Report on "Sub-committee for the Evaluation of Fuel Debris Retrieval Methods"

March 7,2024

Nuclear Damage Compensation and
Decommissioning Facilitation Corporation

Sub-Committee for the Evaluation of Fuel Debris
Retrieval Methods

Table of Contents

1. Background of the Study

For decommissioning Fukushima Daiichi Nuclear Power Station (hereinafter referred to as the “Fukushima Daiichi NPS”) of Tokyo Electric Power Company Holdings Co, Inc. (hereinafter referred to as "TEPCO"), a fuel debris retrieval is regarded as a task that should be tackled with thorough and careful preparation[1] and one of the most technically challenging issues, given that certain progresses have been made in fuel retrieval in spent fuel pools and stagnant water in reactor buildings. In addition, although fuel debris is considered in a stable condition based on the internal investigations of the reactors and interpretations of plant parameters, there is no guarantee that this condition will remain for a long time, rather there is a concern that the risk will gradually increase due to degradations of facilities and equipment etc. Therefore, it is desirable to recover fuel debris as promptly as possible to ensure safety in medium to long term. Therefore, the fuel debris retrieval is an extremely important task for the success of the decommissioning over medium to long term.

Although TEPCO has been examining concepts for further expansions in scale for the fuel debris retrieval (Hereinafter referred to as "large-scale retrieval"), the evaluations of the retrieval concepts are difficult due to uncertainties in the conditions inside the reactors and that engineering proof with unusual site conditions is still in progress. This makes it hard to advance the detailed examinations of the technical problems in a specific retrieval method, which makes the evaluations and selection of the retrieval method further challenging.

Under the current situation we are facing to, it is appropriate to present the direction and priorities of the efforts to be taken and accelerate the studies on the retrieval methods under the existence of uncertainties in technology as well as conditions inside reactor so that large-scale retrieval can be commenced in 2030’. It is necessary to advance the engineering process that narrows down the retrieval options to conduct more detailed and specific studies with identifications of technical issues in order to demonstrate reliable retrieval method. Flexibility will also be necessary in this process. For example, if there are doubts cast over the feasibility of the retrieval methods based on new information from internal investigations etc., the direction of the engineering study will be revisited to narrow down retrieval options again.

Since the fuel debris retrieval is an unprecedented technical challenge and also social and political issues, in narrowing down the direction of the engineering study under great uncertainties, it is necessary to carry out studies with the cooperation among the government (the Ministry of Economy, Trade and Industry and Nuclear Regulation Authority etc.), TEPCO

[1] Quoted from " "Technical Strategic Plan 2023 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc.", Nuclear Damage Compensation and Decommissioning Facilitation Corporation

and the Nuclear Damage Compensation and Decommissioning Facilitation Corporation (hereinafter referred to as "NDF"), as well as specialized and intensive examinations that gather technical expertise from inside and outside Japan. Therefore, under the resolution of the NDF Decommissioning Strategy Committee, the “Sub-Committee for the Evaluation of Fuel Debris Retrieval Methods” (hereinafter referred to as the "Sub-Committee") has been established to provide comprehensive examinations and evaluations mainly on technical feasibility and make recommendations for the selection of retrieval methods in Unit-3 for which engineering study should be advanced at this stage.

This report, as a deliverable of the Sub-Committee, intends to present an overview of retrieval methods currently under considerations and summarize evaluations for each retrieval method and recommendations for a retrieval method based on the evaluations.

2. Overview of Fuel Debris Retrieval Method

2.1. Factors that make fuel debris retrieval difficult

Since the Fukushima Daiichi NPS is damaged reactors and in a special environment that differs from that of normal reactors, following factors that make fuel debris retrieval difficult need to be adequately recognized when examining retrieval methods.

(1) Extremely high-level radiation dose in the primary containment vessel (hereinafter referred to as "PCV") and the Reactor Pressure Vessel (hereinafter referred to as the "RPV")

The dose equivalent rate in the PCV/RPV is in the order of several Sv/h to several hundreds of Sv/h, which hinders access by workers.

(2) High-level radiation dose inside reactor buildings

The dose equivalent rate inside the reactor buildings is in the order of several mSv/h to several tens of mSv/h, and the entry by workers is limited to a short time.

(3) Lack of the on-site information

Because of the constraints mentioned in (1) and (2) above, obtaining on-site information is difficult hence engineering studies need to be performed with estimated conditions under great uncertainties.

(4) Construction of containment boundary

When the existing reactor buildings or the PCV is used as containment boundaries, damages due to the accident and deteriorations must be taken into consideration. When a new containment barrier is introduced, appropriate containment properties including seismic resistance that correspond to the on-site conditions need to be considered.

(5) Possibility of criticality

It is necessary to consider the possibility of criticality when PCV / RPV conditions, currently maintained under subcriticality, are changed (e.g., changing the distribution of fuel debris).

(6) Amount of waste generated

It is necessary to reduce the amount of solid waste generated by decommissioning works as much as possible to alleviate overall burdens on storage management on site.

2.2. Overview of fuel debris retrieval methods under considerations

An overview of each method under consideration is provided below.

2.2.1. Partial submersion method

The partial submersion method is a method of retrieving fuel debris exposed in the air or immersed at a low water level.

