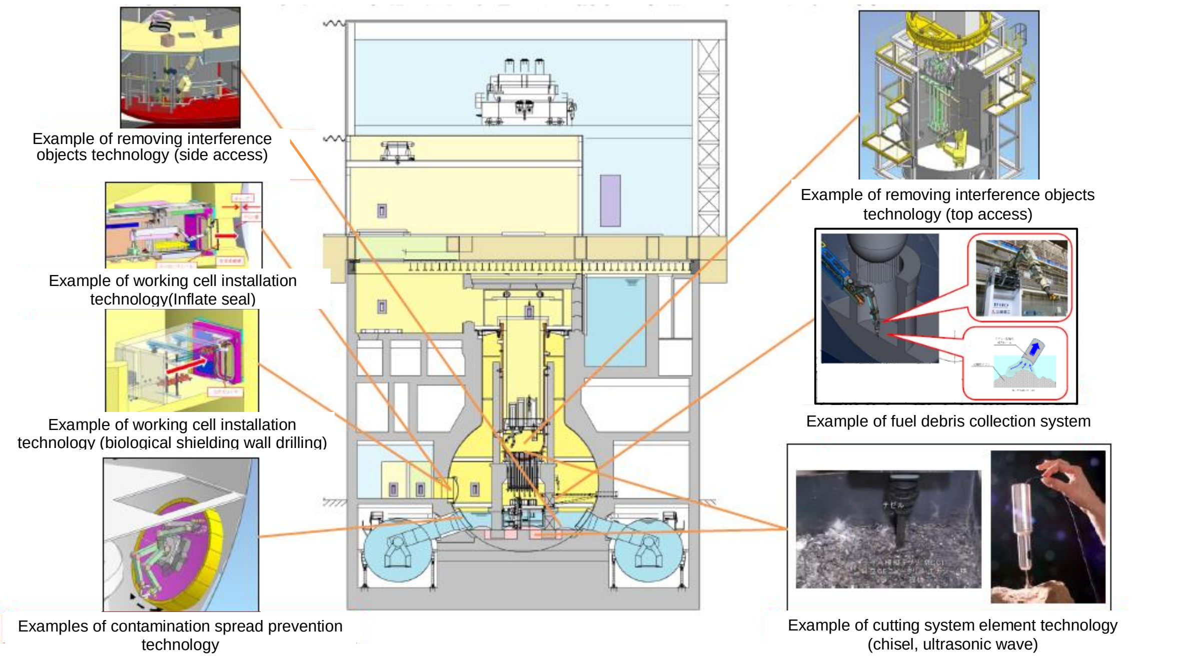
3.1.3.4.2 Development of devices and equipment

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 and protection mechanisms such as the temperature target described in Section 3.1.3.3.4, remote investigation/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 these issues, it is necessary to clearly define the fuel debris retrieval devices/equipment to be used at the next stage from the data obtained at each stage described in Section 3.1.3.1. As the functions to be specifically implemented, the development of a recovery system that can handle various conditions of fuel debris (fragments, sludge, or fine powder), a fuel debris cutting system (laser, boring, or crushing, etc.), and a dust collecting system, is underway. Furthermore, a technique for installing retrieval equipment is required. The technology used for remote operation, including installing the working cell for establishing a containment function (gas phase) and the device for removing obstacles to provide an access route, are now under development. (Refer to Fig.12)

Although these technological developments are currently under way in the project for decommissioning/ contaminated water, in the future, the developed devices and equipment will be combined and undergo remote mock-up tests to verify that the performance mentioned above is demonstrated on the actual site.

This remote mockup 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 purpose, such as utilization in units 5, 6. Therefore, in cooperation with related organizations, NDF is working on organizing and examining how to proceed with the remote mockup test plan, the way of the test plan review, the scope of the mockup facility to be maintained, the necessary time, operation management, etc.



(Images provided by IRID)

Fig. 12 Fundamental technologies for retrieval of fuel debris and internal structures

3.1.3.4.3 Establishment of system equipment and working areas

When retrieving fuel debris, it is necessary to install system equipment (Container/ Working cell/ including devices and equipment) to establish safety functions and operate them appropriately. Also, it should be prepared that sufficient spaces for installation, operation, and maintenance, and for installing shields for reducing radioactive 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 Section 3.1.3.3.2, a circulation water cooling/purification system required for maintaining the containment function of the liquid phase described in Section 3.1.3.3.3 and cooling function described in Section 3.1.3.3.4, and a criticality control system required for controlling criticality described in Section 3.1.3.3.5. The installation plan for the respective unit is being examined[13]. Because it is essential to monitor the internal situation when retrieving fuel debris, the development of measurement systems (visualization, pressure, temperature, radiation, criticality (rare gas concentration, etc.) hydrogen concentration, etc.) is an important future issue to be addressed. An investigation on how to implement the system equipment integrating these systems is under way.

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-dose area in the reactor buildings and interference with other tasks, study of setting up the systems, including

[13] IRID, "The report of the result FY2017, "Advancement of retrieval method and system for fuel debris and structure inside reactor" Subsidy for Decommissioning and Contaminated Water Management project by the supplementary budget FY2016, released in April 2018, http://irid.or.jp/wp-content/uploads/2018/06/20170000_10.pdf

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 (collecting, transferring and storing)

The fuel debris retrieval work requires to establish a comprehensive system consisting of a series of steps from collecting, transferring to storing of retrieved fuel debris furnished with safety functions such as maintaining subcritical condition, containment function, countermeasures against hydrogen generation, and cooling. Specifically, the basic specifications of the canister such as the total length and inner diameter has been studied taking easiness of its handling, the storing efficiency and maintaining of the subcritical condition into account[14]. The allowable transportation period has been investigated in accordance with the estimated volume of hydrogen generation from canister. Based on these results, details of equipment/systems for collecting, transferring, and storing of the retrieved fuel debris need to be discussed. Storing facility considering to the safeguards requirements is also necessary to be studied based on the estimated volume of the retrieved fuel debris. It is also important to plan mock-up tests for confirmation of handling of the canister combined with a fuel debris retrieval devices.

Proper handling method/devices for retrieved fuel debris in the subsequent stage need to be studied and improved taking the data obtained from work experience in previous stage described in the Section 3.1.3.1 as well as above mentioned technical issued into account. It is currently considered to be appropriate that the retrieved fuel debris at the step of the fuel debris sampling must be collected in the shipping container for transporting to the radioactive material analysis and research facility outside of the site, and retrieved fuel debris during the small-scale fuel debris retrieval step should be stored appropriately at a temporary storing facility until completion of the actual storing facility because volume of the retrieved fuel debris at this step will be small.

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

3.1.3.5.2 Treatment of radioactive waste during fuel debris retrieval

During fuel debris retrieval work, various radioactive waste such as replaced or disassembled components or parts other than retrieved fuel debris are to be generated from fuel removal device/facility inside/outside of the PCV, at each stage of fuel debris retrieval work including its

[14] IRID, "The report of the implementation FY2017, "Development of technology for Collection, Transferring and Storage of fuel debris" Subsidy for Decommissioning and Contaminated Water Management project by the supplementary budget FY2015, released in June 2018, http://irid.or.jp/wp-content/uploads/2018/06/20170000_03.pdf

preparation and withdrawal work. It should be properly classified and stored under safe condition same as fuel debris.

It is practically difficult to accumulate and organize necessary and sufficient information such as distribution and characteristics of the fuel debris and the radioactive wastes such as core internals in PCV prior to its 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.

It is important to develop a classification standard in order to judge appropriately such material into fuel debris or radioactive waste during retrieval work, even if only limited information on the retrieved material is available in advance. From above reason, detailed studies on treatment of retrieved materials including classification standard needs to be continued based on the findings and information obtained from the investigation inside of the PCV.

3.1.3.5.3 Study on Safeguards Measures

Nuclear facilities in Japan need to observe the duties concluded with the International Atomic Energy Agency ("IAEA") of comprehensive safeguards agreement and its additional protocol, and are expected to show that nuclear materials are utilized for peace 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 supplemental access by IAEA.

In the Fukushima Daiichi NPS, as above, it had been confirmed via the IAEA safeguards activities that the nuclear material was 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 execution of the safeguards, greatly changed. In a sound nuclear power plant, the nuclear material is clearly counted as an item one by one with a fuel assembly of a certain defined shape as one unit, but implementation of conventional material accountancy and safeguards is deemed difficult for the units 1 to 3 of the Fukushima Daiichi NPS, since the fuel assemblies would no longer maintain their shape as an item due to melting, the damaged facilities would not allow necessary containment/surveillance schemes for key measuring points, and high radiation would restrict the entry of human beings into the areas and prevent normal investigation activities, and so forth. Additional safeguards operations are currently applied under this situation to the units 1 to 3 as an alternative measure to ensure no undeclared relocation of the nuclear materials, and so forth.

Given the fuel debris retrieval (FDR) operations in future intrinsically move nuclear materials from the inside of PCV to the outside of PCV in the units 1 to 3 of the Fukushima Daiichi NPS, corresponding safeguards operations will be required. However, in addition to the difficulty of item control, fuel debris is highly likely to contain structural materials other than nuclear materials and so forth, 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 created to replace the conventional scheme.

Towards the solutions for these issues, discussion started in the Fukushima Task Force established between the IAEA and the Japanese Nuclear Regulation Authority about the safeguards options being reflected to the probable FDR schemes. Japan is providing updated information of the units 1 to 3 of the Fukushima Daiichi NPS from the early stage to the stakeholders including the IAEA, aiming at the prompt and smooth application of the safeguards in the FDR operations. 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)". Realistic and transparent enough material accountancy and safeguards, which would not impose excessive load to the site work, must be proposed proactively by Japan to reach the global 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. 13.

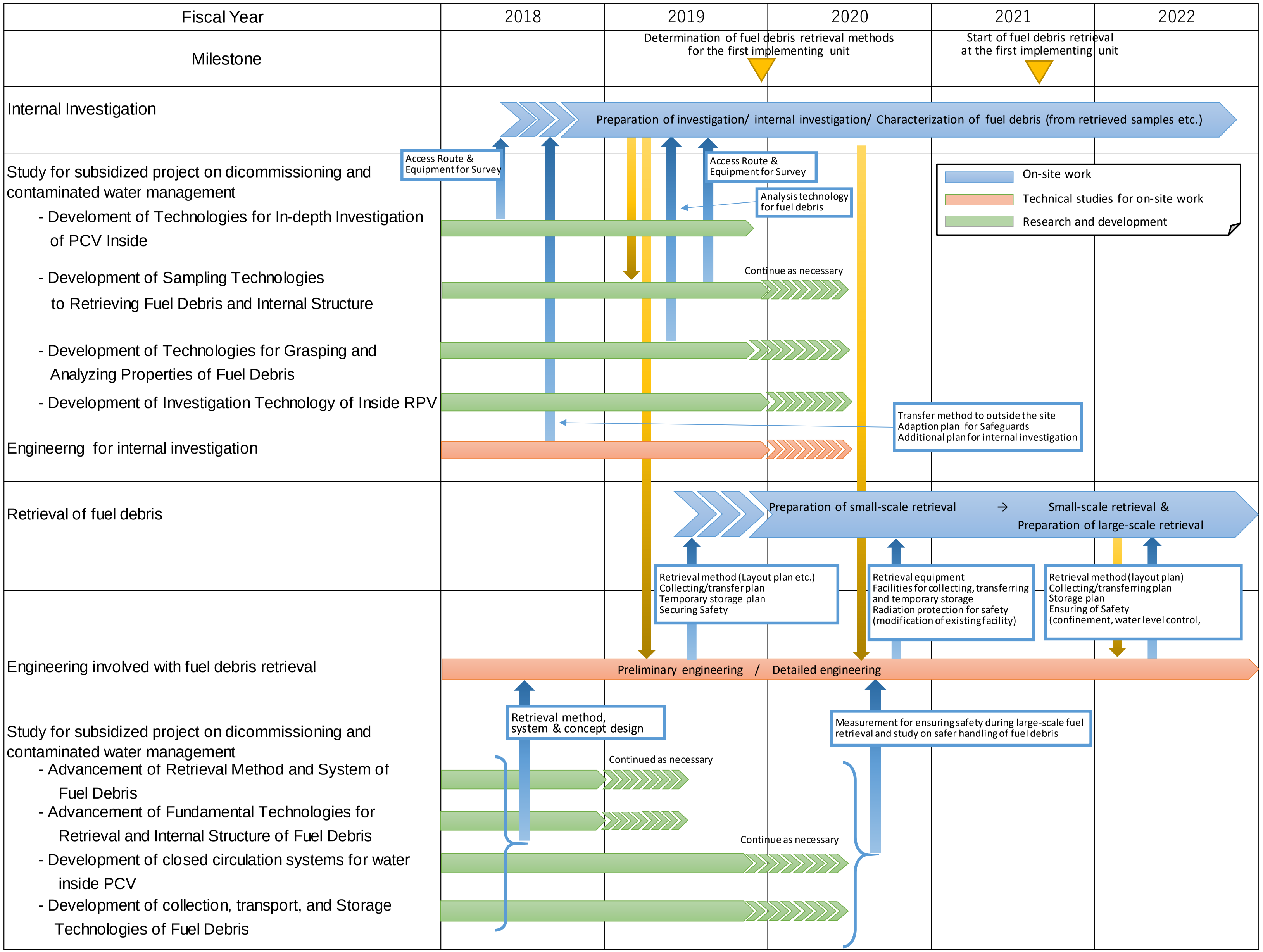


Fig. 13 Technical issues and further plan on fuel debris retrieval

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 will be proceeded 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 strategy

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 IAEA is shown in Attachment 8.

The solid waste, such as concentrated wastewater, waste sludge, slurry in the high integrity container (HIC), "rubbles, etc.", and contaminated building structures, is unlikely to increase in risk in the future, but they are still a source of risk 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 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 estimated 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 proposals 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 Roadmap revised in September 2017 summarizes the basic concept regarding solid waste, based on the content of the strategic proposals.

＜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 and 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 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 and 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 the exposure of workers to radiation
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.

(Note) Numbered and titled by NDF for each item.

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 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 the characterization to processing/disposal of the waste).

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

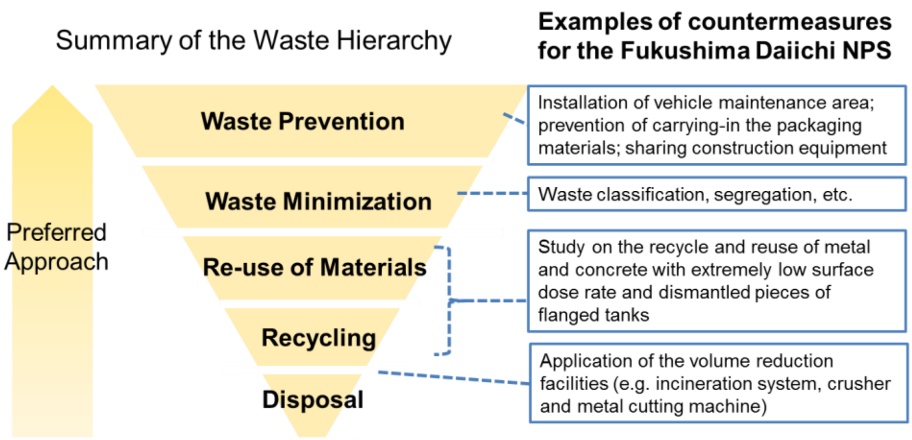
3.2.2.3 **Storage**

3.2.2.3.1 Storage at present

The fundamentals of managing solid waste are to contain 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 waste management departments 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. 14. It is important to instill the concept of the waste hierarchy, and raise awareness on reducing the volume of solid waste to be generated.



(a) Concept of waste hierarchy in UK NDA (b) Measures in Fukushima Daiichi NPS

Source : based on "Strategy Effective from April2011 (print friendly version) ",NDA

Fig. 14 Summary of Waste Hierarchy at the NDA, UK[15] and Countermeasures at the Fukushima Daiichi NPS

Among the solid waste that has been generated by April, 2018, "rubbles, etc." have been classified into rubble, fallen tree, used protective clothing and so on, and about 400,000 m^3 of the waste is stored in temporary storage areas according to the surface dose rates. Among the secondary waste generated by water treatment, about 4,000 used vessels, which have undergone additional measures such as adding shield for increasing water tightness, are stored in used adsorption column storage facilities.

Table 3 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 (Refer to Attachment 9).

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 plan is implemented 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

[15] NDA : Nuclear Decommissioning Authority, Edited based on the "Summary of the Waste Hierarchy" on Figure 7 of p. 60 of the "NDA Strategy Effective from April 2016," 2016.

a year and update the Storage Management Plan as appropriate, as TEPCO expresses to do.

Table 3 Solid Waste Storage Management Status

(a) Management status of rubble, fallen tree, used protective clothing, etc. (as of April 30, 2018)

Rubbles

Surface dose rate (mSv/h)	Storage method	Stored volume (m^3) / Storage capacity (m^3) (Percentage)
≤ 0.1	Outdoor storage	174,800 / 250,700 (70%)
0.1～1	Outdoor sheet covered storage	36,600 / 71,000 (51%)
1 to 30	Soil-covered temporary storage facility, Temporary storage tent, Outdoor container storage	21,900 / 27,700 (79%)
> 30	Containers (in Solid waste storage building)	8,900 / 45,600 (20%)
Total	----	242,200 / 395,000 (61%)

Fallen tree

Classification	Storage method	Stored volume (m^3) / Storage capacity (m^3) (Percentage)
Root	Outdoor storages	96,600 / 134,000 (72%)
Branch/leaves	Temporary storage pool	37,300 / 41,600 (90%)
Total	----	133,900 / 175,600 (76%)

Used protective clothing, etc.

Storage method	Stored volume (m^3) / Storage capacity (m^3) (Percentage)
Container	56,000 / 71,200 (79%)

(b) Management status of secondary waste generated by water treatment (as of May 3, 2018)

Used vessels

Storage Place	Type of Used Vessels	Storage Number	Storage Number / Capacity (Percentage)
Outdoor Temporary Storage area of used Vessels	Cesium adsorption apparatus	767	3,983 / 6,368 (63%)
	2nd Cesium adsorption apparatus	198	
	HICs from multiple radio-nuclides removal system	1,470	
	HICs from improved multiple radio-nuclides removal system	1,263	
	Used vessel from high-performance multiple radio-nuclides removal system	74	
	Used column from multiple radio-nuclides removal system	11	

	Used vessels and filters from mobile-type strontium system	200	

Waste Sludge

Sludge storage facility (Indoor)	597	m^3	597 / 700 (85%)

Concentrated waste liquid

Concentrated waste liquid storage tanks (Outdoor)	9,364	m^3	9,364 / 10,700 (88%)

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 evaluation 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 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 actual equipment for stabilization and immobilization considering disposal for several important waste streams such as secondary waste generated by water treatment.
- Establish method of rationally selecting processing technology to stabilize and immobilize waste based on the above methodology although the technical requirements for disposal are not determined (i.e. preceding processing).
- Have prospect of setting processing/disposal measure for solid waste of which the processing technology considering disposal is not clarified, using a series of method to be developed by 2021.
- Clarify issues and measures concerning storage of solid waste until conditioning

It is described in the Roadmap that, in accord with these efforts, specifications and production methods of the waste packages 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

Under the circumstance that the Building 1 of JAEA Okuma Analysis and Research Center is scheduled to commence operation at the end of FY2020; it is important to improve the accuracy of models to obtain evaluation data based on the limited radiological analysis data. The study will be proceeded 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.

The radiological analysis has been conducted for characterization so far, but target of radiological analysis will be mainly on the predisposal management and review targeted nuclides in near future. The study on radiological analysis to make it simple and rapid is proceeded together to develop efficient radiological analysis method. While reducing exposure by introducing remote sampling method, high dose sampling will be conducted. 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

The secondary waste generated by water treatment is proceeded to be dehydrated, for stabilization and extracted and transferred from temporary storage facilities to storage facilities on a hill as risk reduction measures for the time being.

On the technologies for stabilization, immobilization and conditioning of the secondary waste generated by water treatment, some technologies such as the high temperature processing technology and cement improvement technology has been considered. Challenges for introducing actual equipment should be dealt, and gathering and evaluation of data on technical requirements should be proceeded by using engineering scale test equipment and so on, from the point of view whether it may contributes to establish selection method for preceding processing method. Processing technology expected to be applicable for actual processing should be identified, and specification of waste package should be determined.

Regarding the methods of storing high-dose solid waste generated as a result of fuel debris retrieval, study should be proceeded 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 other solid waste, study should be proceeded 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 **Establishing processing/disposal concept and development of safety evaluation 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 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 will be proceeded until the end of FY 2021. In particular, the research on those such as domestic and international waste acceptance criteria, disposal concepts and safety evaluation methods are conducted; then, the study of disposal concept based on the characteristics of solid waste of the Fukushima Daiichi NPS is proceeded; subsequently, multiple disposal methods are to be presented; and suitable safety evaluation methods will be developed.

The precision of the selection results for preceding processing methods are then to be improved using the specifications of conditioned waste including more precise data on the properties.

3.2.3.4 **Others**

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

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 Subsection 3.5.3. At that time, measures against the waste generated from dismantling buildings and so on should be established based on the progress of decommissioning, future expectations, the conditions of reactor and other buildings, and the latest R&D and so on.

In addition, as measures for promoting efficient decommissioning, the characterization using quick measurement (in situ analysis and on-site analysis) by means of electromagnetic methods, and so on, should be examined in addition to radiochemical analysis, and R&D required for this purpose is expected.

3.2.3.5 **Summary of key Technical issues**

In regard to the technical issues described in this Chapter, entire management of solid waste is overlooked and studies are proceeded on close cooperation between the efforts to respective issue as shown in Fig.15.

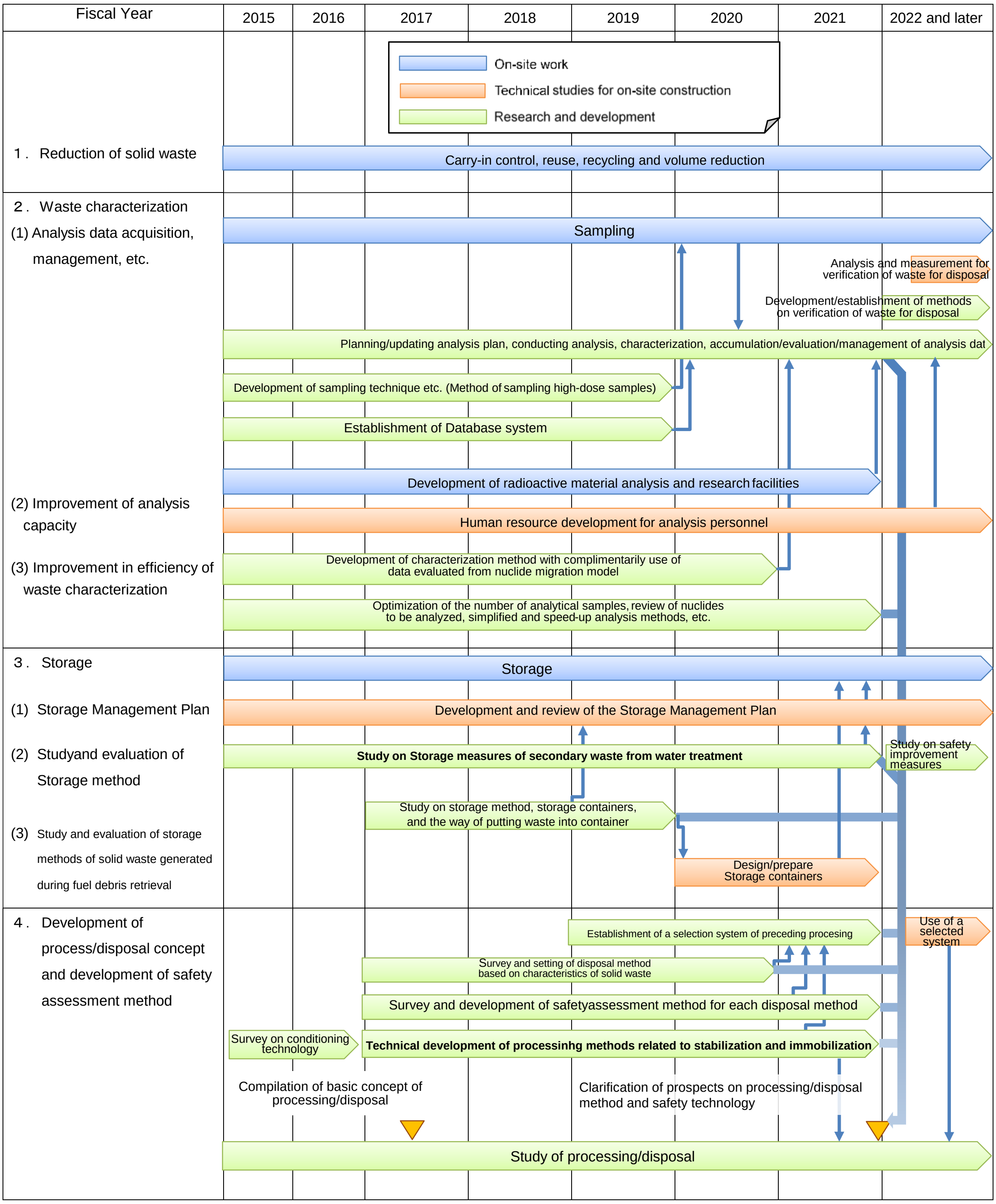


Fig. 15 Technical issues and further plan on waste management

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)[16], 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[17].

(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

For the contaminated water management at the Fukushima Daiichi NPS, as stated in Section 2.2, various measures based on the three principles has been implemented both to the contaminated water in the buildings and trench/pits and uncontaminated water such as groundwater/storm sewage.

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/storm sewage 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. 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 vessel with lower Safety Management. As the risk level of the stagnant water in the buildings, the Hazard Potential is reduced.

As measures against risk reduction so far, drainage of stored water in condenser in Unit 1 turbine building and removal of the stagnant water in the lowest floor area of Unit 1 turbine building

[16] Nuclear Emergency Response Headquarters "Tokyo Electric Power Company, Incorporated Basic Policy on Contaminated Water Problems at the Fukushima Daiichi Nuclear Power Plant On September 3, 2013, Nuclear Emergency Response Headquarters "Tokyo Electric Power Company, Incorporated Additional measures for the problem of contaminated water at the Fukushima Daiichi NPS" December 20, 2013

[17] 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).

(completed in March 2017) have been carried out, henceforth, the quantity of radioactive materials will be reduced continually from the stagnant water in the turbine building where the radioactive material concentration is high.

3.3.2.2 **Steady execution of contaminated water management indicated in the Roadmap**

Since the Fukushima Daiichi Nuclear Power Plant 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 multilayered measures based on the three principles, the site situation has shifted from that requiring urgent measures immediately after the accident to certain stable situation that can examine a medium/long term plan. The multilayered 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 storm sewage infiltration to reduce the amount of groundwater, groundwater bypassing, pumping up of 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 mentioned in the Roadmap are as follows: (1) reduction of the contaminated water generation to about 150 m^3/day (by 2020), (2) storing all the water treated by 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 penetrations between Units 1 and 2 and between Units 3 and 4, respectively (by 2018[18]), (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). It is expected that these preventive and multilayered drastic measures will be steadily implemented to achieve the milestones.

[18] Completed in September 2018.

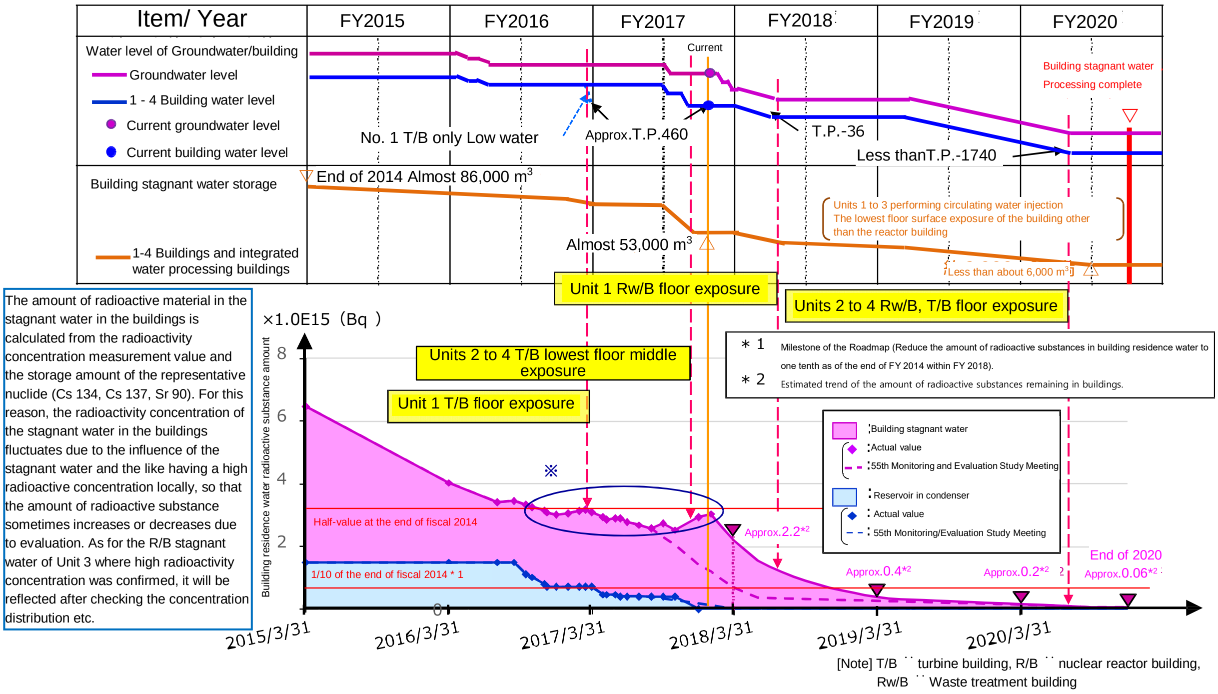


Fig. 16 Changes in the amount of radioactive materials in the stagnant water in the buildings[19]

3.3.2.3 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 medium to 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.

In the present situation, cooling water injected into RPV flows to PCV, then the water leaks from PCV to the torus room in the basement floor of the reactor building. A circulation water cooling and purifying system has been adopted in which the stagnant water is recovered in a turbine building through penetration and purified with cesium adsorbent equipment (KURION and SARRY) and then 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), the function of the buildings for the containment can be secured by preventing outflow of the radioactive materials to the outside of the building. (See

[19] TEPCO, “Progress on the stagnant water in the buildings” Handout 2-3 of 61st The Committee on Supervision and Evaluation of the Specified Nuclear Facilities”, Dated on July 6th, 2018

Attachment 6).

As described in the preceding paragraph, according to the target process of the Roadmap, it is considered that the processing of the stagnant water in the buildings other than the reactor buildings of unit 1 - 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 water.

Furthermore, the studies including feasibility of the PCV circulation cooling system for fuel debris retrieval is under way, and water shielding by repairing the bottom of PCVs has been examined to secure the multiple boundaries. However, it has been found that complete water shielding through repairing the bottom of PCVs is very difficult, so the circulation cooling system should prepare for the inflow of α-particles from inside of the PCVs to the stagnant water in the reactor buildings. Even if the water shielding is applicable, it is necessary to consider the setting of a sufficient difference in water level between stagnant water in the reactor building and the groundwater, in case a large amount 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 3.1.3.3.3. In addition to this, requirements from both sides of the fuel 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.

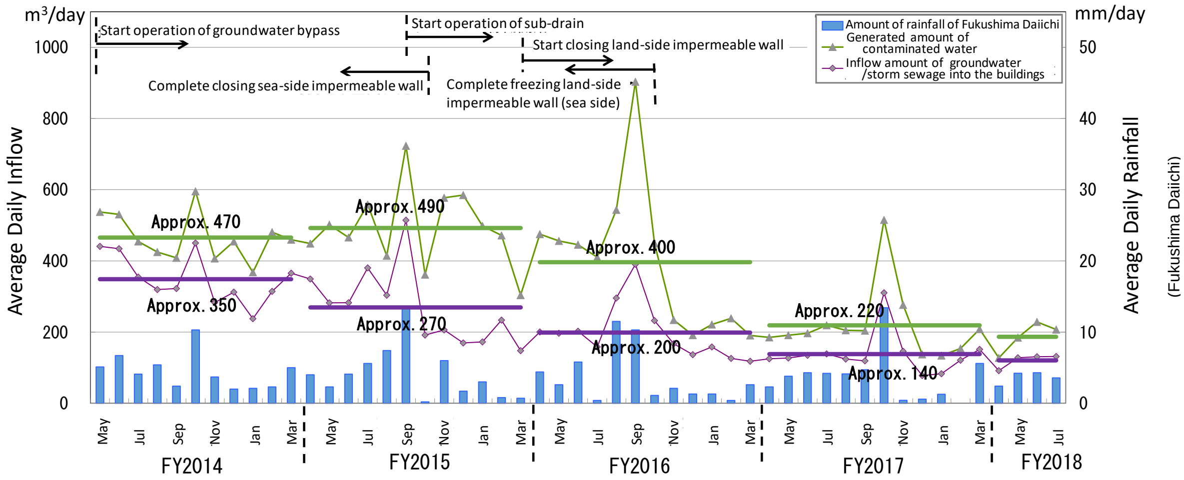
Also, as the fuel debris retrieval proceeds, the water injection for cooling the fuel debris will be no longer necessary. Then, there is no water stagnant in the lowest floor of the reactor buildings. In such a situation, the groundwater level should be adjusted to a level below the lowest floor of the reactor buildings, so 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 and the passive equipment with lower potential of machine troubles.

3.3.3 Technical issues and plans for promoting strategies

3.3.3.1 Steady execution of contaminated water management in the 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 approximately 220m^3 per day in FY2017 from approximately 400m^3 per day in FY 2016 (Fig.17). Also, the amount of the groundwater pumped-up from sub-drains and the groundwater drains in the seawall area have been reduced as well[20].



(Courtesy of TEPCO)

Fig. 17 Transitions of the generated amount of contaminated water and the inflow amount of groundwater/storm sewage, etc. into the buildings[21]

In this way, the condition of contaminated water is being controlled. From now on, further measures should be taken to complete the treatment of the stagnant water while addressing the measures for contaminated water directed by the government's contaminated water management committee[22], and focusing on the problems that have not been clarified yet.

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

In order to reduce the generation of the contaminated water to 150 m^3/day or less in 2020, which is indicated as a milestone in the Roadmap, it has to reduce 70 m^3 per day of the contaminated water that is occurring in FY 2017 by approximately 220 m^3 per day. In the future, further effort to reduce the generation of the contaminated water should be continued by

[20] "Evaluation of Frozen Soil Wall and further Contaminated Water Management", 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
[21] Handout 2 of "Overview of Decommissioning and Contaminated Water Treatment", The Secretariat Meeting (57th) of Team meeting on Decommissioning and Contaminated Water Treatment, issued on September 7, 2018
http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2018/09/2-1.pdf
[22] Quoted from Page 9 of "Evaluation of Frozen Soil Wall and further Contaminated Water Treatment", Committee on Contaminated Water Treatment, issued on March 7, 2018, as follows;
4. Further contaminated water treatment
(1) The generated amount of contaminated water should be reduced even more by continuing multilayered measurements including treatment of the stagnant water in the buildings, reduction of sub-drain water level, storm sewage control, etc.
(2) During heavy rain such as typhoon, generation of contaminated water temporarily increased due to inflow of storm sewage from damaged part of roof of the buildings and unpaved area around the buildings. In response to this, further measurements should be implemented systematically.
(3) Moreover, concerning the structures that water inflows from outside of frozen soil wall such as K-drainage, it is highly likely that it becomes the water supply path to the inside of frozen soil wall. For this reason, survey should be continued and necessary measures should be implemented.

implementing the multilayered countermeasures such as stagnant water treatment in the buildings, lowering the sub-drain water level, measures against inflow of storm sewage into the buildings. Furthermore, the countermeasures against inflow of rainwater including the measures for damaging the building roof by remote equipment are necessary.

(2) Operation in response to lowering of the water level in the building

For areas where the presence of oil on the surface of stagnant water was found, it is necessary to recover the oil in order to avoid the performance deterioration of the contaminated water processing system before exposure of the floor line. Also, after the floor line exposure, since floor line sludge etc. dries, it is feared that dust is developed, so dust countermeasures will be implemented.

Furthermore, installing the pump to the floor drain sump and transferring the residual water in the isolated area will be needed for the floor line exposure. It is necessary to implement the measures of dose reduction for the workers engaging the floor line exposure.

(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 improving reliability of sub-drain.

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

As described in Section 3.3.2.3, establishment of a PCV circulation cooling system as a system for fuel debris retrieval is being studied, and substances generated from fuel debris containing α-particle is mixed to the circulation water. Therefore, it is necessary to properly remove alpha 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 circulation water cooling and purification system in order to maintain the water balance. It is presumed that the water is treated with equipment such as multi-nuclide removal equipment. Therefore, it is necessary to monitor the alpha-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.

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. 18.

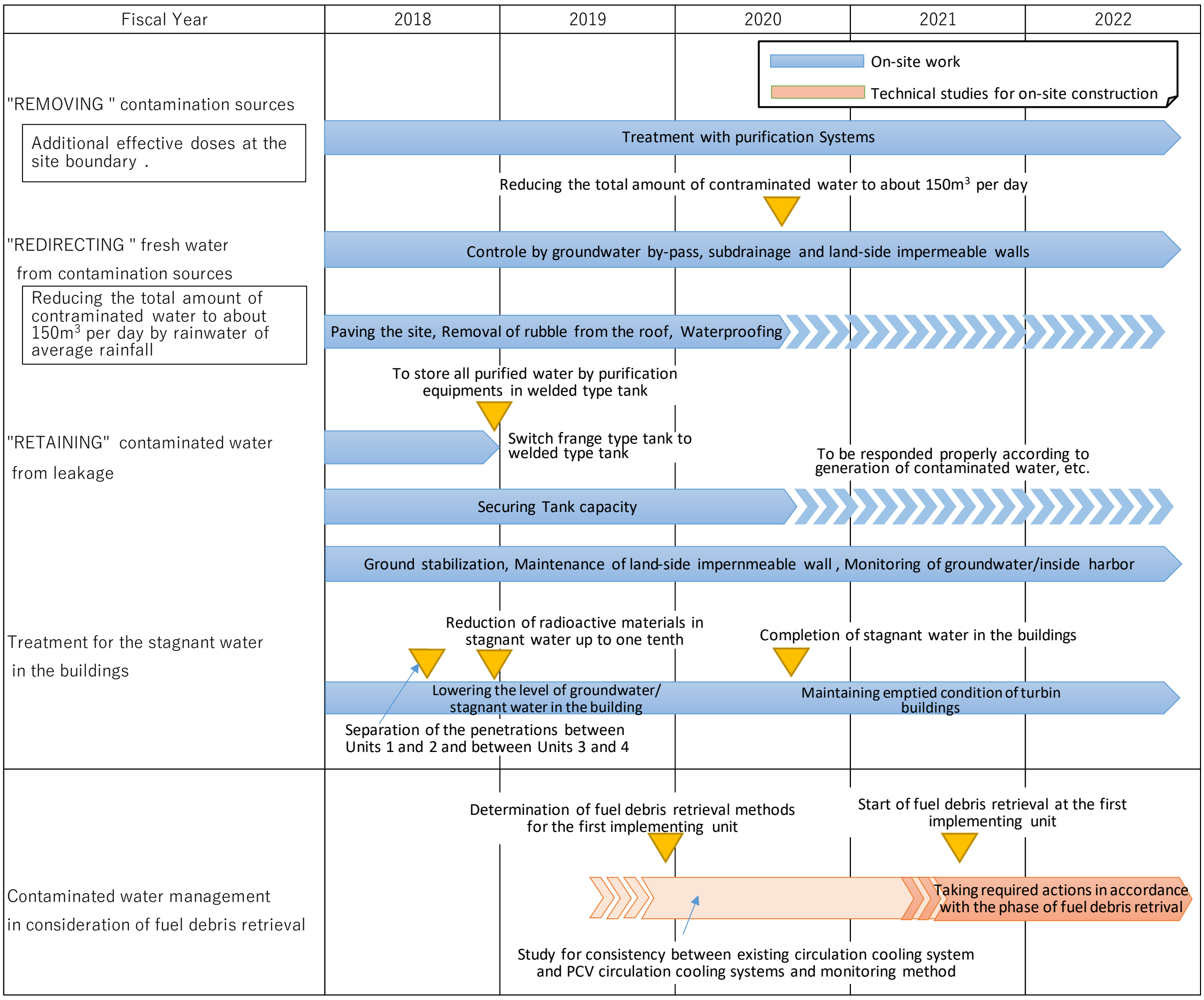


Fig. 18 Technical issues and further plan on contaminated water management (Process Chart)

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) To start removing the fuel from the pool by around

1) FY 2023 for Unit 1

2) FY 2023 for Unit 2

3) Mid FY 2018 for Unit 3[23]

under the rigorous risk assessment and management and taking measures for safety and security including preventing the disperse of radioactive materials.

(2) By transferring the fuel stored in the Common Spent Fuel Storage Pool to the dry cask at the Temporary Cask Custody Area, 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 the pools**

Fuel assemblies (fuel in the pool) stored in the spent fuel pool of the reactor buildings of Units 1 to 3, some of which were damaged by hydrogen explosion etc. are relatively high risk and high priority ranked risk sources (see section 2.3). From the viewpoint of reducing the risk due to radioactive material, the fuel is kept in a solid state not to diffuse as contained 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 starts to be exposed become relatively longer. Also, since it is a nuclear fuel material with a substantial amount of radioactive material (inventory), its hazard potential impact is relatively high. In addition, due to damage to the cooling facility due to the accident and damage to the reactor building at Units 1 and 3, the same functions as the conventional containment function and management function are not completely secured and the safety management importance is also relatively high. For this reason, it is to be transferred to the Common Spent Fuel Storage Pool needs lower safety management than the pool of the reactor buildings in accordance with an appropriate and concrete work plan developed depending

[23] In Unit 3, once started the trial operation for fuel handling equipment in March 2018, several troubles have occurred. After improved quality control issues which are recognized as a common factor, trial operation will be restarted, as well as investigation of the causes and countermeasures are taken. Making the safety as a top priority, TEPCO intends to examine and review the start of fuel removal in the spent fuel pool which was scheduled in November 2018, too. (Reference: "Trouble on FHM for Unit 3 of the Fukushima Daiichi NPS, TEPCO", Handout 3-2 of Secretariat Meeting (57th)/Decommissioning and Contaminated Water Management team meeting, released on September 6, 2018.
http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2018/09/3-2-7.pdf

on the situation of each unit, as soon as possible.

In addition, since the number of spent fuel assets held by each unit is different, there are slight differences in the degree of hazard potential impact. Depending on the rubble condition of the spent fuel pool and on the operating floor, damage condition of the reactor building, units 1 and 3 are inferior to Unit 2 in terms of diffusion inhibition function and further it is judged that there is an impact on retrieval since there is damaged fuel in Unit 1, so these differ in terms of safety management importance (Fig. 5). Based on these points, it is necessary to respond by designing an appropriate and concrete work plan for each unit.

In light of the decline in the decay heat of spent fuel, the evaluation of the increase in water temperature at the time of stopping the cooling was reviewed by confirming the condition at the time of stoppage of the spent fuel pool cyclic cooling system. This system was implemented in recent years and it has been observed that excessive maintainability was lost compared to the conventional evaluation, and an evaluation formula close to actual temperature was obtained[24]. According to this evaluation formula, it has been confirmed that even if the cooling of the spent fuel pool is stopped for about 1 to 2 months, the water temperature will only rise by about 10 to 20 °C by considering natural heat dissipation.

3.4.2.2 **Specific plan for fuel removal from the pools**

Work schedule for fuel removal in Unit 1 to 3 was already specified in the Road map, and TEPCO has been proceeding with their tasks to meet this schedule.

Unit 1, the building cover had been removed, wind breaking fence had been installed,, and then removal of some fallen rubbles generated by Hydrogen explosion were initiated and countermeasures against falling into the spent fuel pool, etc. were initiated under taking measures for prevention of radioactive dust dispersion. The time to start removing fuel in the pool is targeted for FY 2023.

Unit 2 is not affected by hydrogen explosion and maintains the soundness of the building, but it is planned to dismantle the upper part of the reactor building in order to install fuel removal installations. For this reason, Making of opening to have access to the operating floor and a installing a front chamber to prevent dispersion of radioactive material have been implemented. High dosage has been confirmed in the operating floor and surveillance of the operating floor and countermeasures are under way. The time to start fuel removal from the pool is targeted for fiscal 2023.

In Unit 3, due to the influence of hydrogen explosion, instrument and things such as rubbles dropped from upper part of the building and existing fuel handling machine were scattered on the operating floor. Because it was also contaminated, the environmental improvements of operating floor was performed and completed in June 2016. In February 2018, a cover for fuel removal from the pool was installed. Once started the trial operation for fuel handling equipment in March 2018,

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[24] "Change of evaluation formula for water temperature in spent fuel pool, TEPCO" Handout 3-5 of Secretariat Meeting (50th)/Decommissioning and Contaminated Water Management team meeting, released on February 1, 2018.

several troubles have occurred. TEPCO intends to examine and review the start of fuel removal in the spent fuel pool which was scheduled in November 2018[23].

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

The fuel is also being stored in the pool of Units 5 and 6 reactor building under stable conditions same as a normal nuclear power plant. The Roadmap states that the fuel of units 5 and 6 should be properly stored in each spent fuel pool for the time being and will be removed them from each pool at when such removal work becomes not to affect fuel removal work, etc. of Units 1 to 3. With regard to some of the new fuels, there is a plan to begin exporting them to fuel processing manufacturers. Also, with regard to the spent fuel, it should be taken out at an appropriate time in view of the capacity of the shared pool and dry cask temporary storage installation.

While conducting the above-mentioned safety measures properly, fuel removal operation from the pool should be steadily pursued. Although these efforts are first examined according to the condition of each machine, 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 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 the pool, appropriate capacity should be reserved both in Common Spent Fuel Storage pool and in Temporary Cask Custody Area in each unit. As of now, because there is insufficient free capacity to transfer fuel in the pool of Units 1 to 3, 5 and 6 as shown in Fig. 19, it is necessary to advance the expansion of dry cask temporary storage installation etc. and to secure the spare capacity by transferring the fuel out of the premise. 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 shared pool, those that satisfy the conditions and have a relatively long cooling period are to be stored.

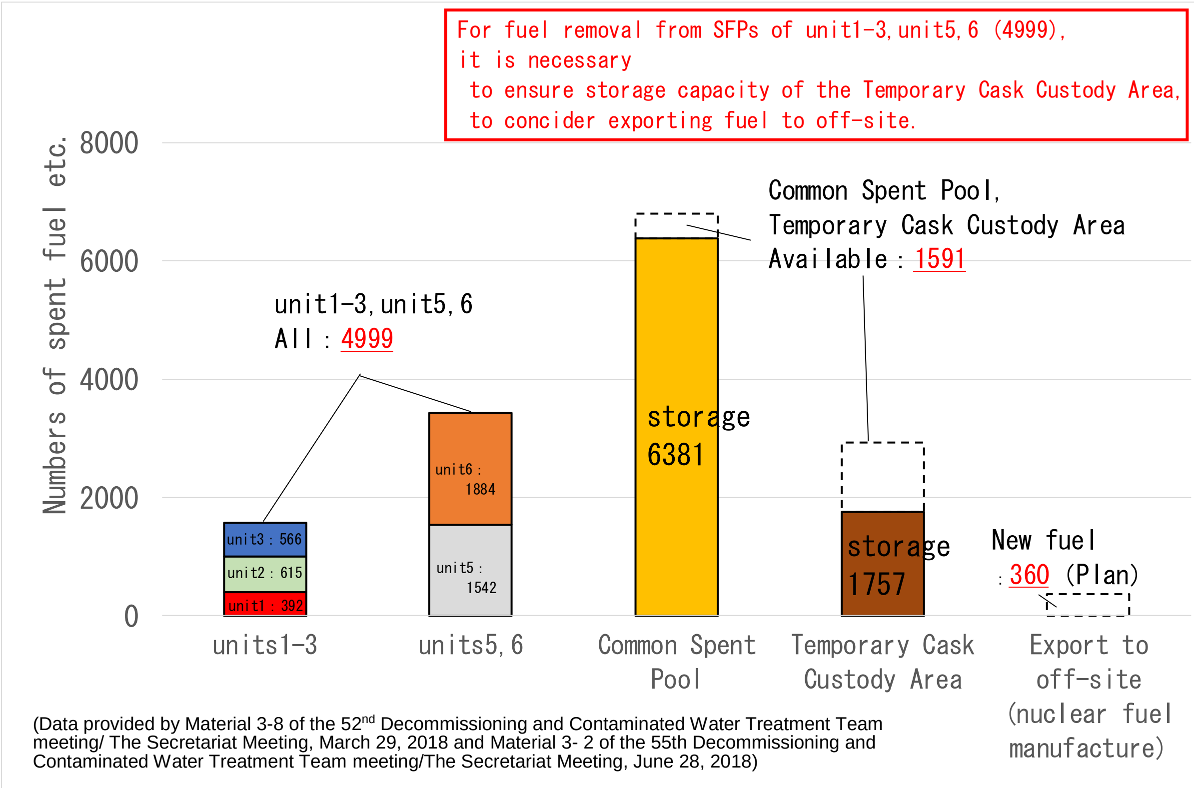

Fig. 19 Storage situation of spent fuel etc.(as of Jun 28, 2018)

3.4.2.4 **Decision on storage and future treatment methods**

The spent fuel pools is storing many kinds of spent fuel such as flawless spent fuel, damaged one 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. Corrosion due to seawater sprayed and injected into the spent fuel pool of Units 2, 3, and 4 at the accident is another concern. It is necessary to investigate that additional attention for the handling/storing of such fuels is required compared with that for normal spent fuel.

Storage and future treatment methods for removed fuels from the pools will be decided around 2020 based on the investigation results on long-term integrity assessment and treatment method for them.

3.4.3 Technical issues and future actions for prompt strategies

3.4.3.1 **Removal of fuel from the pools**

(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 Section 3.4.2.2, there are a number of things to be prepared in parallel, such as fuel removals in the pools of both Units 1 and 2 that start for FY 2023, preparation work on fuel debris retrieval at the time of removal of fuel in the pool of Unit 3. Therefore, it is necessary to adjust yards (securing flow line) with interference works and resources management and to prepare a detailed construction plan. As described before, fuel of Unit No. 5 and 6 should be removed in appropriate time. In case such operations use shared pool, adjustment is required as such removal work becomes not to affect fuel removal work, etc. of Units 1 to 3.

(2) Removing fuel from the pool of Unit 1

In Unit 1, a hydrogen explosion occurred at the upper part of the building when the accident occurred, so the upper building collapsed and the roof slabs and other rubbles were scattered on the operating floor. Also, existing fuel handling machine and overhead cranes are damaged and exist in a form that they cover over the spent fuel pool. Therefore, careful examination of timbering that has sufficient structural strength was conducted in order to prevent falling as it is necessary to cure the spent fuel pool then remove them as soon as possible.

Also, from the viewpoint of the influence on the surrounding environment, it is necessary to take measures against dust dispersion at the time of removal of the rubbles. It is confirmed that the well plug is shifted from the predetermined position, the dosage has been confirmed in dosage of about 200 mSv/h on the plug and it cannot be readily approached, there is a concern of skyshine (the effect that the radiation upward from the radiation source falls on the ground surface due to diffusion in the air and the dosage near the surface rises). Therefore, after taking safety measures such as prevention of radioactive dust dispersion and dose monitoring, it is necessary to proceed treatment for the same.

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 in pool

In the Roadmap, plan (Plan (1)) that installing a common container for both fuel removal and fuel debris retrieval, or Plan (Plan (2)) that a cover exclusively for fuel removal only on the operating floor are selected for consideration at an appropriate time. NDF has shown the necessity of adopting plan (1) which is superior in terms of earlier fuel debris retrieval time, lower worker exposure dosage, radioactive material dispersion amount, and waste generation amount, etc.[25][26], TEPCO is now being consideration. Study on Plans (1), sufficiently consideration of the preconditions for the fuel debris retrieval plan for top access should be made such as shielding at the time of operation, uploading, installations weight (structural integrity, etc.), there is an issue that it requires suitable design for use over the fuel debris retrieval period. In either case, it is necessary to judge the plan selection by an appropriate time based on the relation with the fuel debris retrieval work and the removal timing of the fuel in the pool.

As a result of the past investigation, a high dosage of 880 mSv/h at most has been confirmed on the operating floor when dismantling the upper part of the reactor building, which is carried out before the installation of the container or the cover. Since contamination by alpha-nuclides has also been confirmed, it is necessary to select a safe dismantling method by remote operation after taking measures such as prevention of dust dispersion.

As mentioned in Section 2.3.3.3, there is an exhaust gas stack of Unit 1/2 around Unit 2, radioactive materials centered on cesium released by the accident may be adhering inside of the stack, and fractures and deformation were found at the junctions of the diagonal bracing of the steel tower that supports the vent stack, therefore, the diffusion inhibition function is low and it is evaluated that the Safety Management is low. If this collapses, there is a risk of influencing the fuel removal process in the pool, so it is planned to disassemble the upper part of the exhaust pipe by a remote equipment prior to fuel removal in the pool.

(4) Unit 3 fuel removal in pool

The fall of rubbles to the spent fuel pool has been confirmed and it is clear that there is a deformed fuel in the upper handle. Fuel in a spent fuel pool need to be taken out combined with removal of the fallen rubble on top of the spent fuel. Accordingly, procedure for removing fuel needs to be developed considering how to remove rubble, as well as it will be required to examine the corresponding method in case fuel assemblies cannot be lifted due to rubbles at the time of fuel removal.

3.4.3.2 **Proper storage of removed fuel**

For the deliberate transportation and storage of spent fuel and fresh fuel possessed by the entire site, a fuel transport plan need to be developed taking fuel stored in the Units 5/6 into account. As well, the storage capacity need to be secured for additional facilities according to that plan.

In particular, when retrieval of fuel in the pool of Units 5, 6 precedes other units, it is necessary to take measures such as adding dry provisional temporary storage installations by the appropriate

[25] "Evaluation and proposal for decision of fuel removal plan of Unit 1and 2 of the Fukushima Daiichi NPS, NDF", Handout 3-5 of Secretariat Meeting (11th)/Decommissioning and Contaminated Water Management team meeting, released on October 30, 2014.
http://www.meti.go.jp/earthquake/nuclear/pdf/141030/141030_01_044.pdf

[26] "Evaluation and proposal for dismantle and remodeling area of the upper part of the operating floor in the reactor building of Unit 2 of the Fukushima Daiichi NPS, NDF", Handout 3-2 of Secretariat Meeting (24th)/Decommissioning and Contaminated Water Management team meeting, released on November 26, 2015.

time so as not to put pressure on the capacity for transferring unit 1, 2's pool fuel to the common spent 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 pool by these efforts.

3.4.3.3 Decision of future treatment and storage methods

As described in 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.

In the decommissioning and contaminated water management project, R&D on the long-term integrity of the fuel in the pool which has contacted with seawater or fallen rubble has indicated that removed fuel can be stored safely under the environment of Common Spent Fuel Storage Pool for a long period. Also, it was confirmed that the effect of seawater and scratches by fallen rubble on the fuel is limited for integrity of stored fuel in the dry cask. In addition, proposals have also been made regarding a fuel inspection method for dry storage.

Furthermore, another R&D 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 severe explosion caused by 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. 20.

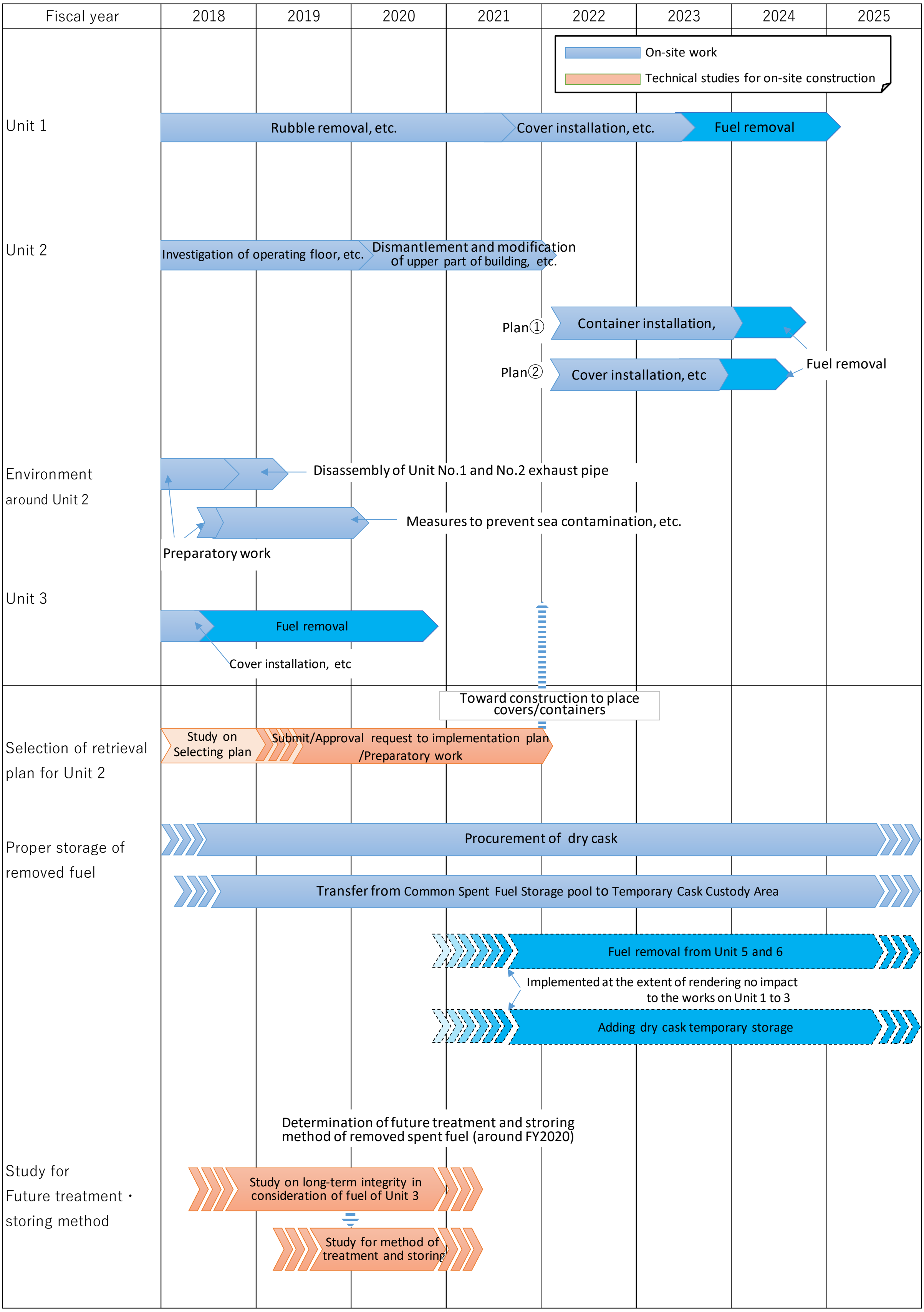

Fig. 20 Technical issues and further plan on removing fuel from the spent fuel pool

3.5 Other specific measures

3.5.1 Sustaining of reactor cold shutdown status

Currently, the plant conditions of 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..[27] 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. 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.

From the standpoint of lightening the contaminated water management load and reducing criticality risks, cooling the fuel debris by air is one possible alternative in the future; however, it is considered there is not enough information on the plant interior for examining this alternative at present.[28] Water supply to each unit was reduced in stages from 4.5 to 3.0 m^3/h after December 2016, and there was no significant temperature rise. Such data will be continuously appraised.

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 the trenches. Fundamental measures were also taken, such as installation of the sea-side impermeable wall and covering of the seabed soil including radioactive materials. As a result, the radioactive material concentration in the port was lowered to about 10 Bq/L, although it rises slightly when rain falls (in the open ditch, Cs-137) (Fig.21). It is lower than the limit concentrations specified by the dose regulations announcement for the area outside the “warning area” (average three-month concentration: Cs-134, 60 Bq/L; Cs-137, 90 Bq/L).

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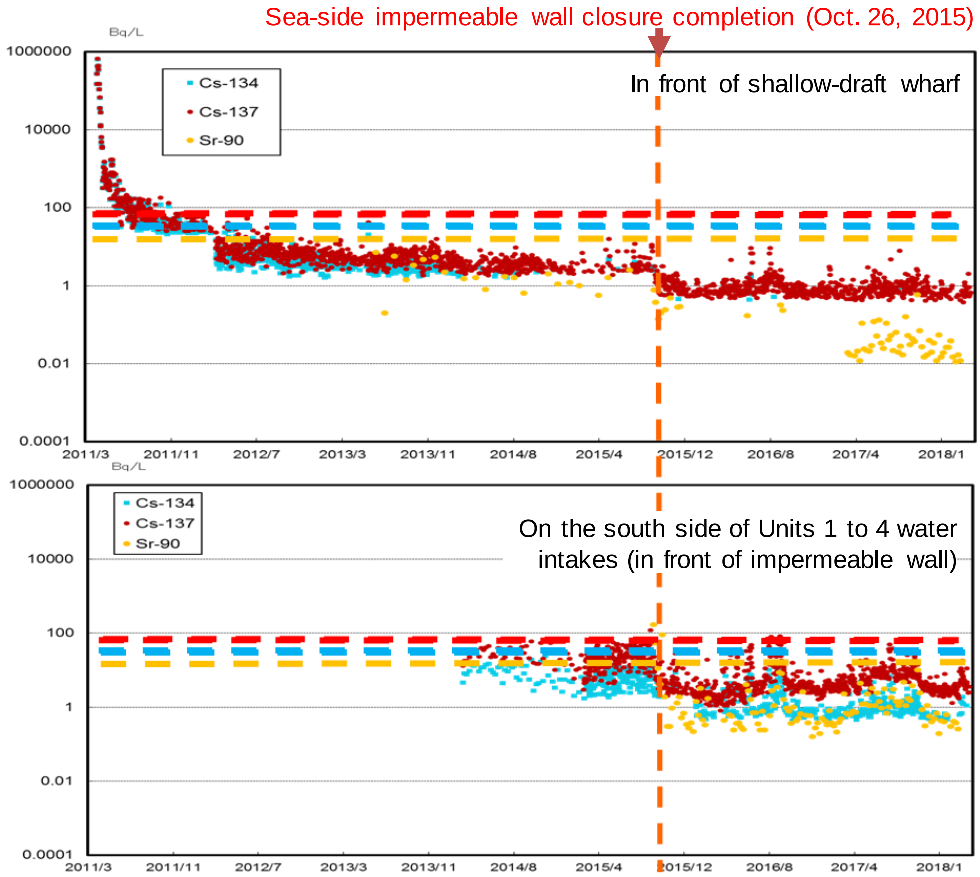
[27] For example, refer to the in-core condition data and diagrams (at the portal website for Decommissioning R&D Information) at http://www.drd-portal.jp/assets/files/current_data_jp.pdf. The website posts the in-core condition data released by TEPCO regarding the Fukushima Daiichi NPS (each unit's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

[28] The possibility of cooling fuel debris by air is conservatively evaluated by the Strategic Plan 2016, Appendix 4.17, “Overview of the analysis evaluation for air cooling in the reactor,” which states: “The results of the Unit 1 analysis that assumed a completely dry engineering method at the start of removal of fuel debris indicated that the maximum temperature of the fuel debris accumulated inside the RPV pedestal was approximately 480°C and the maximum surface temperature of fuel debris, approximately 350°C.”

In addition, the port entrance seawater radiation monitor indicated that the Cs-137 concentration in the seawater had lowered to about 0.1 Bq/L[29].



(Courtesy of TEPCO)

Fig. 21 Radioactive material concentration in seawater in the port

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. 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 apparently rises when it rains. Thus, the radioactive materials eluted from the top of the buildings or from the laid sand, the suspension flow of soil particles from contaminated soil or rubble on the Tokyo Peil (T.P.) 8.5-meter bed, and eluted radioactive materials from the bed, are considered to reach the water in the port. Based on this supply mechanism, measures for reducing the concentration of radioactive material in the drainages channel that flow into the port need to be continued to further reduce the concentration, such as measures against rainwater ingress from the top of the buildings and paving around the buildings.

[29] "Concentration of radioactive material in ground water and sea water at the east side of turbine buildings, TEPCO", Handout 3-6 of Secretariat Meeting (57th)/Decommissioning and Contaminated Water Management team meeting, released on September 7, 2018.
http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2018/09/3-6-2.pdf

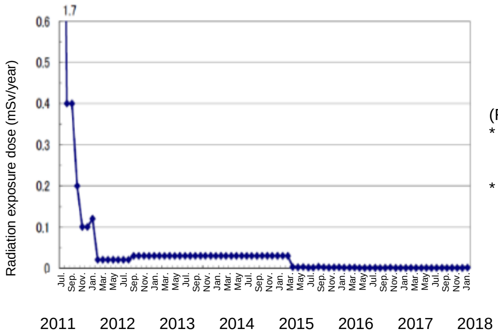
Because soil near the port has contaminants in the shallow layers, the long-term environmental impact evaluation involves technical challenges; namely, unlike the relocation analysis in the deep underground disposal of high-level radioactive waste, knowledge of which been obtained, the influence of unsaturated layers and the effect of adsorption reaction rates need to be considered. Regarding contamination of the soil in the vicinity of the harbor, assessing the impact on the ocean from a long-term perspective and future environmental restoration, it is important to continuously proceed with R&D such as to clarify the near-surface nuclide migration mechanism and refine the analytical models[30].

3.5.2.2 **Management of gas and liquid waste**

The 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 emission control target from Units 1 to 4 is set to a total Cs-134 and Cs-137 of 1.0×10^{7} Bq/h, and it is ensured that the dust monitors near the boundaries of the premises indicate values lower than the limit concentrations for the warning area, and the dose evaluation is conducted once a month. When the emissions from Units 1 to 4 are 1.0×10^{7} Bq/h, the effective dose evaluation value near the boundaries of the site should be 3×10^{-2} mSv/year. The effective dose evaluation based on the actual measurements of July 2018 was about 2.9×10^{-4} mSv/year, indicating that air release is controlled at a sufficiently low level.

[30] Refer to "(6) Environmental fate studies of radioactive materials generated during decommissioning" included in Attachment 12



(Reference)
* Gas-phase concentration limits outside the surrounding monitored area
[Cs-134] 2×10^{-5} Bq/cm^3,
[Cs-137] 3×10^{-5} Bq/cm^3
* Monitoring post (MP1 to MP8) data
The monitoring posts (MP), which measure the dose rate in the air around the site boundary indicated 0.404 to 1.757 μSV/h (Feb. 29 to Mar. 28, 2018; 10-mn. value)
To more accurately measure the fluctuations of the MP2–MP8 dose rates in the air, environmental improvement measures have been taken (cutting of surrounding trees, removal of surface soil, and shield installation).

(Note) The dose evaluation previously differed between the Facility Management Plan and the monthly reports. The method was standardized in September 2012.
Unit 4 was added to the evaluation targets in preparation for the removal of fuel in the spent fuel pools in November 2013.
In FY 2015, the evaluation method was changed to consider the values of continuously operating dust monitors. After this change, the results are released the following month.

(Courtesy of TEPCO)

Fig. 22 Evaluation of annual radiation exposure dose at site boundaries due to radioactive materials (CS-134 and Cs-137) emitted from Units 1 to 4 reactor buildings

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, all beta emitters (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 ratio to the concentration limit of the four major radionuclides is 0.15 or lower.
- A monthly analysis with a lowered detection limit concentration should indicate no significant increase for the six indicators, which are the four major nuclides, Sr-90, and all alpha emitters.
- It should be checked quarterly that the sum of the ratios to the concentration limits of all the target radionuclides is 0.21 or smaller.

As described above, drainage is strictly controlled. Radionuclides having a limit concentration rate of 0.001 or smaller are removed from the checklist. After the application of April 2017, the number of target radionuclides was reduced to 41, including the four major ones.

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 limit concentration rate of 0.22.

3.5.2.3 **Dose reduction through the site decontamination**

Of primary concern immediately after the accident was the workers' exposure to radiation in the 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 Dose Reduction on the Site of the Fukushima Daiichi NPS"[31] and set target dose rates in stages for each

[31] TEPCO, "Efforts for Dose Reduction inside the Fukushima Daiichi NPS ," presented as Handout 3-2 at the 19th

area in the sites to reduce the dose. Decontamination progressed through the removal of highly contaminated rubble, tree cutting, and removal of surface soil, and shielding was provided by such means as facing. As a result of these efforts, the target dose equivalent rate of 5 μSv/h was achieved at the end of FY 2015 in the area that lots of workers work other than the zone surrounding Units 1 to 4 and the waste storage area. In the vicinities of Units 1 to 4, as a result of the contamination zone classification for more detailed contamination control such as by the identification of radiation sources by means of directional monitoring, currently the area in which it is permitted to work with general work clothes has increased to 96% of the entire sites.

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 Roadmap and should gradually reduce the target dose equivalent rate to ultimately reach the pre-accident level.

3.5.2.4 **Reduction of environmental impact**

By the end of FY 2015, the dose evaluation at the boundary of the site ("effective dose"), encompassing additional emissions, attained the target dose of 1 mSv/year or less, 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. Effective dose reduction efforts were continuously made, and at the end of FY 2017, it was 0.90 mSv/year (Fig. 23).

Meeting of The Committee on Supervision and Evaluation of the Specified Nuclear Facilities (March 31, 2014) http://www.nsr.go.jp/data/000051045.pdf.

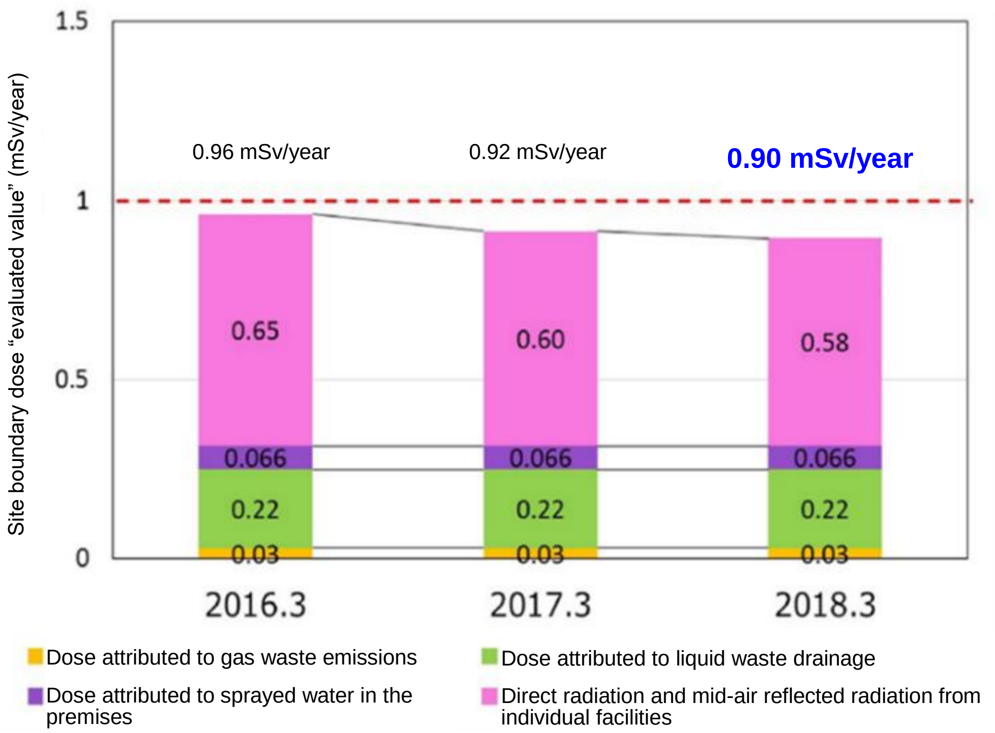


Fig. 23 Effective dose evaluation at site boundaries[32]

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 dose at the boundary of the site contributes not only to the direct 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 dose of under 1 mSv/year.

The representative individuals in the 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[33] of the International Commission on Radiological Protection ("ICRP") into

[32] TEPCO, "Dose Conditions in the Fukushima Daiichi NPS Buildings," presented as Handout 3-7 at the 53rd Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment (April 26, 2018). http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2018/05/3-06-03.pdf

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

Japanese laws.

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 containing 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[34] 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 process of about three years emphasizing the presentation of residual risk. In regard to this Target map for reducing the mid-term risk, TEPCO reported the current approach, issues and responding status according to the further schedule as needed after May 2018.[35] In the reports, as an example, a very large floating structure (VLFS) can become a drifting object and damage nearby equipment if hit by a tsunami, so the mid-term risk reduction map treats it as a risk that requires action in the event of an earthquake or tsunami. 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.

Regard 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[36], TEPCO should continue this kind of efforts for the purpose of avoiding increase of stagnant water as a result of water inflow into the building due to tsunami and reducing damage of essential facilities in preparation of Chishima Trench Tsunami which was identified as a highly imminent possibility.

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

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[34] Refer to “Target Map for Reducing the mid-term risk” in NRA web: http://www.nsr.go.jp/disclosure/committee/kettei/04/04_01.html (Category: the Fukushima Daiichi NPS related topics)

[35] TEPCO, "Measures Taken in Response to Risk Map Appraisal Instructions," presented as Handout 1 at the 60th Meeting of The Committee on Supervision and Evaluation of the Specified Nuclear Facilities (May 18, 2018). http://www.nsr.go.jp/data/000230852.pdf

[36] TEPCO, “Progress on countermeasures against earthquake and tsunami”, presented as Handout 3 at the 63th Meeting of The Committee on Supervision and Evaluation of the Specified Nuclear Facilities (September 14, 2018). http://www.nsr.go.jp/data/000245445.pdf

3.5.3 Plan for decommissioning measures for nuclear reactor facilities

In the Roadmap, TEPCO should formulate the decommissioning plan of 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.

As for Units 5 and 6, spent fuel removal should be carried out with reference to progress of works in Units 1 to 4, and then, decommissioning plans should be formulated for Unit 5 and 6[37]. TEPCO intends to use Units 5 and 6 as full-scale test mockups for remote-controlled decontamination in the reactor buildings, internal PCV research, and fuel debris retrieval systems. After their use as mockups, their effective use should be discussed among the relevant parties, to the extent that later decommissioning work will not be influenced.

3.5.4 Concrete efforts toward securing safety

3.5.4.1 Efforts to ensure work safety

In FY 2017, the average number of workers per day was consistently 5,000 to 6,000, while the number of accidents (number of workers involved in an accident) was reduced from 20 in FY2016 to 11 in FY2017, thanks to thorough compliance with plant rules (22 standardized safety rules, TBM-KY [tool-box meetings (talks) and *kiken yochi* or danger forecasting] training, and thorough 5S methodology (sort, set in order, shine, standardize and sustain), introduction of accident cases to other sections, reinforcement of safety control mechanisms and organizational supervision. However, while the number of workers involved in an accident was reduced, the causes of many of the accidents were similar (falling and stumbling), as indicated by an analysis on personnel, equipment and management. To further reduce the number of accidents, a safety policy has been established from the viewpoint of awareness raising, skills improvement and management, to continuously improve the labor environment.[38]

Similar to fuel debris retrieval operation, for the work plans that require workers to intervene in a high-dose environment and that complete remote-control system operation is difficult, it is

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[37] "The Act for partial amendment of the Act on Regulations to Nuclear source materials, nuclear fuel materials and reactor to reinforce safety measures for nuclear use" has been enacted and promulgated in April, 2017. It was imposed that power reactor licensees must develop and publish its measurement in conjunction with decommissioning of power reactor (Implementation policy for decommissioning) (will be enforced in October 2018). The nuclear facilities installed in the Fukushima Daiichi NPS have been designated as a specific nuclear facility, its application to Unit 1 to 4 has been exempted by the government ordinance, because "Implementation Plan for preservation on specific nuclear facility and protection of specific nuclear fuel material" (Implementation Plan) was formulated and smooth transition to decommissioning are being performed. TEPCO is proceeding studies for Implementation policy for decommissioning for Unit 5 and 6.

[38] TEPCO, "FiY2017 Accident Occurrence Conditions in the Fukushima Daiichi NPS" and "FY 2018 Safety Action Program," presented as Handout 3-7 at the 53rd Meeting of the Secretariat of the Team for Decommissioning and Contaminated Water Treatment (April 26, 2018). http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2018/05/3-07-03.pdf

important to evaluate the environment according to input resources from the viewpoint of "justification and optimization" aiming to ensure the safety of the working environment as well as suppressing personal dose in appraising multifaceted approaches. Particularly when the work is “for the first time,” “changed,” or “for the first time in a long time,” it is essential to fully implement work training using a mockup in order to 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.

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 collecting, 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 evaluation 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 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 line with the 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

[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/committee/genchicyousei/2015/pdf/0727_01k.pdf

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 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.

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.

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. Therefore, regarding the efforts of each field listed in Sections 3.1 to 3.5, a more proactive, systematic approach will be needed to solve the challenges rather than fulfilling tasks in a reactive manner such as those mentioned above.

The Fukushima Daiichi NPS decommissioning involves many uncertain factors, and the decommissioning plan, in addition to the information and expectations obtained at the time of planning, should be flexibly reviewed according to the various knowledge and conditions that will emerge with the progress of the project. If the information and expectations at the time of planning are significantly different from the information obtained with the progress of the project, it may be difficult to perform the work as scheduled, and thus it is necessary to keep confronting such project risks when the project is proceeded. Moreover, the delay resulting from the appearance of such a risk may influence the ensuing tasks, and may further influence the progress of the entire project.

Furthermore, it is important to optimize resource allocation and scheduling while ensuring the consistency and feasibility of the entire efforts to be promoted concurrently while having interrelations, as shown in Fig.24. In order to perform full-scale fuel removal from spent fuel pool and fuel debris retrieval beginning in near future safely and smoothly, it is a growing issue to coordinate the use of the site by ensuring area which can be stably used with sufficient room. Namely, while this complicated and multilayer project should be controlled based on individual tasks of appropriate scale and control size, the entire decommissioning project should make progress comprehensively in consideration of the mutual relationship among the smaller projects. The overall plan of the decommissioning project should be formulated and discussed while presuming intermediate targets to the extent possible from a facility-wide mid-and-long-term perspective.

Regard to the project risks to sustain stably for entire decommissioning project as this, it is essential to take appropriate responses from the proper implementation of progress management and fund management of work, while learning from overseas precedent cases.

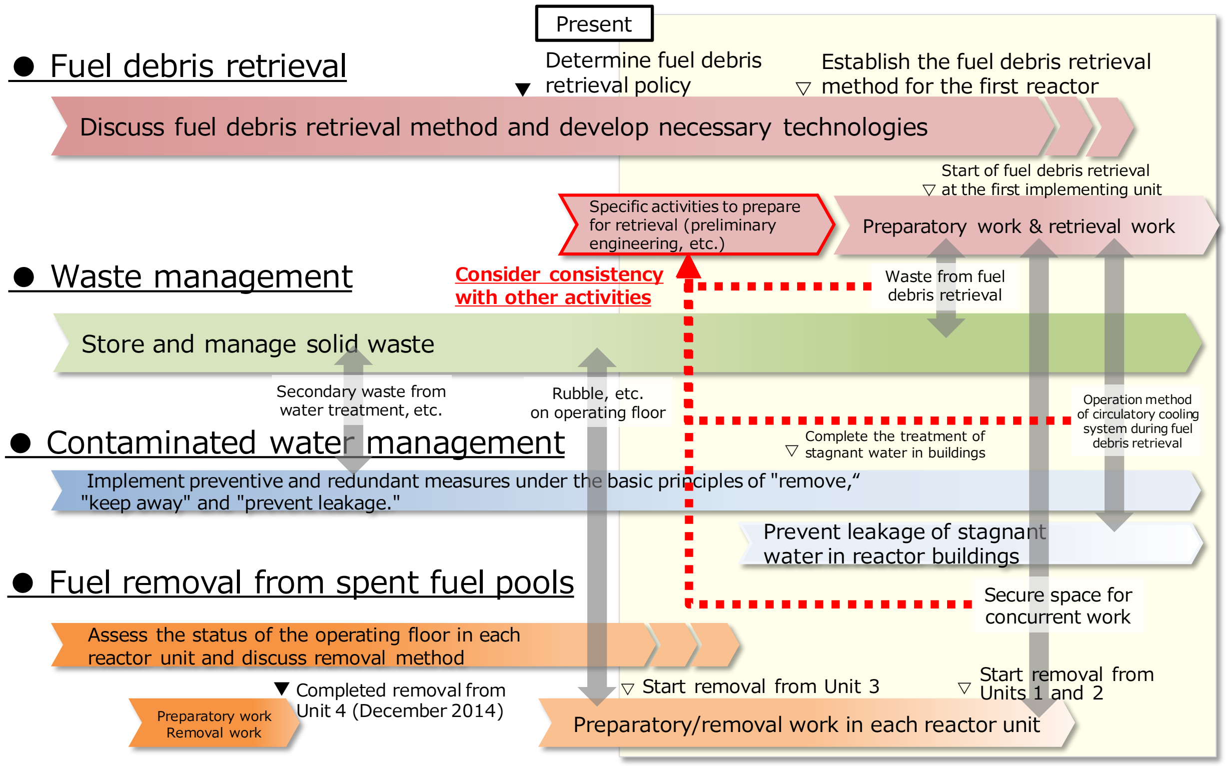

Fig. 24 Need for a mid- and-long-term viewpoint overlooking the entire activities

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 the buildings, 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 for heat attack countermeasures, wet-bulb globe temperature (WBGT) indicators (which indicate the three factors that have a great impact on the heat balance of human bodies: humidity, radiation heat, and ambient temperature) have been installed at seven places, and the reinforcement of acclimation to heat, and checking of heat attack records and health checks (for early discovery of health problems) are performed, to name a few. In FY 2017, there were no heat attacks that resulted in a worker having to leave, the same as in FY 2016, but the number of workers who suffered from a heat attack increased slightly from four in FY 2016 to six in FY 2017. Accordingly, the elimination of heat attack incidents has been determined as an important target for the FY 2018 safety policies, and safety actions are being continued.[38]

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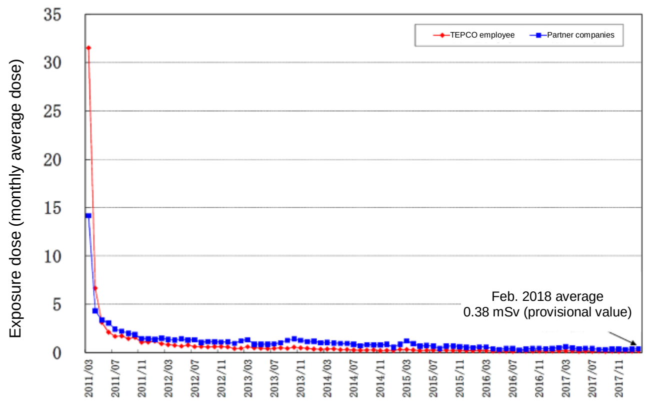
[40] TEPCO, "Results of Questionnaire for a Better Labor Environment (8th Meeting) and Future Improvement Plans," presented as Handout 3-7 at the 49th Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment (December 21, 2017). http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2017/12/3-07-02.pdf

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

As radiation exposure control, the monthly average radiation exposure dose in fiscal years 2014 to 2017 has been about 1 mSv. The FY 2017 monthly average radiation exposure dose was about 0.36 mSv, which is below the target radiation exposure dose of 1.7 mSv/month (Fig.). Monitoring the workers' eye crystalline lens dose limit was started in FY 2018 independently based on the statement of ICRP[42], intending to reduce the dose from 150 to 50 mSv/year. Currently control methods are examined to apply the limit dose of 100 mSv for five years from FY 2019.[43] With the progress of the project, work in a high-dose environment is expected to become more frequent. To comply with the dose limits of individual workers, a limit should be designated that will be lower than the legislative limit. When a worker's exposure is at or above or may be above the limit, such worker is to be excluded from engaging in radiation work or requested that the worker prepares a dose control plan where the dose control methods will be determined in detail and work according to the control plan to ensure that the dose does not exceed the legislative limit dose.



(Courtesy of TEPCO [21])

Fig. 25 Changes in each worker's monthly exposure dose (Monthly average dose)

As measures for dose reduction in the premises as described in Subsection 3.5.2.3, high-dose rubble removal, surface soil removal, and decontamination by facing and shielding have been performed, and as a result, the target 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 area). The area where workers can wear ordinary uniforms or similar attire has extended to 96% of the entire premises. 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.

[42] 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).

[43] TEPCO, "Changes in Control Methods for Eye Crystalline Lens Equivalent Dose Limit Change," presented as Handout 3-7 at the 52nd Meeting of the Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment (March 29, 2018). http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2018/04/3-07-02.pdf

In the future, while continuing the actions specified in the Roadmap for improvement in the work environment and conditions,[44] it is needed to specifically design internal radiation exposure prevention measures in preparation for the fuel debris retrieval that will generate alpha-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 containment 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 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 quick action.

4.2 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. The concept of safety is essentially different from the operation at normal nuclear facilities. Namely, as described in Subsection 2.3.3, it is required to achieve relocation to a storage area with a higher control level as early as possible in consideration of temporal changes in the risk levels; safety assurance in and outside the premises may be influenced if retrieval is started with insufficient preparations and measures. If excessive protective measures are selected, retrieval may be difficult. Therefore, it is a challenge to realize balanced

[44] The following is a summary from Chapter 5. (2), "Efforts for improving working environment and conditions" of Roadmap:
A. Expansion in the areas where staff can wear ordinary uniforms, and improvement of the working environment by the provision of a restaurant, larger rest stations, partner company buildings, etc., and the use of an appropriate working plan.
B. Establishment and implementation of a working safety and health control system run integrally by TEPCO and the original contractors, and the provision of worker safety with the participation of partner companies
C. Effective radiation exposure dose reduction measures, integrated management of radiation exposure dose data by TEPCO, and radiation control by providing original contractors and subcontractors with information, guidance and advice.
D. Improvement in working safety health level through implementation of risk assessment, the use of experience-based education and training facilities, patrolling, and close coordination and communication among workers engaged in different work.
E. Continued follow-up after physical checkup, heat attack prevention measures and prevention measures against influenza and other infectious diseases, promotion of the use of health support counseling services, and implementation of emergency medical system.
F. Working conditions knowledge expansion activities such as holding of seminars, and provision of proper working conditions by continued counseling services.
G. Working contract with all workers and registration with the appropriate social welfare services, checking with the original contractors where necessary.

risk reduction. Referring to safety efforts from overseas damaged reactors and legacy sites (refer to Chapter 7), 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.

Because it needs to discuss specific tasks and regulations to be observed simultaneously, NDF, TEPCO, the Agency for Natural Resources and Energy, and the organizations involved should mutually cooperate, and positively communicate with the Nuclear Regulation Authority. It is also necessary to make appropriate efforts, such as presenting policies and observation data related to ensuring safety at an early stage. 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 indicate.[45,46] 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 facilities at the Sellafield site.

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

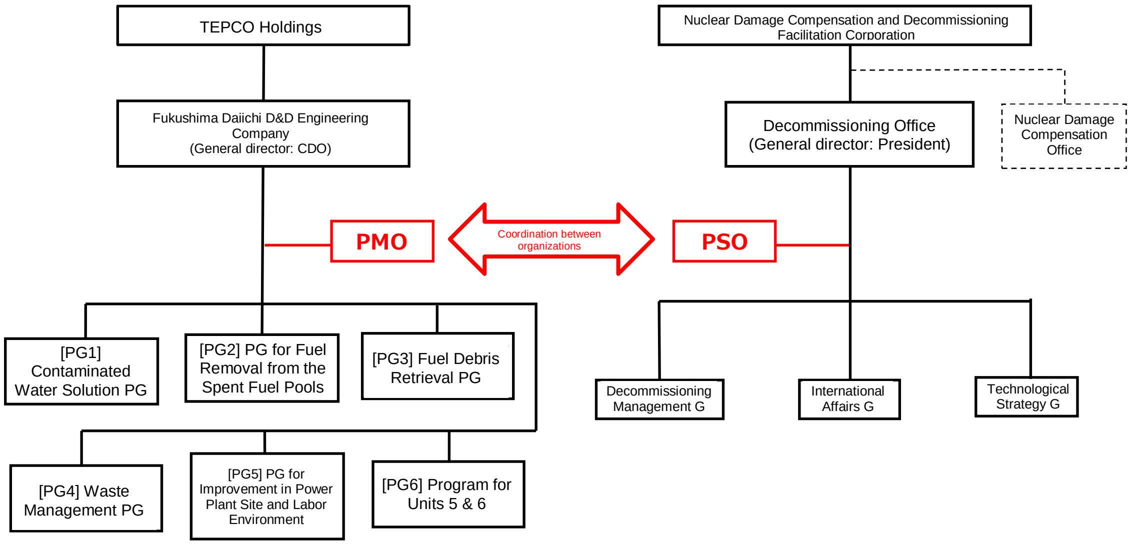
To date, TEPCO has used the project management method to carry out large projects such as the new or additional installation of a reactor: The company, as an example, prepared a structural diagram of the Work Breakdown Structure (WBS), in which the project is disassembled and layered based on units such as tasks. Regarding the decommissioning, the company has partially prepared a project structure for various work relating to decommissioning. However, line operation

45 EPRI, The Cleanup of Three Mile Island Unit 2, a Technical History: 1979 to 1990, EPRI, NP-6931 (1990).

46 NRC, Three Mile Island Accident of 1979 Knowledge Management Digest, Recovery and Cleanup, NUREG/KM-0001, Supplement 1 (2016).

management and project operation coexist in actual management, leading to slow decision-making, there is a challenge that it is not necessarily efficient as a whole. It is necessary to shift the organization management to project-oriented management and reinforce the organization and functions to coordinate the projects.

Therefore, at TEPCO, in addition to the conventionally located Program Manager (PGM) and Project Manager (PJM), a Program Management Office (PMO) responsible for project control has been set up. NDF, as the supervisory and supporting organization, recently established a Program Supervision & Support Office (PSO). These project operation sections in TEPCO are to conduct the project safely and steadily under the supervision of safety and quality control division (Fig. 26).



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

Fig. 26 NDF and TEPCO Organizational System for Project Control

These projects that TEPCO will perform need to be positioned clearly in the Reserve Fund for the Decommissioning System. TEPCO is the licensed decommissioning company in the Policy for Preparation of Withdrawal Plan. Based on the planning of the project, NDF has recently shown TEPCO the following: 1) the status quo of the decommissioning project and operational targets for the mid-and-long-term perspective; 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. 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 NDF to the Minister of Economy, Trade and Industry, who is in charge of decommissioning. TEPCO and 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 project (Table 4).

Table 4 Description of the Projects Included in the Withdrawal Plan

Program	Purpose	Three-year targets	Major tasks (for the coming three years)
① Contaminated water solution program	・ Implementation of fundamental measures against contaminated water ・ Removal of contaminants that may have an impact on the Fukushima Daiichi NPS boundaries	・ The effective dose at the boundaries of the premises should be maintained at a level below 1 mSv/year. ・ The total volume of contaminated water under an average rainfall amount should be controlled (should be no greater than 150 m^3/day in total). ・ Tank capacities should be prepared 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 (create a structure that prevents the movement of stagnant water from the reactor buildings to other buildings).	・ Subdrain reinforcement and land-side impermeable wall related tasks ・ Measures against rainwater ingress into buildings ・ Welded tank preparation, flanged tank removal, etc. ・ Transportation of stagnant water in the buildings, installation of purification equipment, etc. ・ Purification treatment of stagnant water in the buildings ・ Stabilized storage measures for secondary waste from water treatment (sludge) resulting from the decontamination system ・ Appraisal and implementation of other risk reduction measures
② Program for fuel removal from the spent fuel pools	・ Spent fuel removal from Units 1 to 3 ・ Storage in shared pool, etc. in stable condition	・ Unit 1 fuel removal cover installation and related work can 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 spent fuel pool is completed. ・ Environment improvement in the vicinity of Unit 2 is completed.	・ Unit 1 operating floor rubble removal ・ Unit 2 investigation inside the reactor building operating floor and building upper part dismantling ・ Unit 3 fuel removal cover installation, fuel removal and stable storage ・ Dismantling of Units 1 and 3 shared exhaust stack upper part
③ Fuel debris retrieval program	・ Units 1 to 3 fuel debris retrieval method system construction ・ Units 1 to 3 fuel debris retrieval, containment, transportation and storage	・ Determination of Unit 1 fuel debris retrieval method and implementation of the engineering that enables it. In addition, preparations for the start of retrieval should be making progress.	・ Appraisal of fuel debris retrieval method for each unit (steady implementation of engineering, etc.) ・ Detailed condition investigation inside the containment vessel ・ Preparations related to fuel debris retrieval ・ Technology development, mainly by TEPCO HD
④ Waste management program	・ Establishment 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 provided. ・ Substances that otherwise would become waste should be recycled, reused and treated for steady volume reduction.	・ Waste storage and volume reduction treatment equipment (incinerators, etc.) ・ Establishment of mid- and-long-term storage plan (including the storage of adsorption towers and concentrated liquid waste and slurry) ・ Technology development, mainly by TEPCO HD
⑤ Program for improvement in power station premises and working environment	・ Use based on scheduled premises utilization schedule ・ Preparation of working environment infrastructure	・ According to the premises utilization plan, various measures related to decommissioning are steadily carried out. ・ To retain and improve the working environment in the station, infrastructure should be prepared.	・ Retention of buildings in good order ・ Provision of decommissioning infrastructures ・ Provision of buildings and rest facilities
⑥ Program for Units 5 and 6	・ Units 5 and 6 equipment retention and control ・ Decommissioning plan planning and implementation	・ Spent fuels are stably kept cooled.	・ Retention of cooling equipment ・ Decommissioning planning and proposal creation ・ Relocation of mega-float

To make that the mechanism of the described project management functions effectively, it is necessary to enable TEPCO to control its engineering task and make it function effectively, based on a deep understanding of the technical work of individual tasks under appropriate operation control. This means that the power utility company, whose major operation is equipment control, must have a wide range of experience and use technological expertise that such a company conventionally does not have. TEPCO should commit itself to both technological areas and human resources/organizational control, in collaboration with not only other power companies, but also manufacturers, general contractors, and engineering companies, while utilizing the expertise of external specialists including international ones. Through such collaboration, the company should accumulate technology and know-how including engineering capacity, and in collaboration with suppliers including related companies and partner companies, reinforce the supply chain management including cost management.

4.4 Developing and securing human resources

4.4.1 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.

Therefore, the Decommissioning R&D Partnership Council has prepared a draft technology map to grasp the overview of necessary core technologies and personnel required for the decommissioning of the Fukushima Daiichi NPS. (Attachment 10) On this map, some human resource fields seems to be able to obtain by training people in the technological talent pools of the existing nuclear industry such as analysis engineers that are currently known for its necessity. Also, there are fields where technological personnel should be obtained from a wider variety of fields not limited to the existing nuclear industry or should be developed in a planned manner. 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 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. A subgroup of Professional Engineer, in the Council for Science and Technology proposed that an elective subject “Nuclear Reactor Systems and Facilities” in the second stage of the qualifying exam of Professional Engineers (PE) for the fields of nuclear power/radiation should include “Reactor Decommissioning including Handling after Severe Accident”, and another elective subject “Nuclear Fuel Cycle and Radioactive Waste Management and Disposal“ should include “Decommissioning and Nuclear Fuel/Radioactive Waste Management and Disposal after Severe Accident”. Following this, qualifications of the major positions such as PEs are asked in the public offerings for the Project of Decommissioning and Contaminated Water Management beginning from 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 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 Fukuoka 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.

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

To carry out R&D activities sustainably for a long period, industry, academia, and the government related to nuclear power should steadily continue efforts for human resources such as developing and securing of future researchers and engineers.

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

To this end, the Ministry of Education, Culture, Sports, Science and Technology (MEXT)'s the Center of the World Intelligence Project for Nuclear S&T and Human Resource Development ("World Intelligence Project") has been proactively facilitating HRD via research activities among universities and colleges. 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. "Conference for R&D Initiative on Nuclear Decommissioning Technology by the Next Generation (NDEC)," intended for students, and "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 who with excellent results receive awards in 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.

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 research and development 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.

We should not think these activities for fostering next-generation decommissioning personnel 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 measures steadily in accordance with the 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[47] based on the NDF Act. According to this policy, NDF has been gathering expertise of R&D institutions and managing a variety of R&D project, such as clarifying the inner reactor conditions, feasibility study of retrieval method and so on, that support steady implementation of the Roadmap.

Since the policy for fuel debris retrieval has been determined, such R&D processes are to enter a new phase in the future soon ahead. 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 government and the enterprise 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. Research institutes are expected to enhance the technologies required for decommissioning through considerations on the status of the project and the fundamental R&D activities according to scientific and technological issues (needs) regarding the decommissioning.

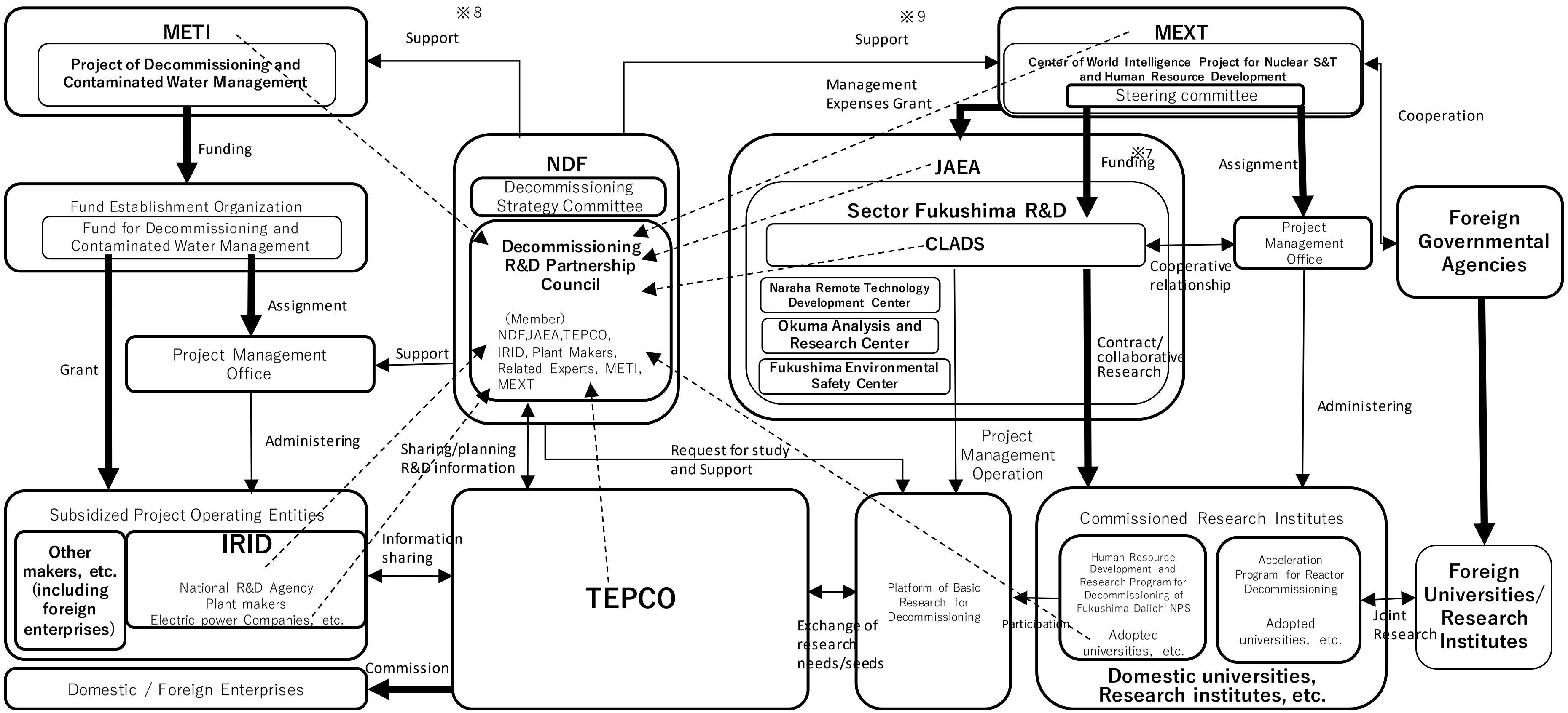
For this challenge entering into an the pathless field, it is important to further enhance many approaches from different angles through the collective effort of Japan such as realizing effective R&D, cooperation between the related organizations including those overseas, utilization of research facilities,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

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 variety of industrial-academic-governmental institutions engaged with the Fukushima Daiichi NPS decommissioning

[47] The R&D Duties Implementation Policy, http://www.dd.ndf.go.jp/jp/committee/policy/index.html

R&D projects through the areas of basic/fundamental research, applied research, and development/utilization (Fig. 27 and 28). 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 regularly 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 manners of collaborating with related organizations, gathering international expertise and promoting comprehensively and systematically. 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 arrow mean supply 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. 27. Whole picture of R&D structure of the decommissioning of the Fukushima Daiichi NPS (As of FY 2018)

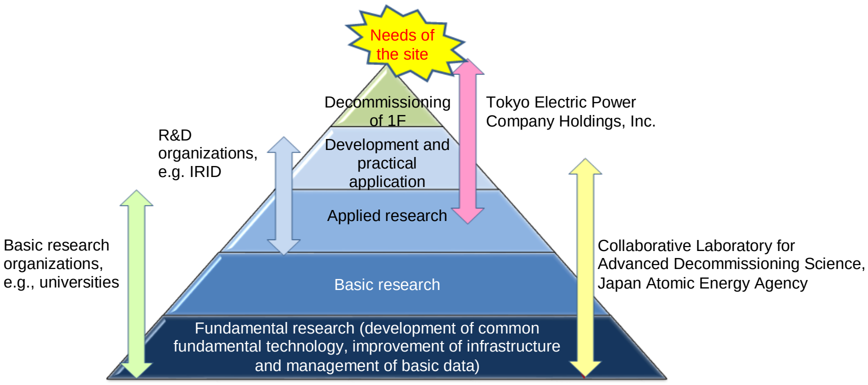


Fig. 28 A conceptual picture of the division of roles among main R&D institutions for the decommissioning of the Fukushima Daiichi NPS

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

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 Project of Decommissioning and Contaminated Water Management carried out by selected subsidiary companies (Attachment 11).

In both cases, aiming at the overall optimization of the decommissioning project as a whole as described in Section 3.6, project-oriented R&D management will be required. R&D tasks that are raised as necessary through the engineering considerations conducted by TEPCO should be shared with NDF. An appropriate implementing institution takes over the implementation of such R&D tasks in a timely and accurate manner under the coordination of NDF. Then, the result of the R&D will be accurately provided to the site in a timely manner. As NDF was designated to oversee (manage and supervise) the project management of TEPCO under the Decommissioning Reserved Fund System described in Section 4.3, it is important to realize effective R&D management through the system.

Specifically, for the time being, R&D tasks are going to be identified according to the progress of the preliminary engineering implemented by TEPCO as described in Section 3.1.2, and then, it is presumable that the timing to implement such R&D tasks will be determined through considerations through the project management. To realize an R&D management system under such project-based schedule, appropriate information sharing on the situation of R&D implementation by TEPCO and on the R&D tasks of which the necessity became clear by engineering considerations should be carried out under the project management system enforced jointly by NDF and TEPCO as described in Section 4.3. To this end, TEPCO and NDF should marshal the R&D tasks currently in progress, and R&D tasks required in the future under the project management system in relation to the engineering schedule, that is, clarifying when the problem must be solved and which project needs it.

In this regard, even including implementing the tasks in the Government-led Project of 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 are more difficult are considered to need supports by the government.

As actual processes for the decommissioning become apparent according to the progress of the project management, R&D tasks that are intended to apply to the site become clearer. Therefore, it will be required for TEPCO to make efforts to raise the ratio of technological development to improve the safety and efficiency of the decommissioning work. In addition, taking into consideration the fact that the United States Department of Energy (DOE) has received a recommendation from the task force to elevate the science and technology budget among the budgets for decommissioning of the legacy sites[48] and the DOE has declared a policy to increase the budget[49]. For the Fukushima Daiichi NPS as well, it is important to steadily figure out and implement the required technological development under the Reserve Fund system.

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, we have to extract the R&D tasks which might become critical in the future. At the same time, we also have to maintain and expand the infrastructures of personnel, organization and facilities 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

To 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 the theories. For this purpose, NDF has built a task force on research collaboration and specified the 6 Essential R&D Themes that should be preferentially and strategically targeted based on the discussions at the Decommissioning R&D Partnership Council. Moreover, the Platform of Basic Research for Decommissioning[50] was investigated and compiled R&D strategies for the Themes, based on

48 Secretary of Energy Advisory Board, "Report of the Task Force on Technology Development for Environmental Management", U.S. Department of Energy, (2014).
49 U.S. Department of Energy, "Departmental Response: SEAB Task Force Recommendations on Technology Development for Environmental Management", (2015).
50 Promotion council of basic and generic research jointly managed by JAEA/CLADS and MEXT the Center of the

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 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, NDF has compiled the Basic Future Direction of the six Essential R&D Themes drawing on the discussion of the subcommittee meetings of the Platform and presented it to MEXT (Attachment 12). The Basic Future Direction includes background of the issues, awareness of the problems by the consumer-side and a conceivable image of the research. It is adopted in the call for proposal of the World Intelligence Project started in May 2018 by JAEA.

5.3.2 Construction of basic research centers 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 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 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/CLAD from the newly adopted tasks in FY2018.

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

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World Intelligence Project: Decommissioning Research and Human Resource Development Promotion Program selection agency. See https://fukushima.jaea.go.jp/initiatives/cat05/haishi05.html.

controlled devices and installations. Specifically, prior to sending the devices into the harsh environment inaccessible for people, testing in a real-scale mockup 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 mockup actively.

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 as well. The 1st Building that is to handle low-dose samples such as rubble and the 2nd Building that is to handle high radiation samples such as fuel debris are respectively under construction and designed.

As seen above, R&D infrastructures related to decommissioning, contaminated water management and environmental decontamination measures are being set up mainly 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: Winscale Unit 1 in UK, Three Mile Island Unit 2 in the US, Chernobyl Unit 4 in Ukraine. These reactors have taken stabilization and safety measures for a long time. Furthermore, there is significant uncertainty in the management of various radioactive substances in past nuclear development facilities called “legacy sites” which are located in the UK, US and France etc. In these sites, decommissioning and environmental remediation have been implemented for a long-term. For this reason, these countries have been challenging the issues such as technological difficulties called “unknown unknowns” (unknown issues that even uncertainty level is not known), project management over several decades, and securing of large amount of funds.

In order to make steady progress on the decommissioning of the Fukushima Daiichi NPS as a risk reduction strategy described above, it is important to learn from the measures taken for the reactors which had accident and from the decommissioning activities of the legacy sites being undertaken in the world while utilizing technologies and human resources at the world’s highest level. In addition, to secure and maintain understanding and support from international communities, it is also important to engage in decommissioning open to international societies.

Moreover, the decommissioning of the Fukushima Daiichi NPS is expected to offer the opportunity of development for cutting-edge science and technology and to become a source of innovation. For instance, the multicopter developed in the U.K. which enables three-dimensional dose assessment (RISER) was tested for applicability to dose assessment at the Fukushima Daiichi NPS in February and April of 2017. As the result, it could be measured the dose distribution inside the Unit 1 and 3 buildings. This test result at the Fukushima Daiichi NPS in a harsh environment is expected to utilize for development of drones and so on in the future. In this way, technologies and knowledge acquired through decommissioning activities of the Fukushima Daiichi NPS can be beneficial for the decommissioning engaged in each country.

The international institutions such as IAEA, Organization for Economic Co-operation and Development/Nuclear Energy Agency (“OECD/NEA”) have a role of contribution to design the international standard, share the knowledge and experience among nations, and form the international common perceptions for decommissioning. To proceed with the decommissioning of the Fukushima Daiichi NPS in an open manner, it is important for Japan to participate in the activities of these institutions. At the same time, it is expected to fulfill a part of Japan’s responsibility to the international society by 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

Concerning the long-term process of the Fukushima Daiichi NPS decommissioning, cooperation with overseas decommissioning agencies should be continuous partnership not transient one. 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 reinforce a continuous partnership with these institutions such as Nuclear Decommissioning Authority (NDA), Commissariat a l’energie atomique (CEA), United States Department of Energy, Office of Environmental Management (DOE/EM) under government-level framework. TEPCO should also establish a long-term partnership with overseas decommissioning operators, and these should be broad cooperation-based.

Also in the past, 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 5. In the future, it is also requested to learn a lesson from various countries to utilize it for the decommissioning of the Fukushima Daiichi NPS. Moreover, it is 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.

Table 5 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” (1st meeting: February 2012).
Japan-France Nuclear Energy Committee	It was established under the joint statement of Japan–France top-level meeting in October 2012 (1st meeting: February 2012).
Japan-US Decommissioning and	After the Fukushima Daiichi NPS accident in March 2011, the establishment of the US-Japan Bilateral Commission on Civil

<table>
<tr><td colspan="2">Environmental Management Working Group</td><td>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 (1st meeting: December 2012).</td></tr>
<tr><td colspan="2">Japan-Russia Nuclear Working Group</td><td>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, (1st meeting: September 2016).</td></tr>
<tr><th colspan="3">Inter-organizational Cooperation Agreement</th></tr>
<tr><th>Domestic</th><th>International</th><th>Descriptions</th></tr>
<tr><td>NDF</td><td>NDA</td><td>Exchange of information for various technical knowledge on decommissioning, etc. and personal exchange are provided. (Concluded in February 2015)</td></tr>
<tr><td>NDF</td><td>CEA</td><td>Exchange of information for various technical knowledge on decommissioning, etc. and personal exchange is provided. (Concluded in February 2015)</td></tr>
<tr><td>TEPCO</td><td>DOE</td><td>Umbrella Contract was made and information is exchanged as needed. (Concluded in September 2013)</td></tr>
<tr><td>TEPCO</td><td>Sellafield, Ltd.</td><td>Information Exchange Agreement for site’s operation, etc. was concluded. (September 2014)</td></tr>
<tr><td>TEPCO</td><td>CEA</td><td>Information Exchange Agreement on for decommissioning was concluded. (September 2015)</td></tr>
<tr><td>JAEA</td><td>NNL</td><td>Comprehensive Agreement for advanced technology on nuclear R&D, advanced fuel cycles, fast reactor, radioactive waste</td></tr>
<tr><td>JAEA</td><td>CEA</td><td>Cooperation Agreement for specific technical issues on molten core-concrete interaction, etc.</td></tr>
<tr><td>JAEA</td><td>Belgium Nuclear Research Center</td><td>Agreement of Cooperation for Nuclear R&D and Research on the accident of the Fukushima Daiichi</td></tr>
<tr><td>JAEA</td><td>Nuclear Safety Research Center (Ukraine)</td><td>Memorandum for decommissioning research, etc. of the Fukushima Daiichi NPS and Chernobyl was concluded.</td></tr>
<tr><td>JAEA</td><td>IAEA</td><td>Research Agreement on characterization of fuel debris</td></tr>
</table>

6.2.2 Integrating and utilizing wisdom in the world

In regard with the wisdom in the world that should be obtained for the decommissioning of the Fukushima Daiichi NPS, there are a variety of approaches not only in technical aspect, but also operational aspect such as system/policy, providing strategy, project plan/operation, safety, regional communications, and so on. Up until now, there are opportunities to support the decommissioning of the Fukushima Daiichi NPS by international society, and several kinds of supports have been given by overseas governmental institutions and experts including DAROD project led by IAEA and collaboration projects promoted by OECD/NEA. It is deeply appreciated to these supports.

As for system and policy among matters regarding management, 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 5. As for formulation of strategies, planning and management of projects, we learned from opinion exchanges with the NDA, case studies, and the efforts of overseas engineering firms. These are utilized for the introduction of project management techniques. Concerning the effort to communicate with the local residents, as described in Chapter 7, the decommissioning of the Fukushima Daiichi NPS should be implemented with broad understanding and support of local residents. Based on this idea, the efforts of local societies in various countries have been learning reference to overseas practices.

Moreover, as for 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 Section 4.2.

In the technical aspect, while learning the use situation of technologies in the decommissioning of legacy sites and so on, many suggestions from joint research by national projects and universities have been obtained. For example, as described in Section 5.3.1, 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” project has just been initiated as the Essential R&D Themes (Attachment 12). 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 several foreign companies are participating in the project as subsidized operators. Moreover, our country participates in the international joint research PreADES project led by the OECD/NEA from the viewpoint of characterizing fuel debris and so on. As with the World Intelligence Project by MEXT, international joint research with overseas organizations in the U.K., the U.S.A. and so on are implemented as well.

We have to keep on proceeding with the decommissioning of the Fukushima Daiichi NPS while gathering and utilizing global knowhow. 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 know-how and experience with regard to decommissioning and so on overseas (Attachment 13). Recently, OECD/NEA has established a committee named CDLM (Committee on Decommissioning of Nuclear Installation and Legacy Management) to exchange opinions concerning the decommissioning in April 2018, Japan should participate in this kind of opportunity actively.

Also in the future, as described in Section 5.3.2, by developing international R&D centers organized around JAEA/CLADS where various talents from Japan and overseas interact, it is essential to develop an environment to accumulate global know-how on decommissioning. It is also important to promote international joint research continuously to obtain new technical know-how for decommissioning effectively and efficiently and, in doing so, it is also necessary to pay attention to overseas demand for the research utilizing fuel debris and so on. In addition, as described in Section 5.1.1, the country and the operator must divide the roles appropriately to proceed steadily to 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.

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 should understand the latest status to the utilization of global-level technologies and human resources.

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 and contributing to gather wisdom and knowledge from the world, it is important to proceed with the decommissioning in a manner open to the international community. It is also necessary 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 6, Approach for dissemination of information to the world)

Table 6 Approach for dissemination of information to the world

Holding or attending International Conference (FY2017)		
Conference Name	Period	Organization
International Congress on Advances in Nuclear Power Plants (ICAPP) 2017	April, 2017	NDF, JAEA, IRID, TEPCO
Fukushima Research Conference (FRC)	Jun, Jul, Sep and Nov. 2017 and Mar. 2018	JAEA
Japan-US Nuclear R&D Collaboration Symposium	June, 2017	JAEA
The 2nd International Forum on the Decommissioning of the Fukushima Daiichi NPS	July, 2017	NDF, TEPCO
Seminar in Ulsan Institute of Science and Technology (Korea)	September, 2017	NDF
IAEA side event	September, 2017	METI,
MIT-TIT Workshop	October, 2017	IRID
OECD/NEA Steering Committee	October, 2017	NDF
OECD/NEA Working Party on Decommissioning and Dismantling	October, 2017	METI
Nuclear decommissioning forum (In France)	December, 2017	NDF,JAEA
Uk-Japan Nuclear Industrial Forum	January, 2018	METI,NDF, TEPCO
NRC Regulatory Information Conference (RIC)	March, 2018	NDF
WM Symposia 2018	March, 2018	TEPCO
ASEM The 5th Nuclear Safety Seminar	March, 2018	METI
Announcement in other conferences (FY2017)		
Releasing the Strategic Plan to the embassies of EU countries	November, 2017	NDF
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 1-4 （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
Portal site of Decommissioning R&D Information（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 Project of Decommissioning and Contaminated Water Management(https://en.dccc-program.jp/)	MRI

6.3 Close cooperation with relevant domestic organizations

As described in 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 know-how 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, close cooperation between related domestic organizations must be promoted more than ever.

7. Local community engagement and further enhancement of communication

7.1 Approaches for local community engagement and further enhancement of communication

For the continuous implementation of the decommissioning of the Fukushima Daiichi NPS, symbiosis with the local community is the major premise. It must be developed awareness that the decommissioning of the Fukushima Daiichi NPS is implemented primarily for the local community and it should be aimed at decommissioning that contributes to reconstruction, making an effort to build a community-based, trusting relationship.

In the practice of communication which forms the basis of such trusting relationships with the local community, the starting point is to listen sincerely to the opinions of people of various positions including local residents. In the session entitled “Thoughts on Decommissioning of 1F with the Local community” of the International Forum on the Decommissioning of the Fukushima Daiichi NPS[51], many participants from inside and outside the prefecture including local residents attended and expressed their feelings about the decommissioning and spoke with the experts. It was suggested that a lot of people have questions and requests about the plans and activities of the decommissioning, anxiety and doubt about safety and risk management of the decommissioning, dissatisfaction and requests about the way to disclose information regarding the decommissioning. In addition, the discussions were held on how dissemination of information can be improved and on how decommissioning should assist local reconstruction. For those concerned with the decommissioning, it is important to proceed with information disclosure and communication, accepting these feelings of the local residents and responding to them positively.

It is particularly important to respond to the questions about projects, plans and decommissioning activities and to the anxiety about safety and risk management and, for this purpose, while providing information appropriately on safety measures, work progress and radiation safety and keeping interactive communication, a common understanding with the local residents must be formulated regarding the risk reduction policy to proceed with the future decommissioning. Moreover, as described in Section 2.3.3.4, in order to help the effort, it is important to create a mechanism of risk monitoring which indicates the progress of continuous and speedy risk reduction, for example, by grasping the time variation of the risk.

Interactive communication is not satisfactory through simply sharing information between the transmitter and receiver, what is needed is a mutual effort to reduce the gap in understanding by continuing adequate dialogue. By understanding interests, doubts and anxieties and by continuing the process of the corresponding dialogue, based on mutual understanding between concerned parties including the local residents and through the involvement of many stakeholders, it must be

[51] Day 1 of The 2nd International Forum on the Decommissioning of 1F, held in July 2, 2017, in Hirono-machi, Fukushima prefecture, and Day 1 of the 3rd International Forum on the Decommissioning of 1F, held in August 5, 2018

aimed at reaching a more desirable decision-making process.

On the foundations of this kind of communication, it is necessary to initiate specific efforts that decommissioning and the related various activities will be regionally-oriented industries through the contribution to reconstruction and revitalization of the local community. Just as, for example, on-site infrastructure maintenance such as management of the canteen in the new main office building, operation and management of electric and air-conditioning equipment is commissioned to local companies at the Fukushima Daiichi NPS, TEPCO keeps on promoting the purchase of locally available goods and services and so on to proceed with the decommissioning work with the continuous cooperation of the local community. Moreover, a group of research facilities constructed in the Hamadori region to play a part in the Innovation Coast Scheme (see Section 5.3.2) where, by accumulating global know-how, R&D for decommissioning and human resources development are being promoted are also important facilities for symbiosis with the local community. It is greatly anticipated that expansion of these activities related to the decommissioning leading to new technologies, new industries and job creation and their acceptance by the local community will lead to reconstruction and revitalization of the Hamadori region.

7.2 Actual effort for better communication

In the future, when undertakings such as fuel debris retrieval will begin in earnest, referring to the various overseas experiences and with proper cooperation between the related organizations such as the government, TEPCO and NDF, it is necessary to consider and practice more careful ways to communicate.

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 preparing videos on the situation of the decommissioning task and the brochure "Important Stories on Decommissioning, 2018"[52] as well as by active explanations to and conversations with local residents and officials of related municipalities.

NDF will continuously hold the "International Forum on the Decommissioning of the Fukushima Daiichi NPS", provide clear information on the decommissioning of the Fukushima Daiichi NPS, and exchange opinions with the local residents, while making efforts to make it an opportunity for both Japanese and foreign experts to widely share the latest progress and the technical results of the decommissioning. Moreover, NDF are vigorously conducting active explanations to and conversations with the local residents and the officials of the related municipalities. In addition, in the viewpoint of being thorough with clear explanations and putting themselves in the listener's shoes, the brochure "Hairo no Iroha (ABCs of decommissioning)"[53] has just been prepared to communicate the story of decommissioning which tends to be technical in a simple way by

[52] http://www.meti.go.jp/earthquake/nuclear/pdf/reactorpamph_pdf_8MB.pdf
[53] http://www.dd.ndf.go.jp/jp/about/pdf/hairo_iroha_2018_1.pdf

narrowing the focus, in an effort to disseminate accurate and clear information on the decommissioning. Also in the future, it has been decided to continue these interactive conversational activities more vigorously to sincerely accept the opinions of local residents.

TEPCO is continuously working on explanations to and conversations with local residents and the officials of the related municipalities through management and the risk communicators at the "Prefectural Safety Assurance Conference for the Decommissioning of the Fukushima Nuclear Power Station" sponsored by Fukushima Prefecture and so on, and on the explanations to and conversations with local representatives and so on regarding the progress of the Roadmap. In November 2017, the Decommissioning Communication Center was established to enable the integrated dissemination of information by adjusting the system of information dissemination on decommissioning, which had been divided into departments and, at the same time, by disclosure of web contents and regular publication of the info-magazine on decommissioning of the Fukushima Daiichi NPS, "Hairo Michi (the way to decommissioning)", efforts will be made to further strengthen the careful dissemination of information on the situation of decommissioning task and so on. Moreover, to have people observe the real state of progress of the decommissioning task on the site of the Fukushima Daiichi NPS is very effective for formulating a common understanding of decommissioning. TEPCO has been proactively accepting visitors to the Fukushima Daiichi NPS, including evacuees, and 12,000 visitors were accepted in FY2017. 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 and improving the visit (route and content) will be attempted[54]. In addition, in March 2018, TEPCO released web-related content[55] through which viewers can experience a real sense of actually visiting the premises.

7.3 Further spread of communication and measures to Reputational damage

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 seven 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, 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 risk reduction activities due to radioactive materials. In order to avoid this vicious circle, while making efforts in regard to proper safety management to prevent leakage of radioactive materials and so on, it is more important than anything to quickly reduce the existing risk.

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[54] TEPCO, Approach to the Countermeasures for Decommissioning and Contaminated Water Management of the Fukushima Daiichi NPS - Information Dissemination and Communication -, Handout 3-5 of the 16th Fukushima Council for Countermeasures for Decommissioning and Contaminated Water Management, April 27, 2018,
http://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/fukushimahyougikai/2018/pdf/0427_01f.pdf

[55] "INSIDE FUKUSHIMA DAIICHI - A virtual tour of the site of decommissioning -",
http://www.tepco.co.jp/insidefukushimadaiichi/index-j.html

Moreover, in order to prevent reputational damage, in addition to communicating with the local residents as described above, approaching a wider range of people becomes necessary. Not to mention the local residents, press, market and distributors, efforts to widen the range of communication to consumers including those overseas become necessary. In case of problems, a sincere and careful explanation must be provided as much as possible on the major premises of preciseness and transparency, and also after any problems, it is needed to actively communicate the execution status of safety measures thereafter and the improvement status of safety management onsite. Furthermore, considering the case of internal investigation of Unit 2 executed in January and February 2017 when a high dosimetry value was measured, causing an overreaction inside and outside the country, it is important to try to disseminate information carefully even during normal times.

In December 2017, the government formulated the "Strategies to Eliminate Negative Reputation and to Strengthen Risk Communication", and the concerned government agencies are working on it in an integrated manner[56]. Moreover, TEPCO formulated and published the "Action Plan to Combat Harmful Rumors" in January 2018[57]. Based on these, it is important for the concerned organizations to continue their concerted efforts.

[56] Reconstruction Agency, Strategies to Eliminate Negative Reputation and to Strengthen Risk Communication, see the portal site (http://www.fukko-pr.reconstruction.go.jp/2017/senryaku/)

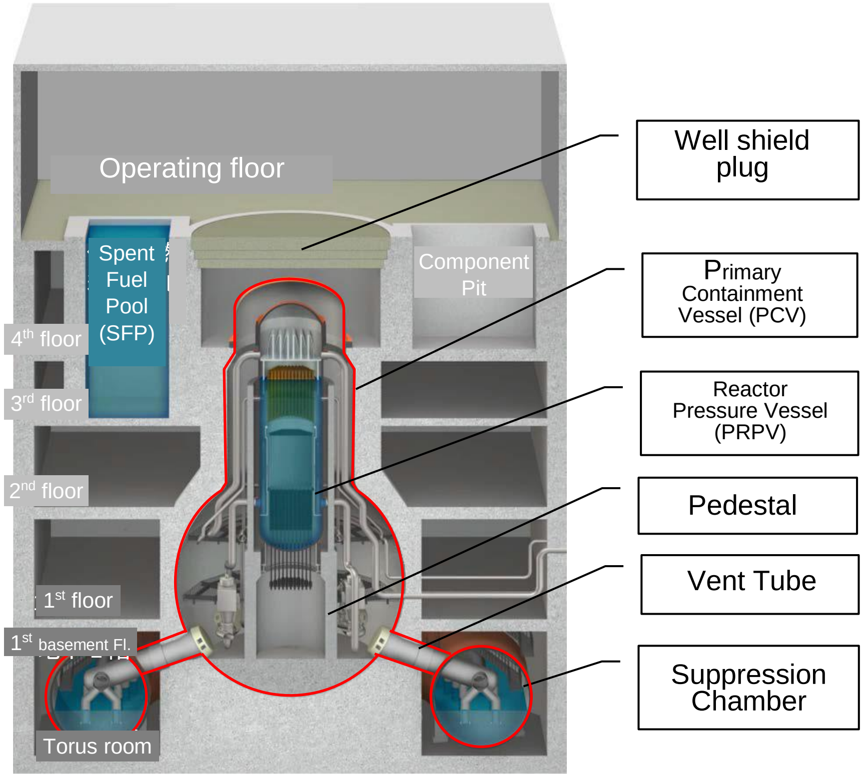
[57] Development of Action Plan against Harmful Rumor, TEPCO, January 31, 2018 http://www.tepco.co.jp/press/release/2018/1475368_8707.html

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
Underwater ROV	A remotely operated underwater 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.
Roadmap	Government-developed “Mid-and-long-term Roadmap” toward the decommissioning of TEPCO’s Fukushima Daiichi Nuclear Power Station Unit 1 to 4
TEPCO	Tokyo Electric Company Holdings, Inc.

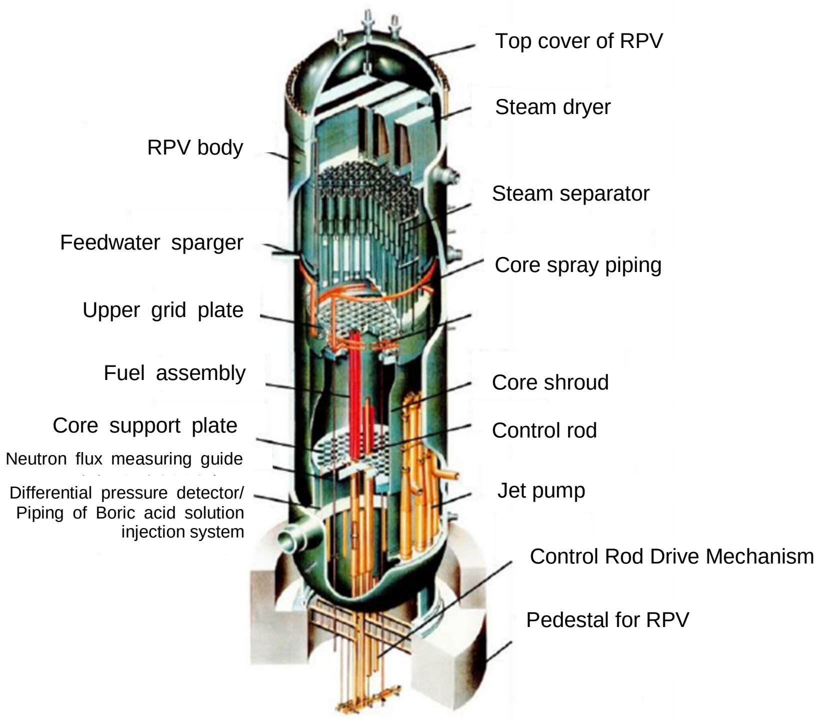
Withdrawal Plan	Withdrawal plan for reserve fund
The Policy of Preparation of Withdrawal Plan	The Policy of preparation of withdrawal plan for reserve fund for decommissioning
Fukushima Daiichi NPS	Fukushima Daiichi Nuclear Power Station of Tokyo Electric Company Holdings, Inc.

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 Pail) 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 Roadmap and the earlier published strategic plan

[1st Edition of the 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).

[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.

[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 Roadmap from the viewpoint of proper and steady implementation of decommissioning of the Fukushima Daiichi Nuclear Power Plant.
  (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 Plant 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, Proven, Efficient, Timely, 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.

[Roadmap Revised 3rd Edition (June 12, 2013)]

- 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 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 three priority methods for fuel debris retrieval. Recommendations for policy decision on fuel debris retrieval were made and efforts after policy decision including preliminary engineering were recommended as strategic proposals.
- Recommendations were made for compiling the basic concept concerning solid waste treatment and disposal.

[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".

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.

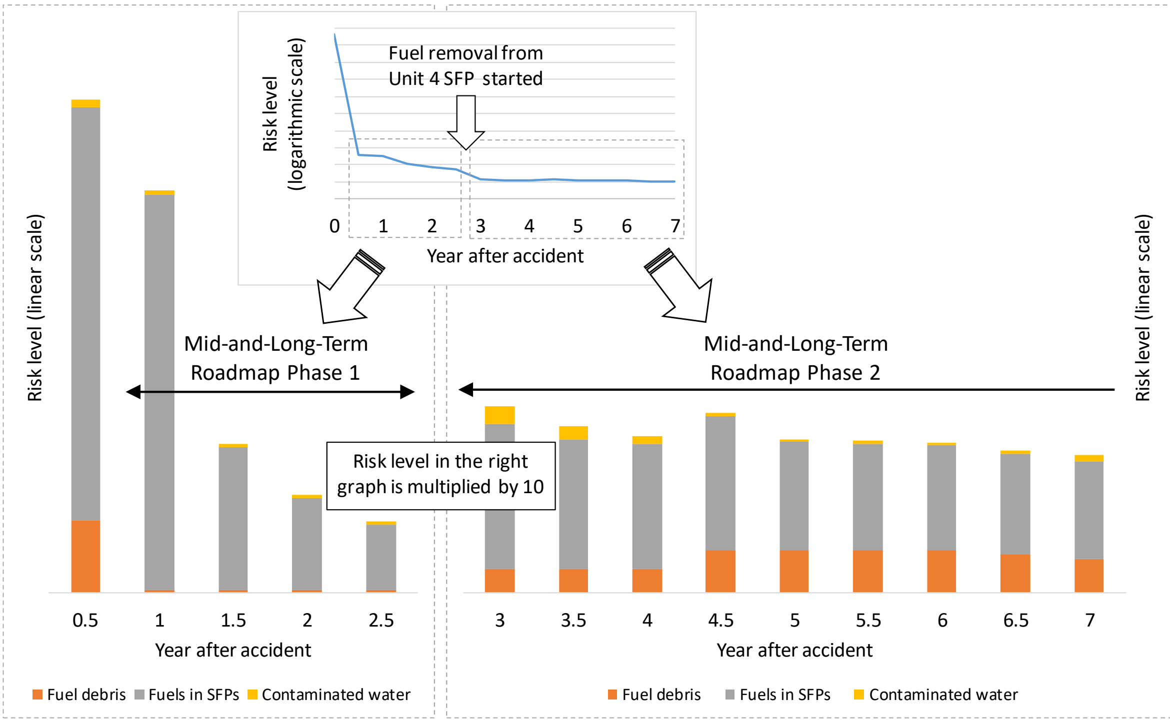


Fig. A2-1 Reduction of risks contained in the Fukushima Daiichi NPS (Same of Fig.4 of p.17)

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 pool and fuel in dry casks are not shown which stay in the region of sufficiently stable management.

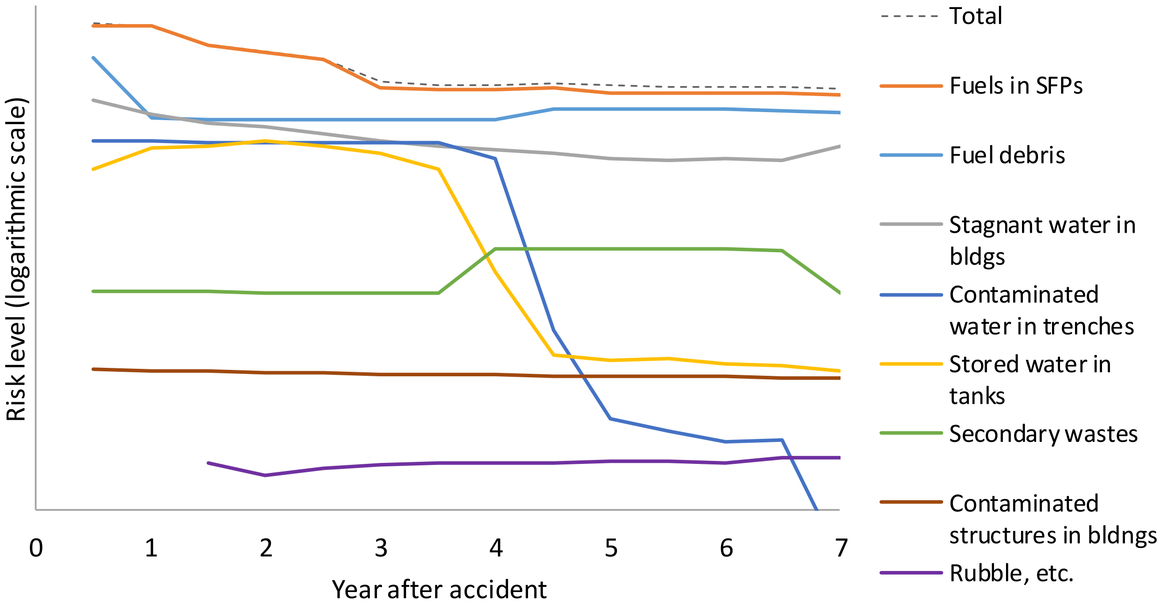


Fig. A2-2 Change in the risk level of every major risk source

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.

(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 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, etc. have been conducted as preparations of fuel removal, and recently the cover for fuel removal was installed (in 2018), resulting in reduction of risk level.

In the future fuel removal in SFP in Unit 3 is scheduled to start from about the middle of FY2018 and in Unit 1 and 2 by 2023 to reduce the risk level.

(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 in 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 in 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.

Recently, 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 is rising. This is considered as an effect that isolated water, etc., which was not included in the risk assessment, has leaked in, and investigation and study are required in the future.

(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 Unit 2 to 4, treatment of the stagnant water has been completed and trenches were blocked (in 2015).

Stagnant water in the seawater pipe trench in Unit 1 with lower concentration compared to those in Unit 2 to 4 is now being continuously processed.

(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 o 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 (will be completed in FY2018).

(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), fallen 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 fallen 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 (Unit 2 to 4) ● Start of pumping up by sub-drain system ● Closure of sea-side impermeable walls	
2016				
2017			● Completion of condenser drainage (Unit 1-3)	● 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	● Installation of new solid waste storage facility
Future actions	● Start of retrieval from first implementing unit in 2021	● Start of Unit 3 removal in the middle of FY2018 ● Start of Unit 1 and 2 removal, aiming by FY2023	● Completion of transfer to welded tanks (FY2018) ● 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[58] 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 dose[59.] The STP is defined as the volume of water required to dilute 1TBq of radioactive materials and corresponds to the dose coefficient. Ingestion of a certain amount of such diluted water throughout the year will result in an exposure dose of 1mSv. The SED indicator conservatively uses the larger dose coefficient between ingestion and inhalation.

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

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

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 A 3-1 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

[*] 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>

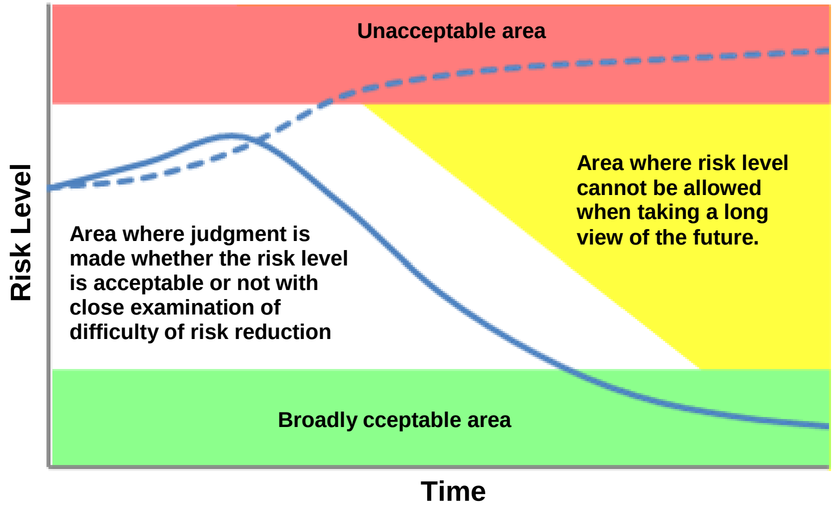
Table A 3-6 shows the overview of containment function, safety equipment, the state of control and surveillance, etc. of each risk source used when Safety Management was assessed..

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 pool and dry casks, 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 is stored either in flanged tanks or welded tanks, and flanged tanks are being replaced to welded tanks.
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　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. A 4 Change in risk over time

Attachment 5 Coverage of fuel debris retrieval

In the 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[60,61].

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.

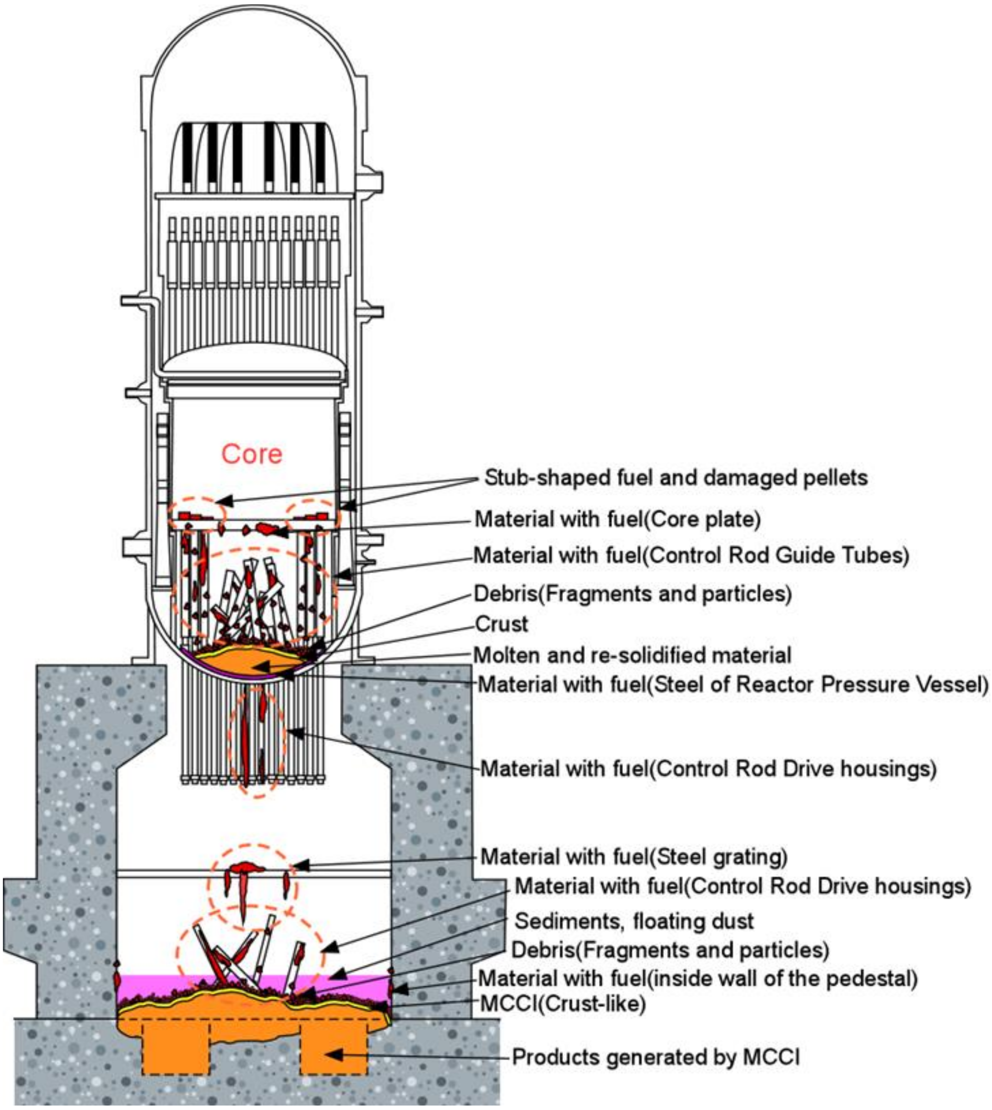


Fig. A5-1 Estimated inside of the PCV of the Fukushima Daiichi NPS

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

61 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, collection, 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.

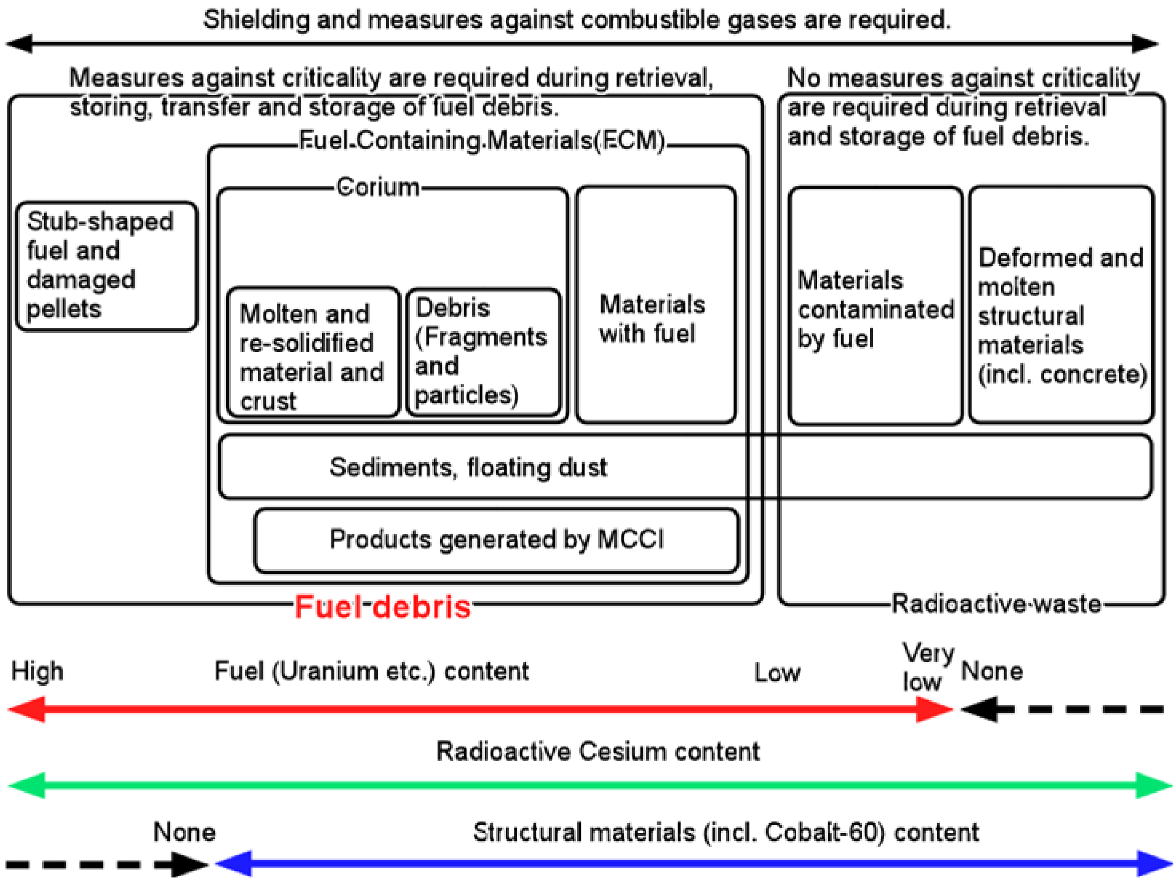


Fig. A5-2 An example of organized concept of fuel debris as fuel debris retrieval target at the Fukushima Daiichi NPS

【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 alpha 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 6 Reduction of liquid phase and contaminated water (Water balance around the reactor buildings)

The capability to seal 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 exposure to the liquid the on the public as with the exposure to the gas.

However, since the primary containment vessels (PCVs) and buildings (torus rooms) are found to be pierced and damaged by the earthquake, it is difficult to statically contain 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. s 1 and 2 show 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

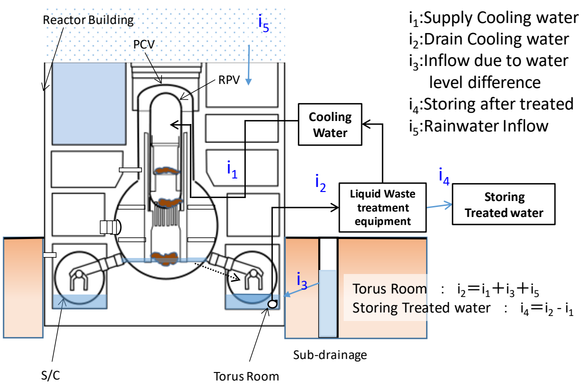
It is important to take measures to prevent rainwater from flowing into the reactor buildings and to set an appropriate groundwater level.

and/or

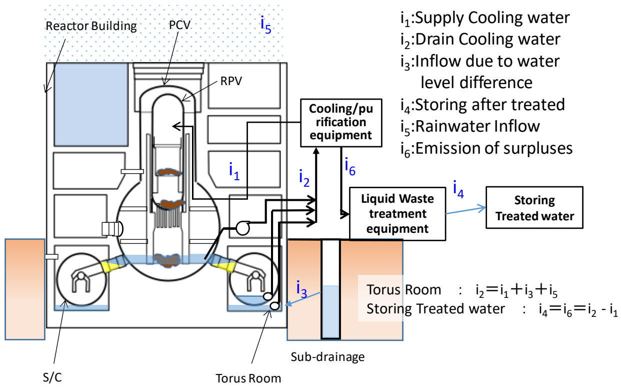
(2) Reducing the emergence of contaminated water

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. A6-1 Water balance around the reactor buildings

Attachment 7 Study on the water level at the bottom of the 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. A7-1) 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.

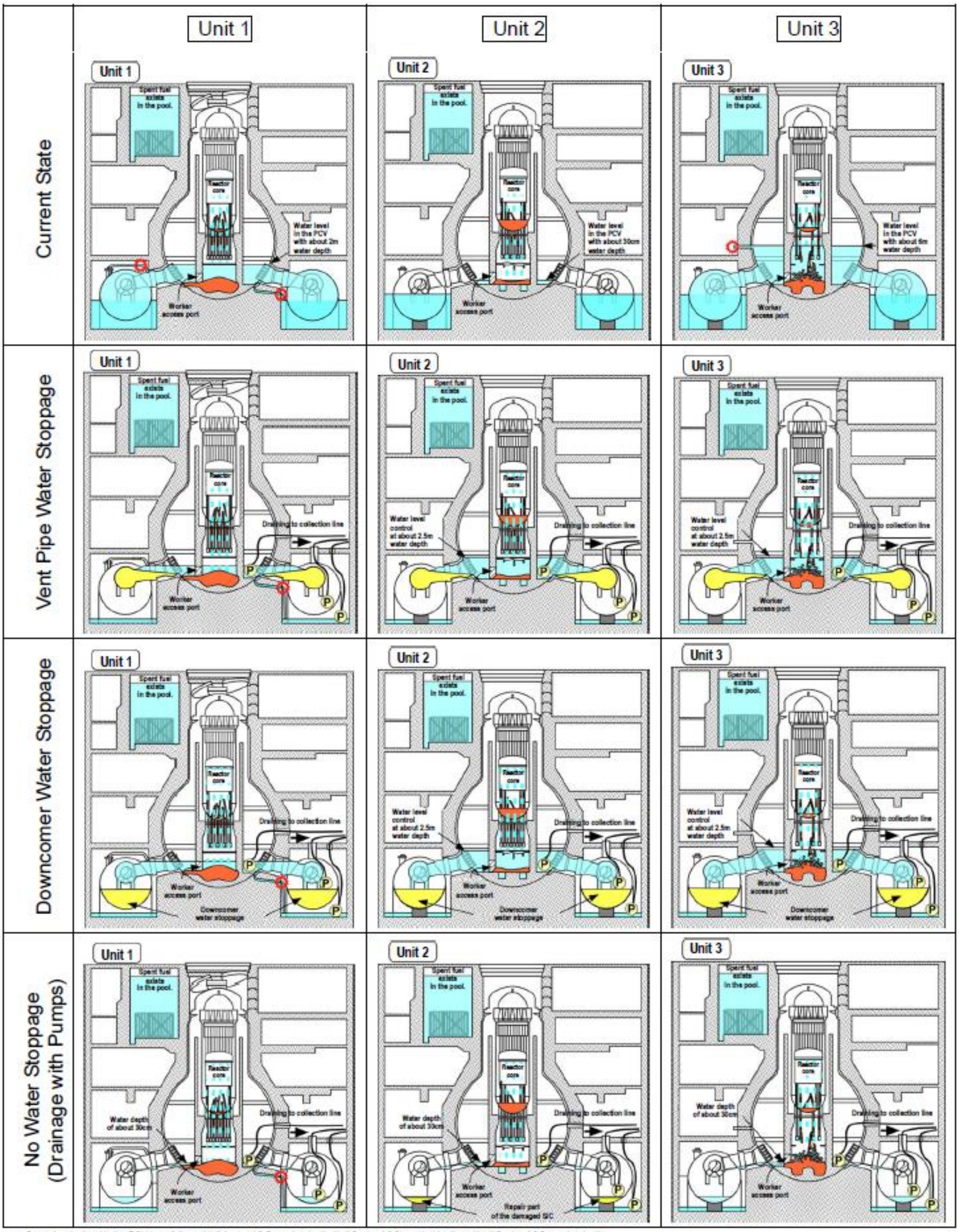
When water stoppage is not performed, the water level in the PCV will be maintained at the same level of the current one and fuel debris retrieval will be performed in the air while the cooling water is kept flowing on fuel debris. In this case, it is necessary to identify and repair the damaged part 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 6.3m and is higher compared to those of Unit 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 2.5m water depth, Unit 2: about 0.3m water depth and Unit 3: about 6.3m 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 Unit 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. A7-1 Water level at the bottom of the PCV and water stoppage in the PCV (Conceptual diagram with assumed results)

Attachment 8 Terms related to radioactive waste management

IAEA Safety Requirements GSR-Part 5 [62] 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. A8. 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.

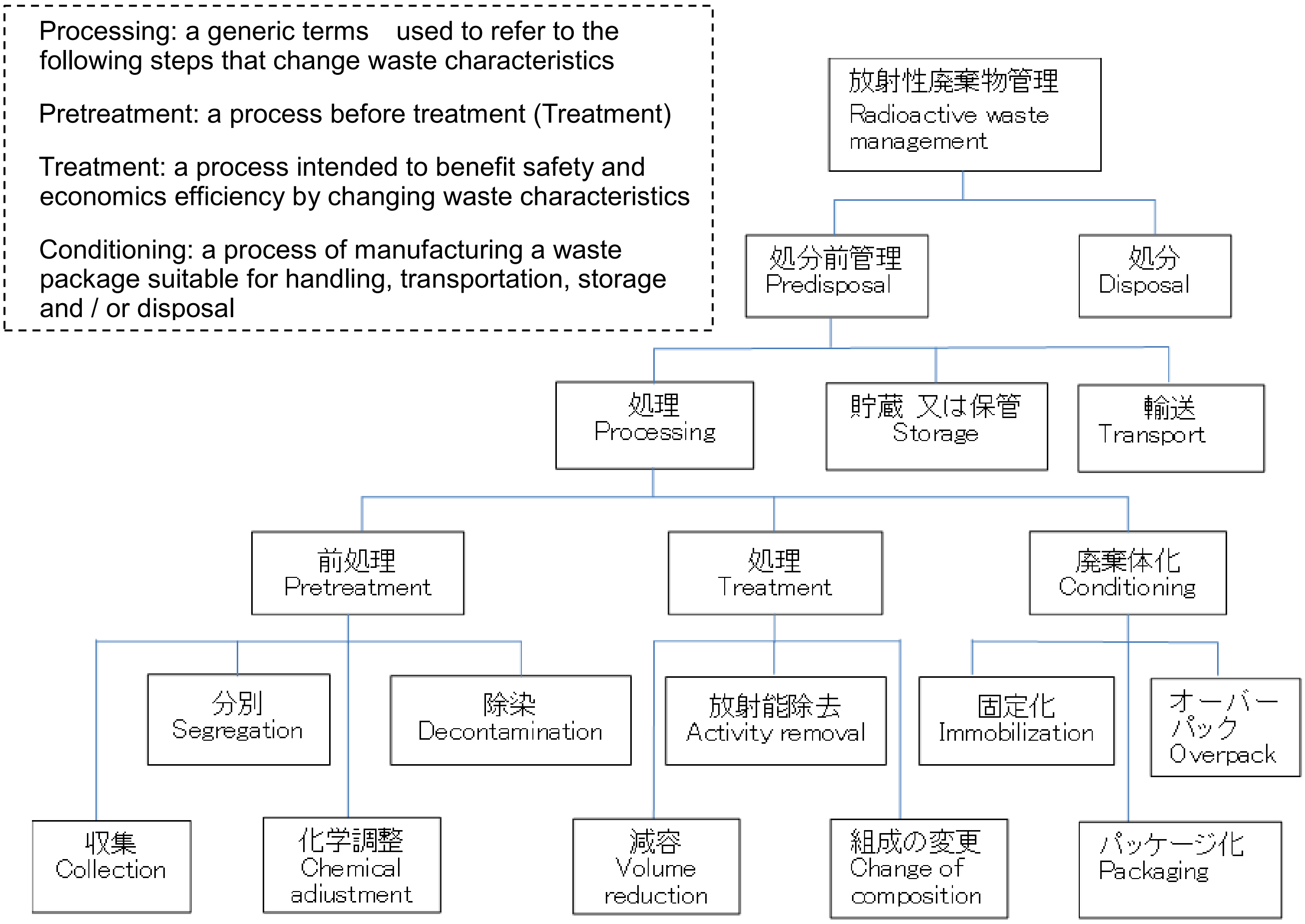


Fig. A8 Terms related to radioactive waste management (IAEA)[63] and their translation examples (For the Japanese translation example, refer to the materials of the Japan Atomic Energy[64][65]

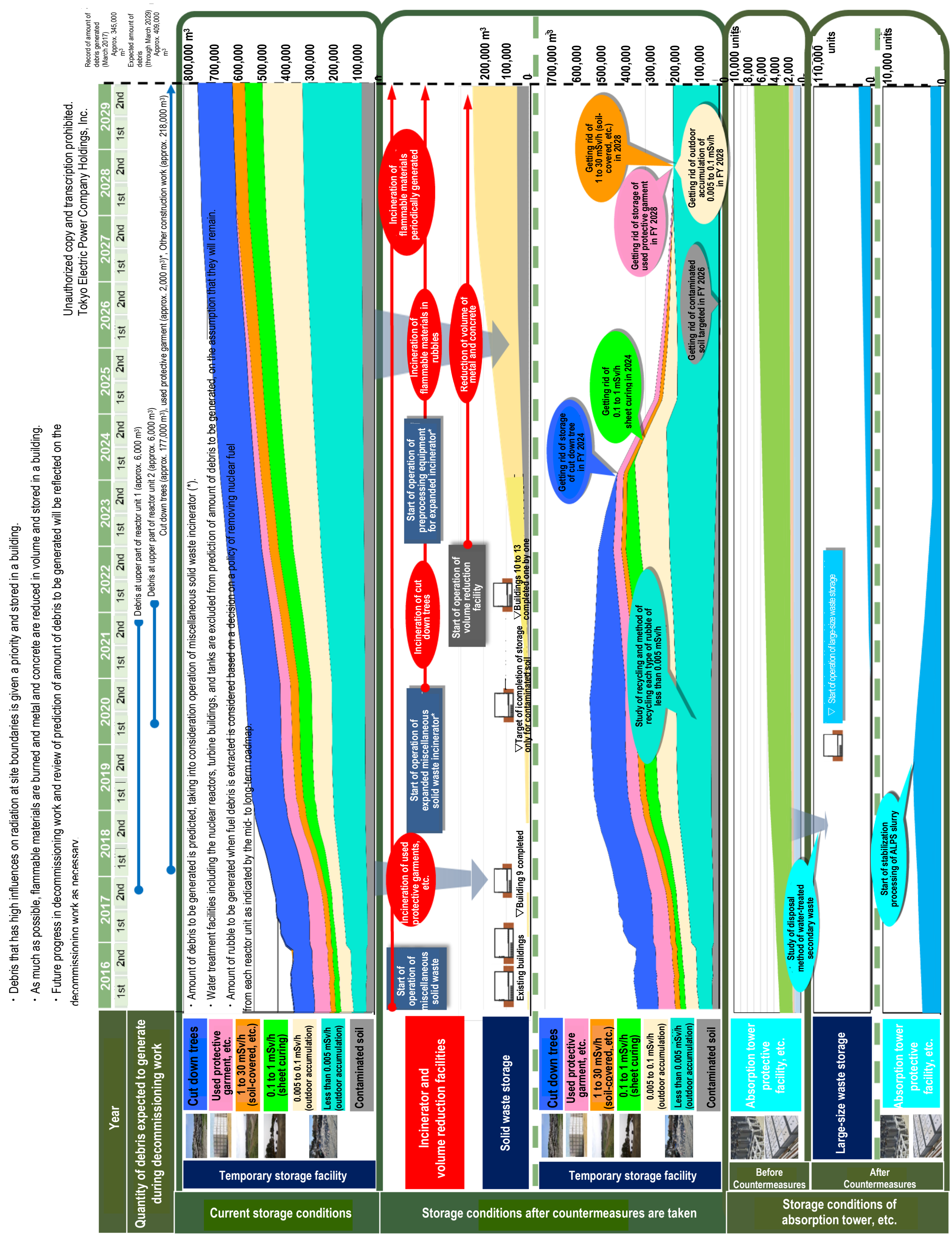
[62] IAEA, Predisposal Management of Radioactive Waste, IAEA Safety Standards Series No. GSR Part 5, (2009). (NSRA, IAEA Safety Standard/Predisposal of Radioactive Waste/General Safety Requirement 5, No. GSR-Part5, July, 2012)

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

[64] A special committee of AESJ, “Processing and disposal of radioactive waste generated by the Fukushima Daiichi NPS accident” 2013 Report, p.7 of Considerations for compiling waste information and solutions, March 2014

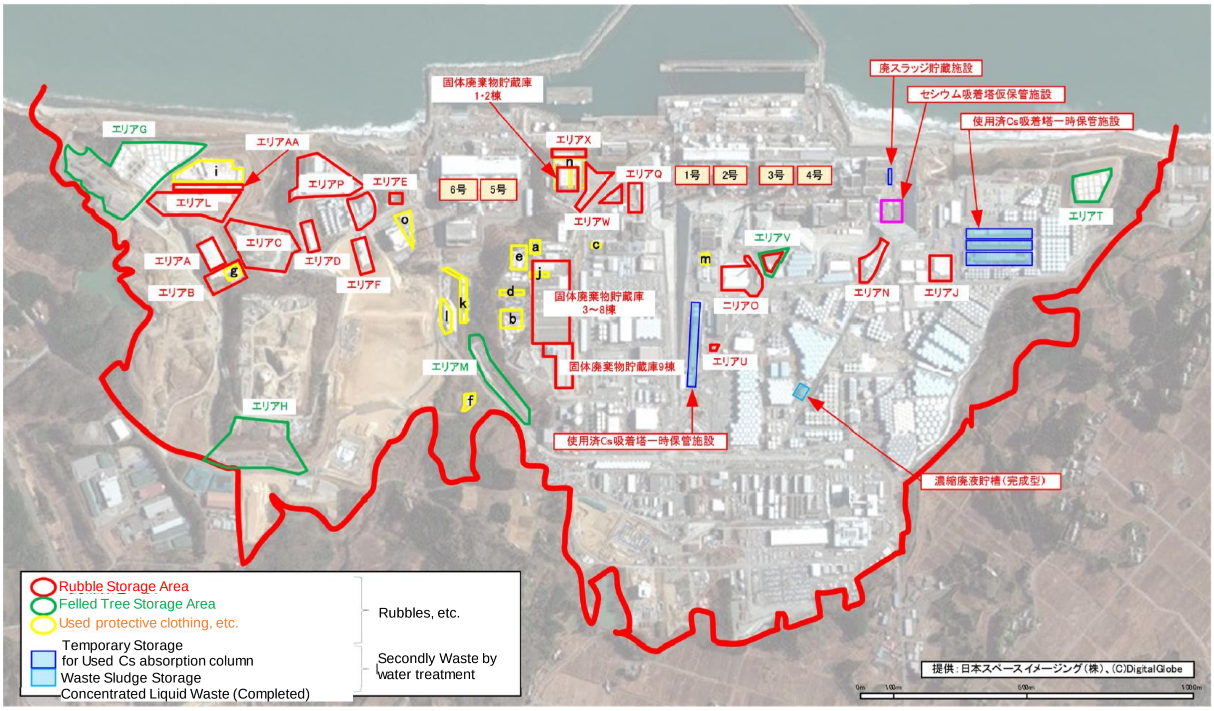
[65] Seiya Nagao, Masafumi Yamamoto, 1st Overview of Radioactive Waste Measurement, Radioactive Waste

Attachment 9 Overall image of Storage Management Plan for the Fukushima Daiichi NPS[66]

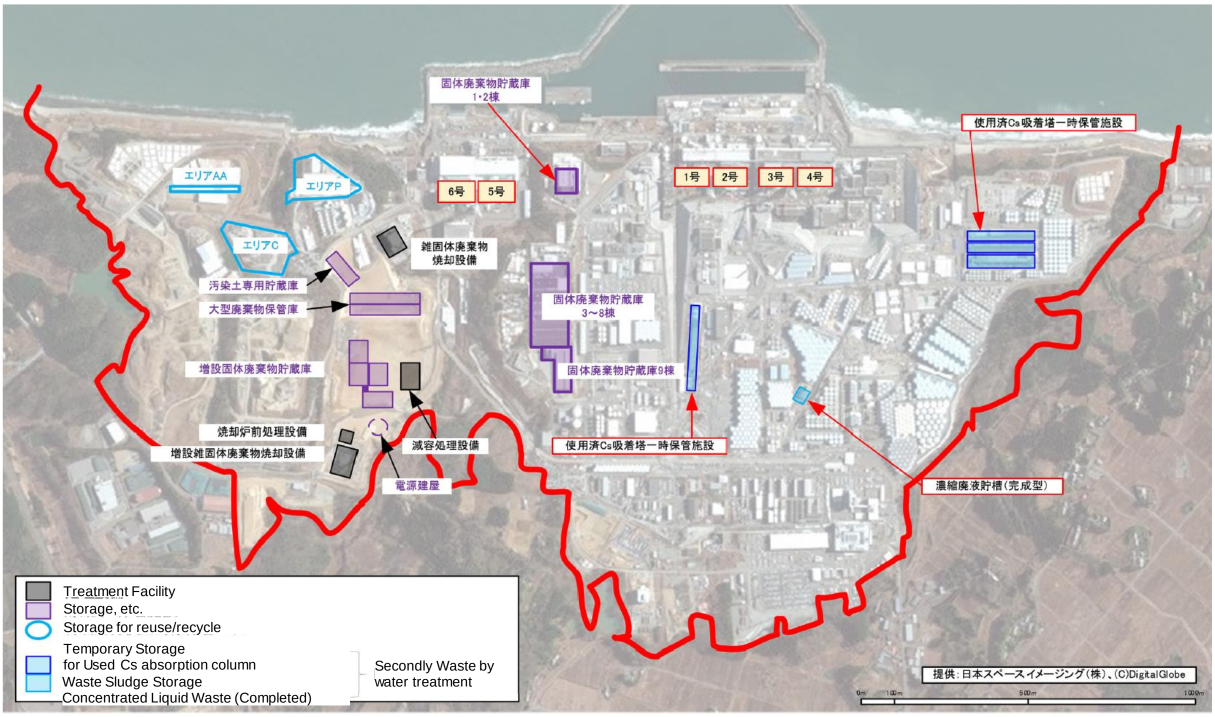


Overview, The measurement of radioactive waste generated by operation and decommissioning of facilities, AESJ 56(9), p.593, (2014).

66 TEPCO, Solid Waste Storage Management Plan for Fukushima Daichi 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.A9-1: Present and future storage conditions of “rubble, etc.” and “secondary waste generated by water treatment” on site of the Fukushima Daiichi NPS

Attachment 10 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 Field) Chemical Engineering, Industrial Chemistry, Chemical Plant, Plant Engineering, Process Engineering, Water Chemistry	(Examples of Field) Civil Engineering, Geotechnical Engineering, Architectural Engineering, Groundwater Engineering, Deep Geological Science, Geohydrology, Soil Science, Solid State Engineering (Concrete, etc.)	(Examples of Field) Material Engineering, Solid State Engineering (Metal, etc.), Metal Corrosion Engineering, Nuclear Fuel Engineering, Actinoid Chemistry, Radiation Chemistry	(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 Field) Project Management, Legal Affairs, Labor Management, Financial Affairs, PA, Risk Communication, External Relations, Information System, Radiation Management
			(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 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 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 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 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 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 Handing 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 11 Current Progress of R&D in the Project of Decommissioning and Contaminated Water Management, etc.

1. Grasping state inside reactor, grasping properties of fuel debris, investigation of reactor inside

1-(1) Upgrading level of grasping state inside reactor (FY 2016 - 2017)

(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 grasping and analyzing properties of fuel debris (FY 2017 - 2018)

(Related projects) Development of technologies for characterization and processing of fuel debris using mock debris (FY 2011 - 2014)

Properties analysis of actual debris (FY 2014)

Grasping properties of fuel debris (FY 2015 - 2016)

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)

(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 of inside of RPV (FY 2016 - 2019)

(Related projects) Development of investigation technology of inside of RPV (FY 2013 - 2015)

1-(5) Development of technologies for the detection of fuel debris inside reactors (using muon) (FY 2014 - 2015)

2. Retrieval of fuel debris

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)

(Related projects) Development of fundamental technologies for retrieval of fuel debris and internal structures (FY 2015 - 2016)

2-(3) Development of sampling technologies for retrieving fuel debris and internal structures (FY 2017 - 2018)

2-(4) Development of closed circulation systems for water inside PCV (FY 2018 - 2019)

2-(5)-1 Development of repair methods for leak spots in PCV (FY 2016 - 2017)

(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-(5)-2 Full-scale test of repair methods for leak spots in PCV (FY 2016 - 2017)

(Related projects) Full-scale test of repair methods for leak spots in PCV (FY 2014 - 2015)

2-(6) Development of evaluation methods of seismic performances of RPV and PCV and the impacts of the damages (FY 2016 - 2017)

(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-(7) Development of corrosion inhibition technology for RPV and PCV (FY 2016)

2-(8) Development of criticality control technologies of fuel debris (FY 2012 - 2017)

2-(9) Development of technologies for non-destructive detection of radioactive material deposited in S/C, etc. (FY 2014)

2-(10) Development of remote decontamination technology in the reactor building (FY 2014 - 2015)

(Related projects) Development of remote decontamination technology in the reactor building (FY 2011 - 2013)

2-(11) Formulation of comprehensive dose rate reduction plan (FY 2012 - 2013)

2-(12) Development of technologies for containing, transportation and storage of fuel debris (FY 2016 - 2019)

(Related projects) Development of technologies for containing, transportation and storage of fuel debris (FY 2014 - 2015)

<u>3. Waste management</u>

3. Research and development of processing and disposal of solid waste (FY 2017 - 2018)

(Related projects) Development of technologies for processing and disposal of secondary waste by treatment of contaminated water (FY 2012)
Development of technologies for processing and disposal of radioactive waste (FY 2012)
Research and development of processing and disposal of solid waste (FY 2013 - 2014)
Research and development of processing and 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)

(Related projects) Evaluation of long-term integrity of fuel assembly, etc. retrieved from spent fuel pool (FY 2012 - 2014)

4-(2) Investigation of method for processing damaged fuel, etc. retrieved from spent fuel pool (FY 2013 - 2014)

5. Contaminated water management

5-(1) Verification tests of tritium separation technologies (FY 2014 - 2015)

5-(2) Verification of technologies for contaminated water treatment (FY 2014)

5-(3) Large-scale verification of impermeable walls (ice wall) (FY 2014)

5-(4) Development and verification of high-performance multi-nuclide removal equipment (high-performance ALPS) (FY 2014)

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).

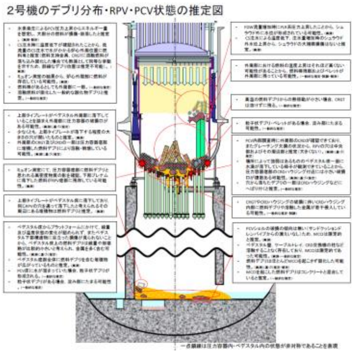


Fig. 1: Example of diagram of estimated fuel debris distribution


Fig. 2

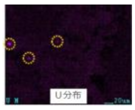


Fig. 3

(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.

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.

FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017
	Assessing conditions inside reactor by advancement of accident progression analysis technology		Assessing conditions inside reactor through application of severe accident analysis code	Advancement of grasping conditions inside reactor by accident progression analysis and actual data, etc.	Upgrading level of grasping state inside reactor	

Fig. A11-1-(1): Upgrading level of grasping state inside reactor

Project objectives
In the decommissioning of the Fukushima Daiichi NPS, the properties of fuel debris will be analyzed and evaluated to obtain data to contribute to the comprehensive analysis and evaluation of state inside reactors, the determination of methods to retrieve fuel debris and internal structures, and the study of containing, transportation and storage of fuel debris. Therefore, tests will be performed using simulated debris, and technologies required for the analysis and measurement of fuel debris will be developed for the fuel debris retrieval.

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) Assumption of fuel debris properties
Molten core-concrete interaction (MCCI) was simulated, and the results of the analysis of the MCCI products, previous severe accidents at nuclear facilities, and information from related documents were surveyed. The information has been compiled in the Fuel Debris Characteristics List, which is updated.
(2) Characterization via use of simulated debris
In international cooperation with the CEA in France, a large-scale MCCI test was performed in view of the condition of the Fukushima Daiichi NPS, and information of the element distribution of products (Fig. 1), crystal structures and hardness was obtained. Re-hydration of deteriorated cement at high temperature, drying behavior of radioactive dust and the release behavior of medium volatile fission products (FPs) that are thought to release in drying of fuel debris are evaluated.
(3) Development of elemental technologies for fuel debris analysis

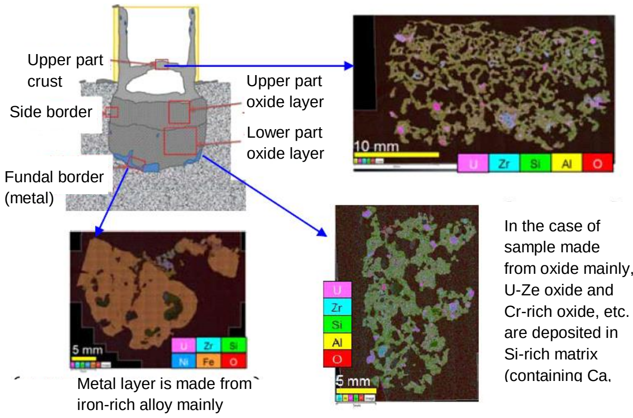


Fig. 1: Element distribution of products by large-scale MCCI test

The following technologies are under study and development: a multi-element simultaneous analysis method using inductively coupled plasma atomic emission spectrometry (ICP-AES), a quantitative porosity assessment method using computerized transverse axial tomography (CT), and a multi-nuclide rationalized analysis method using inductively coupled plasma mass spectrometry (ICP-MS). Study on the transportation of fuel debris samples is underway.
(4) Estimation of aging properties of fuel debris
To study the change by aging in behaviors of fuel debris, testing methods to evaluate the change by aging, and the possibility of chemical and physical changes are being studied.
(5) Estimation of behaviors of fuel debris fine particles (relocation characteristics in air/under water)
Fundamental data on physical/chemical characteristics and behaviors of radioactive fine particles generated from fuel debris is being surveyed and collected.
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 -)

2. Related projects
The following describes the results of previous related projects.
○ Development of technologies for characterization and processing of fuel debris using simulated 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.
○ Properties 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.
○ 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.

FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018
Development of technologies for characterization and processing of fuel debris using simulated debris							
			Properties analysis of actual debris				
Construction of material accountancy method related to fuel debris				Grasping properties of fuel debris			
						Development technologies for grasping and analyzing properties of fuel debris	

Fig. A11-1-(2): Development technologies for grasping and analyzing properties 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 investigation plans and development plans
Detailed investigation plans and development plans for individual reactors have been established, based on the results of the latest investigations of the inside the PCVs of Units 1 to 3.
(2) Development of access/investigation equipment and elemental technologies
i) Establishing an access route into PCV through X-6 penetration, access/investigation equipment
Equipment related to the establishment of an access route to the inside of the PCV through X-6 penetration was studied, and detailed design is being conducted. Then, prototypes will be fabricated and verified in plants (Fig. 1). In addition, detailed design is being conducted for arm-type access equipment to access the inside of the PCV through X-6 penetration and to identify the range of fuel debris based on the shapes of debris and distribution of gamma rays. Then, a prototype will be fabricated and verified in plants.

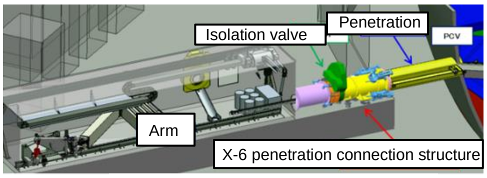


Fig. 1: Connection structure of X-6 penetration

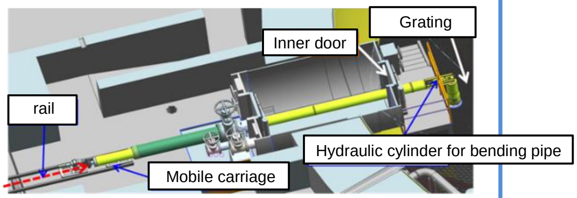
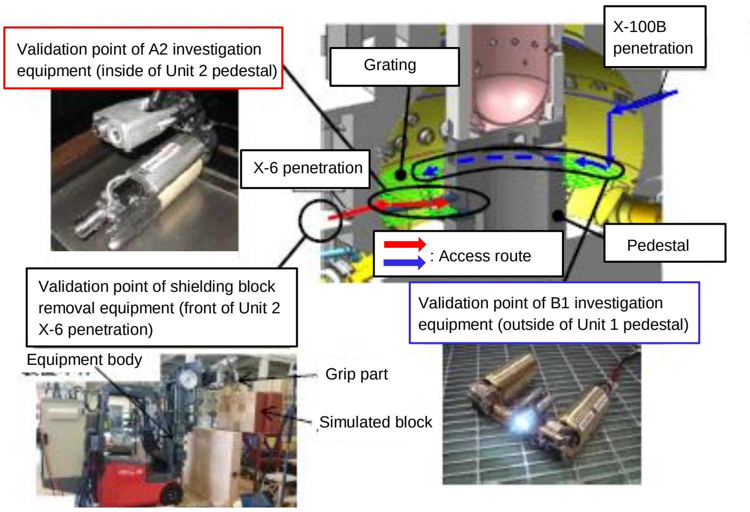


Fig. 2: Boring device of X-2 penetration inner door, grating, etc.

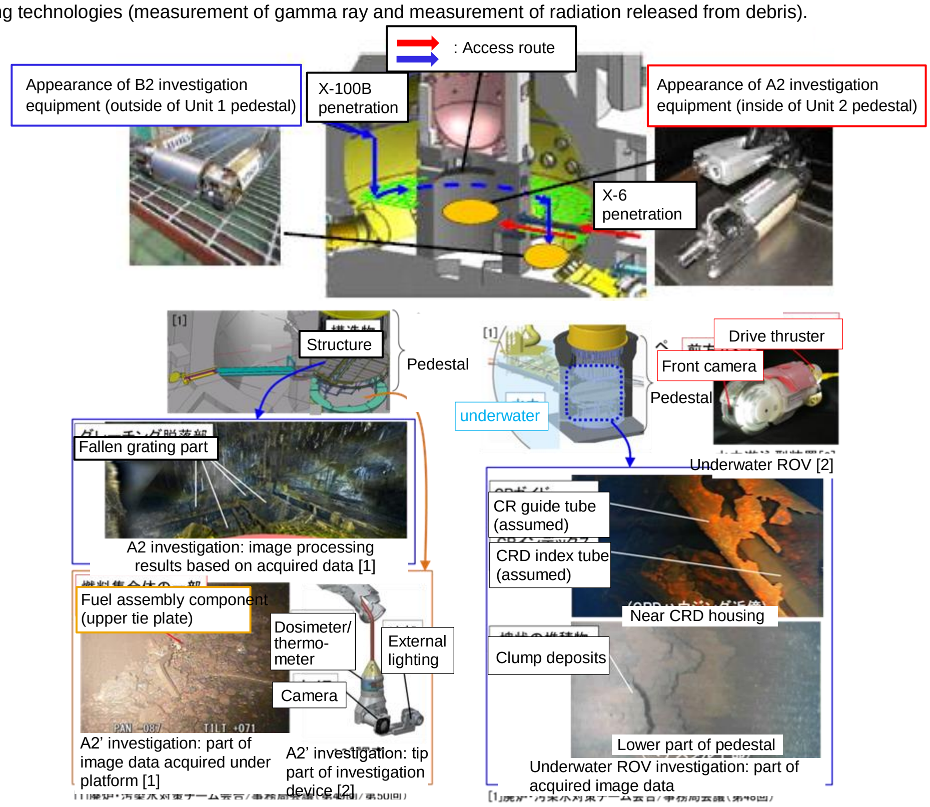
ii) Establishing an access route into PCV through X-2 penetration, access/investigation equipment
Equipment related to the establishment of an access route to the inside of the PCV through X-2 penetration is being studied. Detailed design and prototypes are being fabricated, and they are under verification in plants (Fig. 2). In addition, underwater ROV(remotely operated vehicle) that can access the inside of the PCV through X-2 penetration and has measuring technologies suitable for the purpose of the investigation, which takes into account the deposits over a wide area on the basement floor (distribution and thickness of deposits, and distribution of fuel debris under the deposits, etc.), is being designed in detail, and a prototype will be fabricated and verified in plants.
iii) Verifying the applicability of elemental technologies
In association with the update of investigation plans, measuring technologies are under review, and detailed design of measuring equipment and the fabrication of a prototype are underway. The applicability of access/investigation equipment will be verified in combination.
(3) Mock-up testing, training, and on-site verification
Mock-up testing, training, and on-site verification will be carried out (FY 2019) with the aim of conducting detailed investigations by accessing PCVs through X-6 (Unit 2) penetration and X-2 penetration (Unit 1).
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.



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.

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.
○ 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

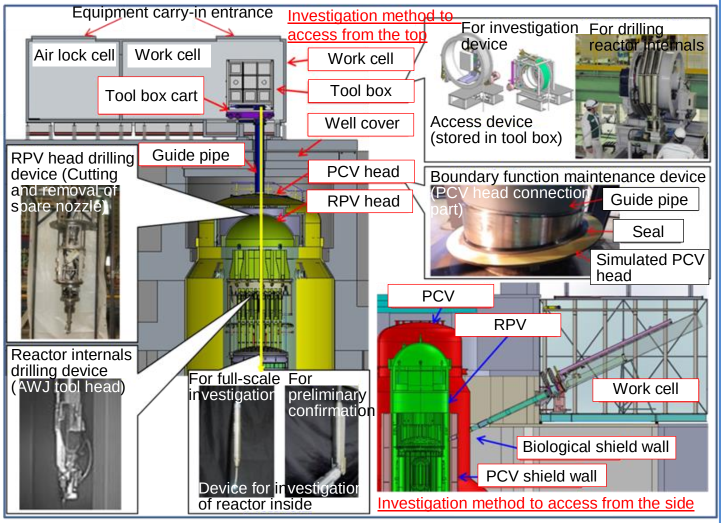
Results of investigation inside the Unit 3 pedestal

FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018
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. A11-1-(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) Development of equipment to access the core
(i) 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 guide pipe at the connection part wth the PCV head were checked through elemental tests.



- Studies were performed on a processing method to make holes in the reactor internals remotely and in narrow space 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.
(ii) Developing equipment to access from the side (side-hole-drilling method)
- The access route to the core from the side was determined, and the 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.
(2) Development and selection of investigation 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.
(3) Designing the overall system of investigation equipment and drafting a construction method plan
- Based on the assessment of radiation exposure due to dust dispersion, it was decided to maintain the inside of PCV under slightly positive pressure (the current status) during the investigation from the side, but under negative pressure during the investigation from the top to prevent the expansion of contamination.
- In addition, the equipment and functions required to ensure safety were summarized in construction method plans.
(4) Problems to be solved and future plans
- The investigation method from the top has been verified as feasible, and the investigation from the side as probably feasible. Therefore, focusing on both investigation methods, prior on-site investigations will be carried out in the early stages toward the designing of equipment applicable to on-site investigations, and information on the conditions of connection parts and environmental information will be collected. In addition, elemental tests will be performed if necessary, and the test results will be reflected in equipment design.
- Study will be conducted on the applicability of ancillary systems necessary for the investigation, and on the determination of the conditions required for the designing of equipment for actual reactors, including coordination with other related construction work.
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 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
		Development of investigation technology of inside of RPV					
					Development of investigation technology of inside of RPV		
						Development of investigation technology of inside of RPV	

Fig. A11-1-(4): Development of investigation technology of inside of RPV

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.

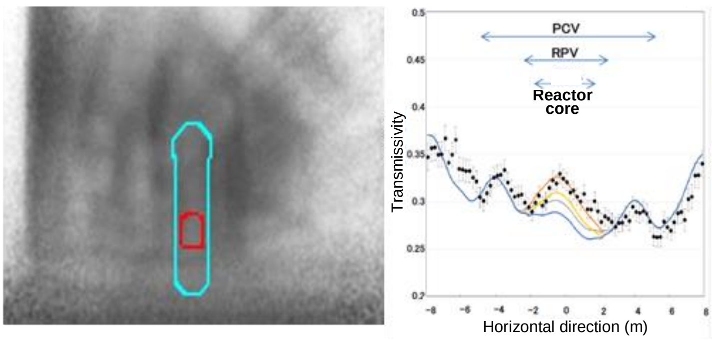


Fig. 1: Result of measurement and evaluation using transmission method in Unit 1


Fig. 2: Small device for transmission method

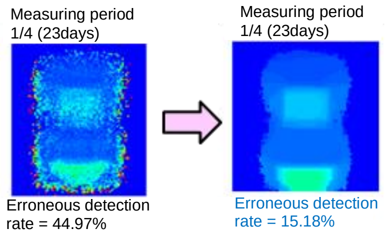


Fig. 3: Simulation result of improvement of erroneous detection rate

Implemented by

International Research Institute for Nuclear Decommissioning (IRID)

FY2011	F2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018
			Development of technologies for the detection of fuel debris inside reactors (using muon)				

Fig. A11-1-(5): Development of technologies for the detection of fuel debris inside reactors (using muon)

Project objectives

Various fuel debris retrieval methods have been studied while focusing on the retrieval directions (top and side) and retrieval environment (submersion and partial submersion). In addition, concepts of systems to ensure safety that conform to each method have been studied. In accordance with the results of these studies and the fuel retrieval policies, technical investigations, elemental tests, and analysis will be performed for issues that have been identified in developing required elemental technologies. In addition, this information and knowledge will be used in the consideration of construction methods/systems while focusing mainly on the in-air/side-entry access method.

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 related to containment function

- To develop elemental technologies to ensure a containment function by maintaining negative pressure, it has been decided as development policy to carry out analysis in combination with elemental tests. Analysis and elemental tests will be performed continuously to develop technologies to ensure a containment function by maintaining negative pressure.

(2) As regards the following technologies, existing technologies will be investigated and comparisons will be made to select outstanding technologies and to enrich our knowledge through elemental tests : technologies for the collection and removal of dust generated from fuel debris, technologies to collect and remove dust in gas systems (Fig. 1, right), and technologies to collect and remove dust and soluble nuclides in liquid systems (Fig. 1, reft).

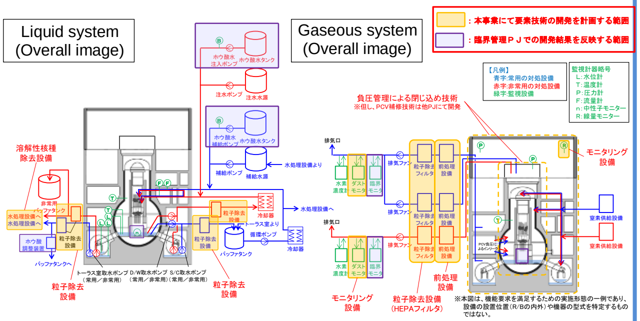


Fig. 1: Scope of element technology development for system formulation

(3) Study on Alpha-nuclide monitoring system required for the retrieval of fuel debris

- We are organizing and identifying the necessity and objective of the nuclide monitoring technology (Fig. 1) in the retrieval of fuel debris and the required measuring range in gas system monitoring. In addition, we are investigating existing technologies for nuclide monitoring in gas systems and sorting out challenges toward the application to fuel debris retrieval.

(4) Study on optimization of ensuring safety of methods and systems

- As regards construction methods whose applicability to each reactor has been studied with a focus on partial submersion-side access, design conditions are being organized and methods to install cells are being studied (Fig. 2).

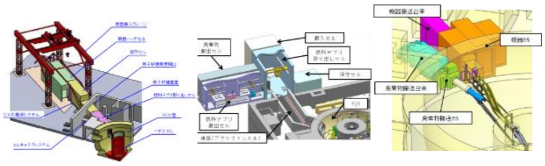


Fig. 2: Installation image of fuel debris retrieval cell

- Safety and functional conditions required for the retrieval of debris are being reorganized and brushed up to review the necessary systems (Fig. 1).

- The results of the public exposure evaluations at the time of fuel retrieval is under review, and worker exposure, which is important, is under examination.

Implemented by International Research Institute for Nuclear Decommissioning (IRID)

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

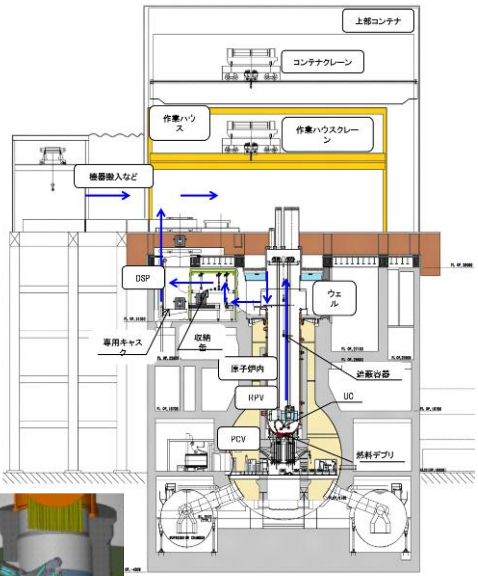


Fig. 3: Concept of partial submersion - top access method (example)

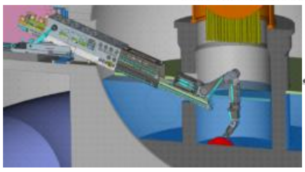


Fig. 2: Concept of fuel debris retrieval equipment in partial submersion - side access method (example)

The concept of fuel debris retrieval equipment that will be applied to the three major methods (such as the one shown in Fig. 4) was studied.

FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018
			Development of technologies for retrieval of fuel debris and internal	Upgrading of approach and system for retrieval of fuel debris and			

Fig. A11-2-(1): Advancement of retrieval method and system of 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 of this project produced including the 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 are under development, and study is underway 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) are under development.

(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 are underway.

(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 are under development.


Fig. 1: State of chisel processing preliminary test

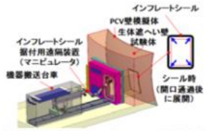


Fig. 2: Inflatable seal element test

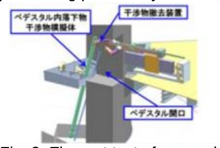


Fig. 3: Element test of removal of interfering objects in pedestal

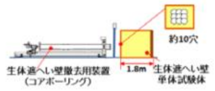


Fig. 4: Element test of biological shield wall removal


Fig. 5: Combined element test image of Robotic arm and access rail

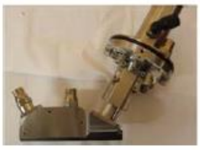


Fig. 7: Prototype of laser head (ONET Technologies CN)


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			
						Advancement of fundamental technologies for retrieval of fuel debris and internal structures	

Fig. A11-2-(2): Advancement of fundamental technologies for retrieval of fuel debris and internal structures

Project objectives

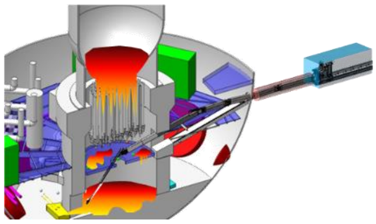
Toward the decommissioning of the Fukushima Daiichi NPS, in view of the results of studies that have been performed so far regarding the retrieval method of fuel debris and internal structures, elemental technologies required for retrieval (prevention scattering of fuel debris, installing retrieval equipment, remote maintenance of retrieval equipment, and monitoring during retrieval) will be developed, and the feasibility of devices and equipment will be assessed.

Project details and progress

To contribute to criticality control during fuel debris retrieval and also to the design of fuel debris retrieval equipment and the rationalization of fuel debris retrieval work procedures, scenarios for fuel debris sampling are being prepared and sampling equipment including access devices are being developed. At the same time, component testing is being performed for related equipment such as arm-type access devices and attachments that would enable the sampling of pebble shape debris and sandy debris while taking advantage of existing safety systems. The activities conducted so far and the results obtained from them are described below.

(1) Study and development of fuel debris sampling scenarios

An overall scenario for fuel debris sampling has been developed in consideration of needs and the results of surveys on conditions inside PCVs, and development has begun on plans concerning the development of required techniques. In addition, the impacts of sampling activities on safety are also being evaluated.



Sampling concept for debris in PCV

Example of access device for sampling

(2) Design and trial production of systems and equipment for the sampling of fuel debris inside PCVs

① Basic design of the fuel debris sampling systems

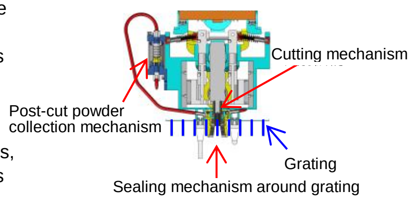
The requirements to be fulfilled are being determined and summarized by sampling systems for debris of different shapes (pebble shape debris, sandy debris, larger cylindrically cut-out debris, etc.) from the viewpoints of minimizing workers' exposure dose and ensuring safety through the prevention of criticality as information to be referenced later on in the basic design phase.

② Design and trial production of devices accessing to fuel debris

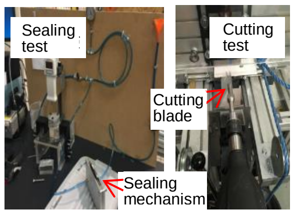
Study is being performed of the feasibility of reusing the arm-type access devices designed for the detailed survey of conditions inside PCVs and the specifications of improved access devices.

③ Design and trial production of fuel debris sample collection devices

Component testing has been performed on attachments, for the collection of pebble shape and sandy fuel debris samples, and their conceptual design is complete. The next step is trial production.



Example of cutting and collection tool of debris



Element test of cutting and collection tool of debris

(3) Conceptual study of sampling systems for fuel debris inside RPVs

Based on the status of the development of the internal investigation of the RPV, work is being performed with the concept of a system that will enable access to debris inside an RPV either from the top or from the side, and attempts are being made to establish plans concerning component testing, etc.

Implemented by

International Research Institute for Nuclear Decommissioning (IRID)

FY2011	F2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018
						Development of sampling technologies for retrieving fuel debris and internal structures	

Fig. A11-2-(3): Development of sampling technologies for retrieving 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

①To 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 is being 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 should be investigated and development challenges should be identified and a development plan should be drafted. Required technology development challenges for the following items should be identified and the development plan should be drafted.

:

i. Formulating technical specifications considering the on-site environment

ii. Investigating plans for access route construction work and its maintenance

iii. Identifying development challenges and drafting a development plan

② Regarding PCV repair technology affecting the construction of closed circulation systems, we also extract technical development challenges corresponding to the situation at the on-site work and extract technical issues corresponding to situations in the field, and draft development plan.

(2) Developing and verifying element technologies for access and connection to PCV

Based on the development plan formulated under (1) above, we will develop and verify each elemental technology required to access and connect to the PCV. Below are examples of possible elemental technologies :

- Remote construction technology for connection
- Remote operation technology for access route inspection during service and construction
- Remote repair technology for connections during service and construction

(3) Verifying access and connection technology on a full-scale

Based on the development results of each elemental technology, we will conduct trial design on access and connection to the inside of the PCV and carry out to verify the design on full-scale. In particular, we will ready full-scale test equipment, for example of Naraha Center for Remote Control Technology Development, to verify the workability on a full-scale, clarify the work requirements for actual construction, and identify technical challenges. :

- Confirming the workability by remote control on 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	F2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018
							Development of closed circulation systems for water inside PCV

Fig. A11-2-(4): 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.

Vent pipe 1/1 scale test

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

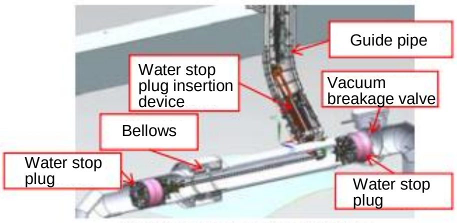
By performing an experiment on a full-scale (1/1) test set, the implementation feasibility and sealing performance of a seal plug that had been improved for easier implementation were verified.

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.



Drawing of water stop plug for vacuum breakage line

(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.

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.

FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017
Development of identification technology of leaks in PCVs						
Development of repair method for PCVs			Development of repair (water stoppage) technology toward water filling in PCV		Development of repair methods for leak spots in PCV	

Fig. A11-2-(5)-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.

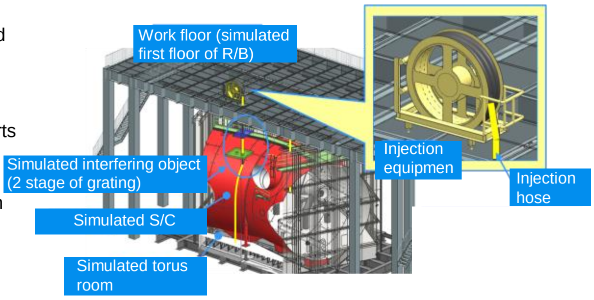
The following were tested using the full-scale test set:

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.



Overview of test facility: full-scale 1/8 sector (simulated Unit 2)
(Test location: Naraha Center for Remote Control Technology Development)

Fig. 1: Overview of the reinforcement test for S/C supports

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.

(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.

④ 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.

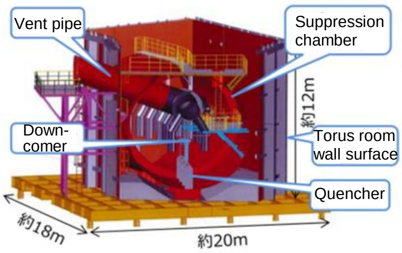


Fig. 2: Full-scale test facility

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. A11-2-(5)-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.

② Development of an approach to evaluating the seismic resistance of pedestals and determining impacts from damage

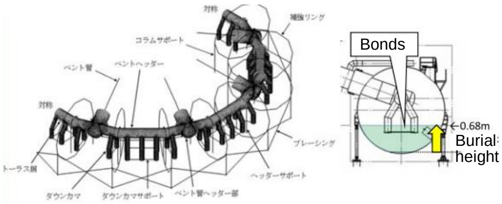


Fig. 1: Vent pipe-S/C system coupled analysis model (Unit 1)

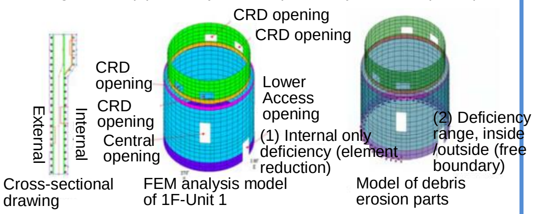


Fig. 2: 3-D FEM elastic-plastic analysis model of RPV pedestal

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

(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						
			Development of evaluation methods for the structural integrity of RPV and PCV			
		Development of evaluation methods of seismic performances of RPV and PCV and the impacts of the damages				

Fig. A11-2-(6): 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.

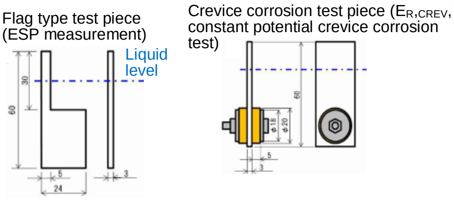


Fig. 1: Electrode composition of corrosion test piece

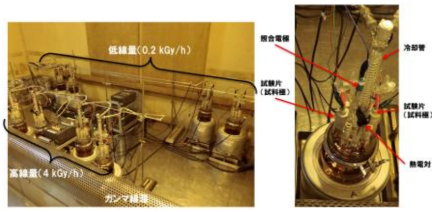


Fig. 2: Test condition under irradiation

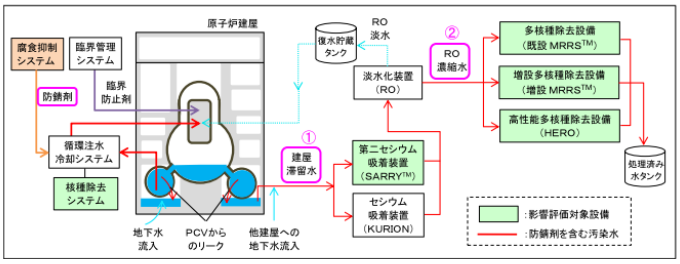


Fig. 4: Example of conceptual design of corrosion control system

Above actions were implemented by International Research Institute for Nuclear Decommissioning (IRID)

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.

PCV material (carbon steel)
50℃, Artificial seawater diluted 1,000 x (19ppmCl⁻)
Test time: 500h

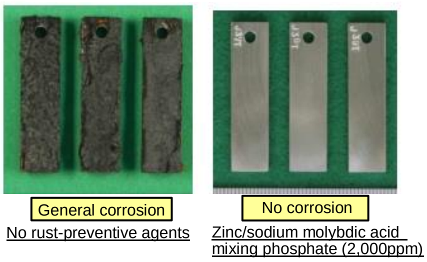


Fig. 4: Development status of anti-corrosion measures

(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.

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. A11-2-(7): Development of corrosion protection 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

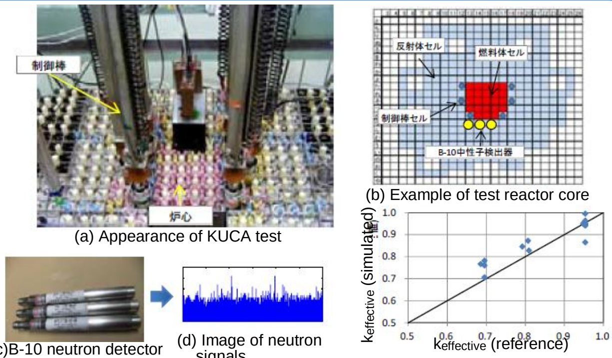
① Development of Criticality Approach Monitoring Method

- 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.



(a) Appearance of KUCA test (b) Example of test reactor core (c)B-10 neutron detector (d) Image of neutron signals (e) $k_{effective}$

$k_{effective}$ (simulated) / $k_{effective}$ (reference)

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

Table 1: Insoluble Neutron Absorption Material (candidate material)

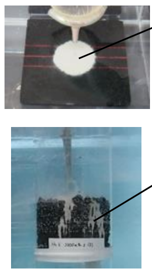


Fig. 2: Example of Workability Verification Test of Water Glass Type Absorption Material

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 (Table 1).

- 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.

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	F2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018
	Development of criticality control technologies of fuel debris						

Fig. A11-2-(8): 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.

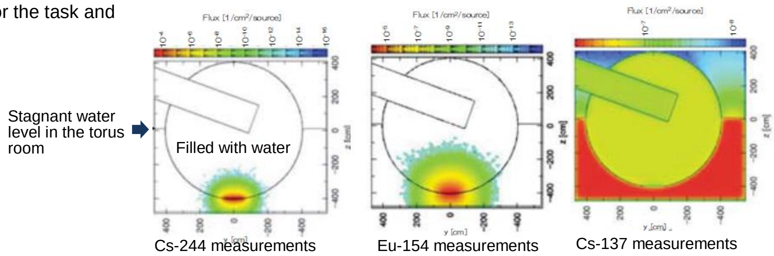


Fig. 1: Distribution of radiation originating from fuel around the S/C (Unit 1)

Fig. 2: Background radiation (Unit 1)

Implemented by

International Research Institute for Nuclear Decommissioning (IRID)

FY2011	F2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018
			Development of technologies for non-destructive detection of radioactive material deposited in S/C, etc.				

Fig. A11-2-(9): 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.

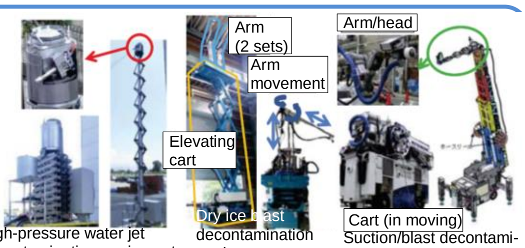


Fig. 1: Decontamination equipment for high places

(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
(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.


Fig. 2: Upper floor decontamination equipment

- 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
Implemented by International Research Institute for Nuclear Decommissioning (IRID) (FY 2013 -)

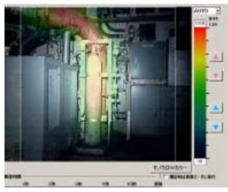


Fig. 3: Investigation result by γ camera in the south side of Unit 1

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.
- 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)

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. A11-2-(10): Development of remote decontamination technology in the reactor building

Project objectives

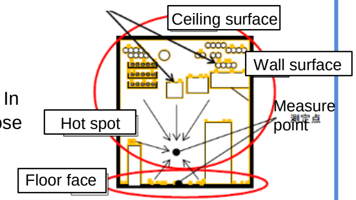
In order to reduce the exposure of workers to radiation in the decommissioning of the Fukushima Daiichi NPS as they engage in work inside reactor buildings, a comprehensive dose reduction strategy was developed combining various dose reduction techniques with remotely controlled decontamination techniques.

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.

(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.



Distribution model of radiation 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.

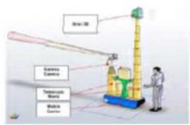
(3) Working toward the establishment of dose reduction strategy

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.

Current distribution of radiation dose rate — Case of approaching to the facilities of ceiling direction and decontaminating — Case of Shielding partially

(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) Remote measurement system of radiation dose(AREVA)

(2) Remote sampling tool (Babcock)

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)

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	F2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018
	Formulation of comprehensive dose rate reduction plan						

Fig. A11-2-(11): Formulation of comprehensive dose rate reduction plan

Project objectives

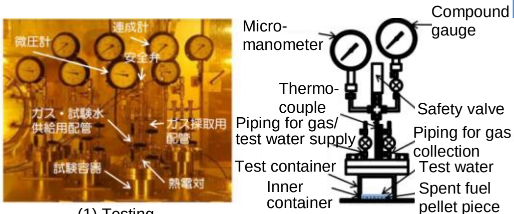
To develop the canister necessary for reliably and reasonably containing, transferring and storing the retrieved fuel debris taking its characteristics into account, as well as to establish conceptual idea of the system for containing, transferring and storing of the retrieved fuel debris in conjunction 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.

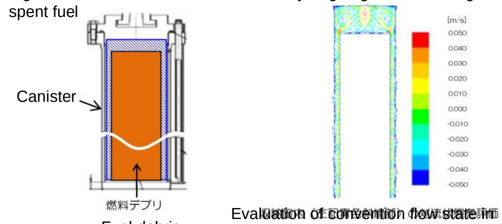
(1) Survey on transferring and storing of fuel debris and producing research plan

Knowledge was expanded and accumulated through a minute investigation on the licensing documents of the Waste Management Facilities of Japan Nuclear Fuel Ltd. at Rokkasho and on gathered overseas information regarding transferring and storing of the damaged fuel for contributing study specified in (2) through (4) below.



(1) Testing (2) Test equipment configuration

Fig. 1: Test measurement of amount of hydrogen generated using spent fuel



(1) Evaluated object

Evaluation of convention flow state in canister (hatched part of the left figure)
(2) Evaluation of convention flow state (example)

Fig. 2: Evaluation of convention flow state in canister

(2) Study on safety requirements and specifications of the canister, and storing system

A flow of a series of process of containing, transferring and storing of the retrieved fuel debris was determined and a primary assessment of the throughput (processing amount of fuel debris, number of the canister, necessary area for storing etc.) of above mentioned process under the predefined set of assumptions was performed. Some ideas for reducing a number of the canister were also investigated. It is also confirmed that conceptual design of dry or wet storing system for retrieved fuel debris need not to be modified based on review of the outcome from related research programs.

(3) Development of safety assessment methods and verification of safety

Various studies and tests were performed to verify the safety of the fuel debris canister. For example, the applicability of water content restriction was studied, as well as possibility of relaxation of the sub-criticality condition was examined for increasing inner diameter of the canister which could increase operability of fuel debris retrieval work. Lid structure of the canister was also studied in order to satisfy safety requirements and aging phenomena of the canister material was assessed taking environmental condition during fuel retrieval work in to account. The Hydrogen generation test was performed using spent fuel (Fig.1) and convective flow inside of the canister was evaluated for determining the effectiveness of hydrogen recombination catalyst (Fig.2). From such examination results, the issue on generated hydrogen gas was addressed and the knowledge required for the establishment of an approach to safety assessment was expanded and accumulated.

(4) Studying on the design/specification of the canister for retrieved fuel debris

It is confirmed that the design/specification of the canister which had been established last year need not to be modified from the outcomes from safety requirements and safety assessment results mentioned in (2) and (3) above.

Above actions were 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 2014 - 2015)

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 - 2016)

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 - 2016)

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 - 2016)

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.

FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018
		Development of containing, transferring and storing technology of fuel debris					
			Development of containing, transferring and storing technology of fuel debris				
				Development of containing, transferring and storing technology of fuel debris			
				Development of containing, transferring and storing technology of fuel debris			

Fig. A11-2-(12): Development of containing, transferring and storing technologies of 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 accicent, 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 results of this project so far reflecting results from the related projects described in Section 2 below.
(1) Characterization
① Analysis data collection, management, etc.
○ Identifying the distribution of contamination
- Analysis of “rubble, etc.”, secondary waste generated by water treatment, and contaminated water have been carried out continuously.
- As to “rubble, etc.”, analysis was conducted for those such as rubble from soil covered temporal storage, and material from the Unit 4 reactor building. In addition, the distribution of contamination in parts of samples was also studied.
- As to secondary waste generate by water treatment, analysis was conducted for sludge from decontamination systems as well as slurry and adsorbers from multi-nuclide removal systems.
- As to contaminated water, stagnant water and treated water were analyzed. The concentration of Sr-90 appeared to be correlated with the concentration of Cs-137 at a certain ratio over the range of about two orders of magnitude (Fig. 1). This finding will be used in characterizing secondary contamination cause by contact with stagnant water, in terms of contributing nuclides.
- In order to study the nuclide migration pattern contributing to contamination, the concentrations of different nuclides were studied in comparison with Cs-137 using existing data. With every reactor unit, samples of rubble from the reactor building showed correlation between the Sr-90 concentration and the Cs-137 concentration (Fig. 2). Similar migration patterns were also observed among other nuclides.
○ Development of sampling techniques, etc.
- For the sampling of zeolite from a cesium adsorption apparatus, a method of drilling at the top of apparatus was studied, and a test equipment for trials was produced (Fig. 3). For remote sampling operation inside the reactor building (R/B), trial use was conducted with a small core boring/sampling tool.

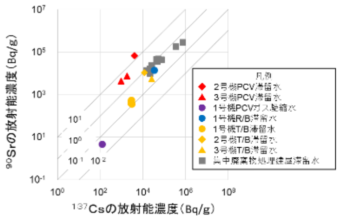


Fig. 1: Correlation of Sr-90 and Cs-137 in stagnant water

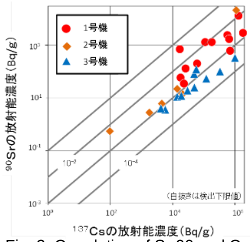


Fig. 2: Correlation of Sr-90 and Cs-137 in rubble inside of R/B

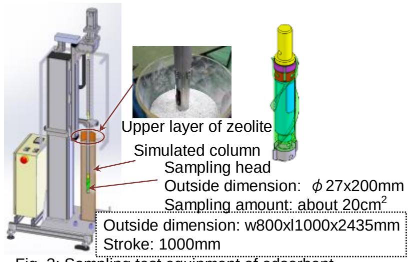


Fig. 3: Sampling test equipment of adsorbent from cesium adsorption apparatus

○ Improving the efficiency of waste characterization
- The patterns of nuclide composition of contamination were broken down, and studied the classification of nuclide migration patterns of contamination. The selection of nuclides for analysis was reviewed, and it was decided to make supplementary use of fuel burnup calculation in the calculation of isotope concentration in order to improve the efficiency of analysis.
- A method to evaluate the representativeness of analysis data was developed, and progress was achieved in the analysis of contamination mechanisms. The nuclides for analysis were reselected, and techniques were developed to simplify and speed up analysis on the selected nuclides, seeking to improve the efficiency and reasonability of waste characterization.
○ Management of analysis data
- Disclosed analysis data was published as reports. For the convenience of users, work was conducted toward enabling publication on the internet and at the same time toward enabling the sharing of data on the management of samples and analysis activities among relevant parties.
② Improving the accuracy of analytical assessment techniques
- The nature of frequency distribution of contamination by radioactive nuclides was identified as lognormal, and estimations of radioactive nuclides had been tried based on this finding (Fig. 4). The inventory of radioactive nuclides of waste was provisionally estimated using an improved assessment method.
- The accuracy of analytical inventory assessment was improved by taking account of variations of analysis data in the estimation of inventory.

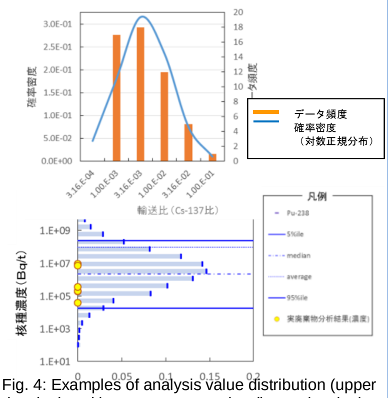


Fig. 4: Examples of analysis value distribution (upper drawing) and inventory assumption (lower drawing)

③ Compiling the results of comprehensive inventory assessments
The concept of a system was been established to determine and update the radiological inventory by conducting comprehensive assessment of the values from the analysis of actual samples and the values estimated using an analytical assessment method.
④ Addressing the harmful substances for disposal, etc.
- Typical harmful substances may cause influence to the disposal system were identified by studying actual examples such as waste acceptance criteria of overseas repositories for harmful substances. Based on the result, studies were conducted on the views with harmful substances regarding allowable concentration of waste acceptance criteria and contained amount within waste. Studies were also conducted on the method used to analytically assess the impacts of harmful substances on the safety of predisposal management and disposal itself, and correction and compilation of data required for assessment will be conducted.
(2) Pre-disposal management
① Study and assessment on the method of storage adequate for feature of solid waste
○ Study of measures implemented in the storage of highly radioactive waste
- Research was conducted and information was collected from a wide range of knowledge/experience at home and abroad concerning measures may be taken to address the issue of hydrogen generated during the storage of highly radioactive solid waste such as about waste specifications, container specifications, hydrogen generation evaluation methods, laws and regulations, technical requirements for facilities, measures taken to address the issue of hydrogen generation. As a result, it was identified that, even with solid waste, it would be a valid solution to use a vent-equipped container for storage, with minimizing the presence of free water, and defining a G value specific to the properties of waste. In order to study the applicability of such method to solid waste of specific types such as HIC slurry, and identify challenges, deeper research has being conducted into the approaches to hydrogen generation by conducting case studies, based on regulations and actual performances of other countries.

- The method of storage has being studied for “rubble, etc.” to be generated from the process of fuel debris retrieval.
○ Technologies for the stabilization and solidification of secondary waste generated by water treatment
- In-drum vitrification technology was focused as a stabilization technology required for pre-disposal management of secondary waste generated by water treatment, in the context of preventing the spread of contamination and the size of the equipment. 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. Then, basic data of those solidified waste was collected such as the results of performing chemical analysis and leaching tests, and composition data and conditions for producing solidified waste required for engineering scale testing were presented.
- 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. 5). 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 m^3. To prepare for sludge removal, simulated sludge was produced and tested to obtain basic data on sludge fluidity.

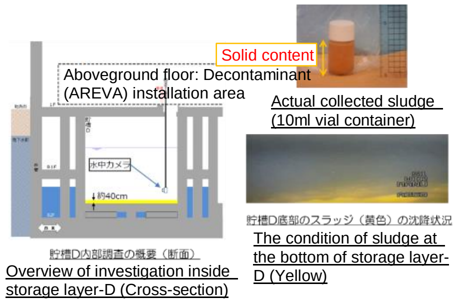


Fig. 5: Sampling of sludge from decontamination equipment

② Selection of preceeding processing method adequate for feature of solid waste
- In order to identify the processing technologies that may be applied to solid waste on the projected scale from those have been proven through actual implementation (high-temperature treatment and improved cement treatment), necessary data will be collected and assessment will be performed using an engineering scale test equipment, etc. At that time, assessment will be conducted on how the processing technologies may be impacted by the salt that waste is likely to contain, radiation, heat, and so on.
③ Contamination assessment techniques for segregation of solid waste
- To enable the reliable segregation of waste, research and studies were performed on methods for the measure/assess contamination by alpha emitting nuclides, and so on, and techniques were developed with due attention to the implementation in the field.
(3) Study of disposal concepts and safety assessment methods adequate for the feature of solid waste
To collect necessary information toward the establishment of disposal concepts and safety assessment methods, in-depth study was conducted on disposal sites abroad (Fig. 6). In addition to that, study was conducted on the conditions for the case of applying solid waste from the Fukushima Daiichi NPS based on various cases, with attention also to earlier examples of waste disposal in Japan and the features of solid waste. Furthermore, the items of the specification may have an impact on the result of safety assessment for disposal will be identified for the solid waste processed by introducing preceeding processing.
(4) Integration of R&D results and study of the waste stream
Regarding the waste stream, latest results derived from previous researches are reflected to it, and establishment of methodology to integrate progress, consistency of results, and challenges to be overcome, is made to start.
Implemented by
(Comprehensive proposal) International Research Institute for Nuclear Decommissioning (IRID) (FY 2013 -)
(Partial proposal) IHI Corporation (FY 2018 -), Orano ATOX D&D Solutions Co., Ltd. (FY 2018 -)

Fig. 6: Detailed survey of overseas repositories

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.

○ <u>Research and development of processing/disposal of solid waste (FY 2013 - 2014)</u>

(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.

○ <u>Research and development of processing/disposal of solid waste (FY 2015 - 2016)</u>

(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.

(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.

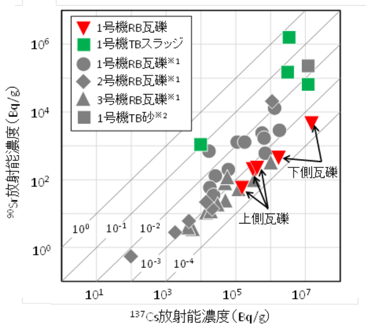
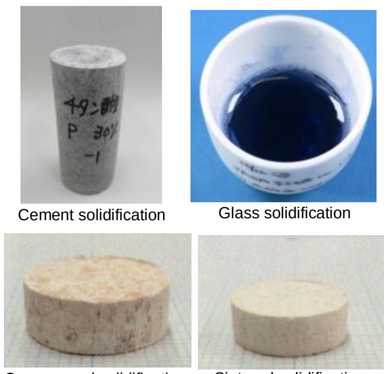


Fig. 7: The ratio of radioactive concentration of Sr-90/Cs-137 in rubble



Cement solidification　Glass solidification

Compressed solidification　Sintered solidification

Fig. 8: Various type of solidification of simulated waste

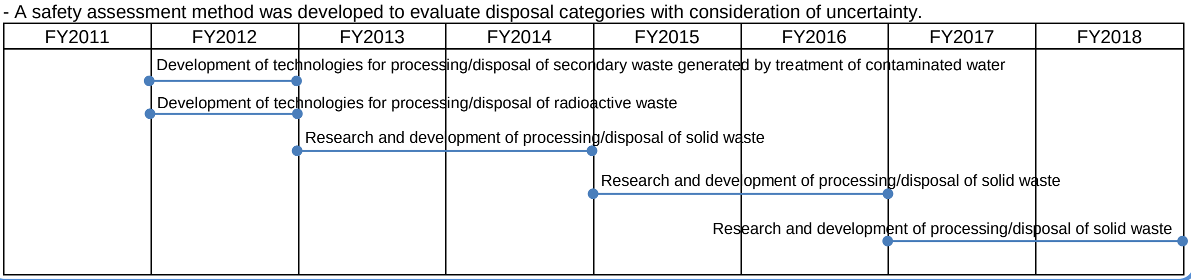


Fig. A11-3: Research and development of processing/disposal of solid waste

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.

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).

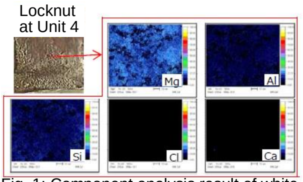


Fig. 1: Component analysis result of white deposition area of locknut at Unit 4

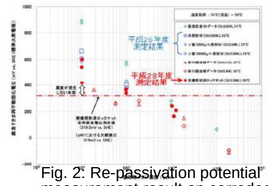


Fig. 2: Re-passivation potential measurement result on corroded crevice of locknut

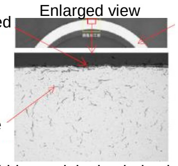


Fig. 3: Hydride precipitation behavior verification test result (Irradiated test piece: 300℃, cooling velocity: 0.04℃/h, stress in a circumferential direction: 70MPa, attached scratches and seawater, fixed rubble)

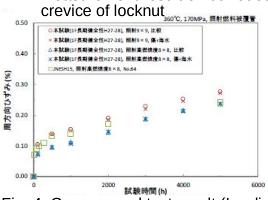


Fig. 4: Creep speed test result (Irradiated test piece: 360℃, stress in a circumferential direction: 170MPa, attached scratches and seawater, fixed rubble)

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

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 the 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).

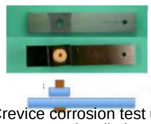
- Development of technology to assess long-term integrity: A corrosion test and a strength test were conducted to evaluate the impact of corrosion, such as debris and stress, with a specimen that simulates the fuel members. It was confirmed that no corrosion or deterioration in strength that could impact 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.


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

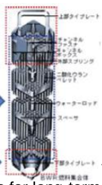


Fig. 1: Evaluation items for long-term integrity of fuel assembly removed from spent fuel pool during wet storage

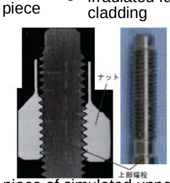

Test piece of simulated upper part
Fig. 2:Appearance of locknut, etc. after corrosion test


Fig. 3:Appearance of top tie plate of spent fuel of Unit 4

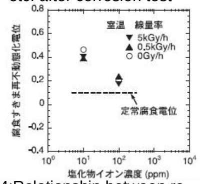


Fig. 4:Relationship between re-passivation potential for crevice corrosion in diluted artificial seawater and chloride ion concentration

- 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).

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.A11-4-(1): Evaluation of long-term structural integrity of the fuel assemblies removed 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).

(1) RRP simulated waste solution (chloride ion 0g/l)
(2) RRP simulated waste solution + artificial seawater (chloride ion 20g/l)
Observation magnification: x50(258x257 μ m)

Fig. 1: Surface observation result of immersion test piece of high-level liquid waste storage tank material

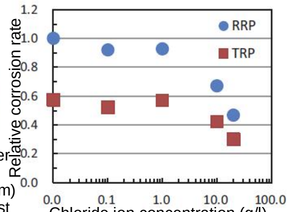
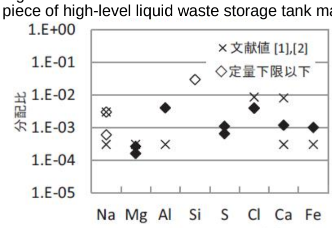


Fig. 2: Corrosion rate of high-level liquid waste storage tank material (relative corrosion rate: corrosion rate of RRP simulated solution containing no impurities is valued as "1")

(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.



[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)

(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.

Implemented by International Research Institute for Nuclear Decommissioning (IRID)

FY2011	F2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018
	Study of Methods to	Process Damaged F	uel Removed from th	e Spent Fuel Pool			

Fig. A11-4-(2): Study of Methods to Process Damaged Fuel Removed from the 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 106 Bq/L to 4.2 x 106 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.


Fig. 1: Kurion's test equipment

(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. 2: RosRAO'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.

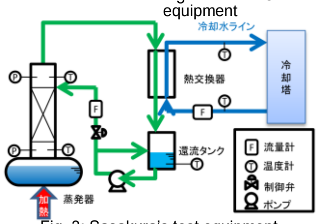


Fig. 3: Sasakura's test equipment

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. 4: Gas hydride method

(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.

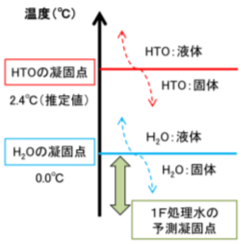


Fig. 5: Crystallization method

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.

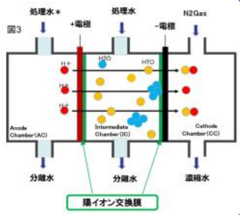


Fig. 6: Electrolytic method

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.

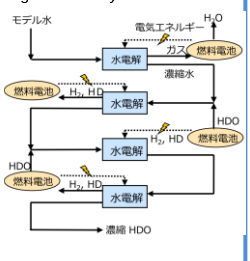


Fig. 7: Electrolysis recombination method with fuel batteries

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. A11-5-(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.

Fig. 1: Adsorption performance test (case of adsorption fiber)

(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.

Fig. 2: Decontamination verification test

(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.

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)

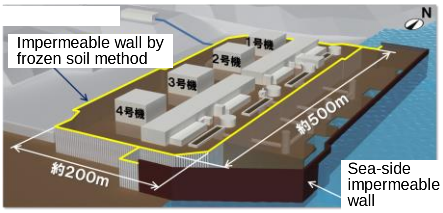
Obayashi Corporation (verification of unmanned boring technology)

Fig. A11-5-(2): Verification of technologies for contaminated water treatment

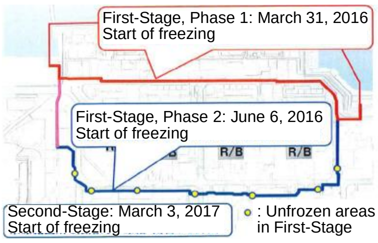
Project objectives

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).

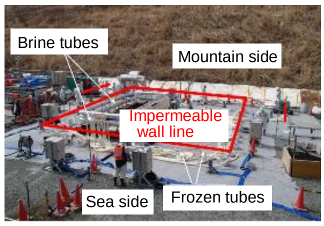
Project details and progress



(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 m^3, 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.



Related project
Implementation period: From August 2013 to March 2015
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)
Operator: Kajima Corporation
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: A11-5-(3): Large-scale verification of impermeable walls (ice 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 removal performance with the small scale test equipment of the demonstration plant.
- 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)
(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.

Fig. 1: Verification test equipment

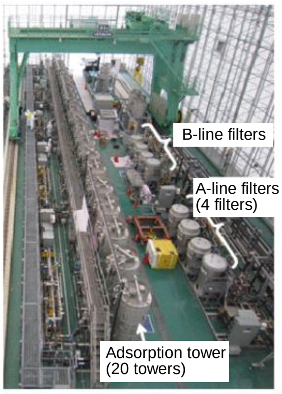


Fig. 2: Demonstration plant

- 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.
Implemented by
Tokyo Electric Power Company Holdings, Inc., Toshiba Corporation, Hitachi GE Nuclear Energy

Fig. A-11-5-(4): Development and verification of high-performance multi-nuclide removal system (High-performance ALPS)

Attachment 12 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), we compiled the Basic Direction of the 6 Essential R&D Themes 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. We also need to remember that 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 Primary Containment Vessel (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 alpha 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 alpha 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 confinement function, the criticality monitoring system, the PCV gas control system, exposure evaluation, collecting, 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 Primary Containment Vessel (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 containment 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 beta-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 alpha ray from the viewpoint of identification of the fuel debris, and gamma 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 particulates generated during decommissioning (incl. alpha 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 alpha dust, it requires safety measures and dust containment solutions. It is necessary to understand physical/chemical properties of alpha 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 dispersion particles (alpha dust) that contain alpha 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 alpha 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 alpha 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 exposure control and it is not systematically organized. On the other hand, the radioactive dispersion 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 alpha nuclides and beta gamma nuclides. While the alpha nuclide of which typical element is plutonium is important from the viewpoint of internal exposure, the beta gamma 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 dispersion 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 dispersion particles, it is important to evaluate the impact of exposure to radioactive materials derived from the fuel debris, especially the one of alpha 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 dispersion 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 med- 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 13 Record of collaborative activities with foreign organizations

Activity	Contents	Participating Organization
IAEA Project		
IAEA side event	・Side events were held along with the IAEA General Conference and explanation of the latest progress situation in the Fukushima Daiichi decommissioning in order to gain an understanding of the Fukushima Daiichi decommissioning.	METI NDF TEPCO
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
OECD/NEA Project		
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 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.	JAEA IRID TEPCO
PreADES	・Knowledge available to understand the characteristics of fuel debris is shared and the methods for safety evaluation on fuel debris sampling and retrieval are organized.	JAEA IRID 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	・From the viewpoint of proceeding with basic, fundamental research for the Fukushima Daiichi NPS, a thermodynamic database, which is suited for the material science analysis to understand the migration behavior of molten fuel and FPs and the characteristics of fuel debris, is improved and enlarged.	JAEA
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
Inviting International Expert		
International Special Advisors (NDF)	・To integrate and utilize a wide range of wisdom. To do so, 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.	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,	IRID

	enhancement of information dissemination and communication, and acquire knowledge including failure experience, IRID invites the prominent experts from the UK,US, and Spain.	
Activities by each organizations		
Cooperation with overseas organizations at the stage of IRID's practical application research	・Improvement of the accident analysis codes (US) ・Development of technologies for prevention of leakage （US） ・ Development of technologies for remote decontamination（UK, US） ・Development of internal investigation technologies（UK, US, France, Russia） ・Internal fuel debris detection and characterization（US, France） ・Fuel debris, structural component retrieval technology development（US） ・ Fuel debris containment, transportation, storage technology development (US) ・Sampling Technology development（UK） ・ Solid waste processing and disposal technology development (France)	IRID
1st International scientific and practical workshop	・In associated with constructing new shelter of Unit 4 of Chernobyl Nuclear Power Plant, participating in the workshop and gathering information on further policies. (May 2017)	NDF
Insider Project	・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.	NDF
TOAL DECOM	・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	・ 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)	METI JAEA TEPCO
The 3rd Fukushima/ Chernobyl/ Three Mile Island International Symposium	・Based on the lessons and cases 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.	NDF JAEA TEPCO