This retrieval method employs a combination of a “top access” in which the reactor well is opened to access the PCV in vertical direction after the containment equipment is installed on the operating floor and a “side access” in which the PCV is accessed in the lateral direction after the containment equipment is installed on the side surface of the PCV on the ground floor. Since a large opening and direct access can be made in the top access, majority of fuel debris inside the RPV and the pedestal is assumed to be retrieved by the top access. The side access will be utilized for the fuel debris outside the pedestal where the accessibility from top is limited. The retrieval operations will be conducted while pouring water into processing areas as necessary for suppression of dust scattering. The side access can be made ahead of the top access to implement safety measures such as preventions of criticality due to accumulations of cutting particles during fuel debris retrieval and heavy drop objects from the RPV. Appropriate containment barriers will be constructed to suppress radioactive dust dispersion and the spread of contamination during retrieval. The basis of containment is that primary containment barrier comprises PCVs and other structures while the secondary containment barrier comprises reactor buildings and other structures. In addition, a gas phase containment system is installed at the primary and secondary containment barriers to achieve active containment through difference pressure control inside and outside the containment barriers.

In the fuel debris retrieval by the top access, since heavy objects such as a cell with the containment functionality and equipment for retrieval etc. will be installed on the operating floor, a large gantry will be newly required to support them with seismic resistance. The gantry is structured with seismic isolation straddling reactor building in a north-south direction in order to avoid interference with the turbine building. In addition, the additional building, in which facilities for safety systems (the gas-phase system and liquid-phase system), water treatment, and the pre-transfer treatment of debris/waste are installed, will be located on the south side of the reactor building.

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

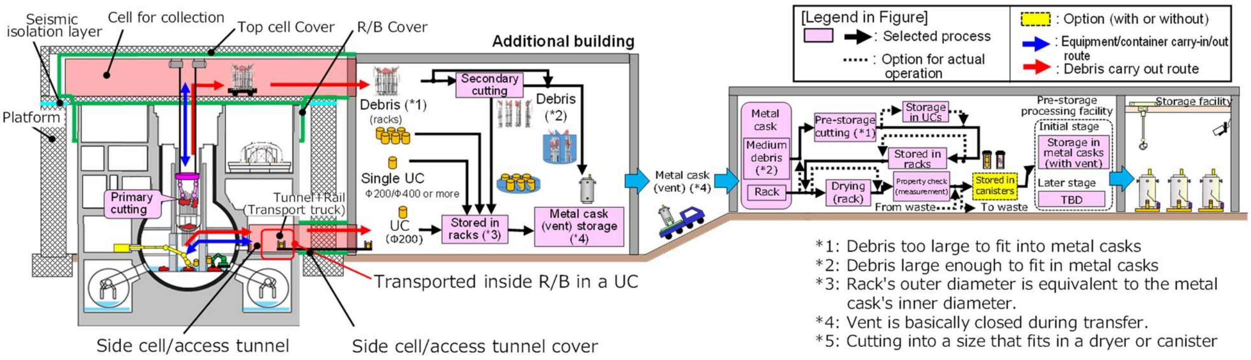

Figure 1 Partial submersion method
- Overall process flow for retrieval, transfer, and storage

2.2.2. Submersion method

The submersion method involves enclosing the entire reactor building with a new structure, called a shell structure, and flooding inside the reactor building to retrieve fuel debris. The water shielding enables to reduce radiation dose in working areas. The shell structure is constructed with a complex support structure made by three layers of thick steel plates, and is designed as containment barriers that support all the loads of the reactor building and water with sufficient seismic resistance.

Remote operated equipment is lowered under water from inside the cell installed on the operating floor to dismantle reactor internal components and retrieve fuel debris inside the RPV / pedestal and outside the pedestal. Fuel debris outside the pedestal is retrieved via a worker access route on the basement floor.

The three-layer structure consists of the inner wall in contact with water and a cell installed on the operating floor as a primary containment barrier, the shell structure interior as a secondary containment barrier, and the outer wall as a water shielding containment barrier. In addition, a gas phase containment system is installed at the primary and secondary containment barriers to achieve active containment through difference pressure control inside and outside the containment barriers.

In the retrieval cell at the top of the shell structure, the top access-related facilities such as the debris retrieval equipment, equipment for safety systems (the gas-phase system, the liquid-phase system), equipment for water treatment and pre-transfer treatment of debris/waste are installed. Pre-transfer treatment of the retrieved fuel debris is carried out in water until it is stored in a shielded container, and cleaning, draining, lid-closing and inspection of the container are carried out in air. The amount of storage shall be limited in order to guarantee the hydrogen concentration at or below the flammable limit for radiolysis of moisture contained in the transfer container. The transfer container is transferred from the shell structure to the pre-storage treatment facility, and the fuel debris is analyzed, sorted, and dried in the process of pre-storage treatment. It is then stored in a storage container and stored in the storage facility.

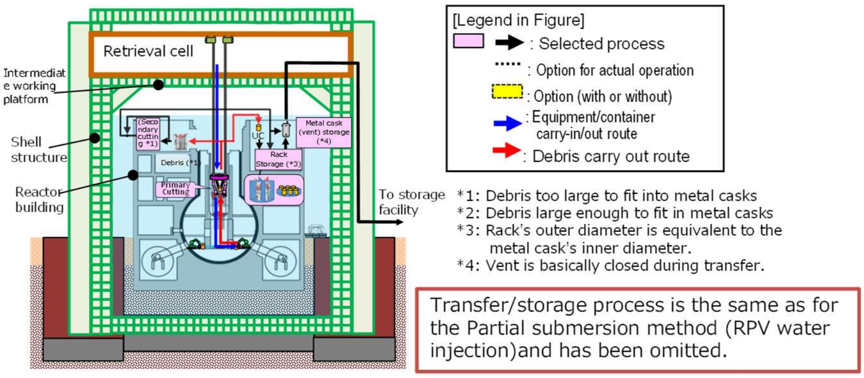

Figure 2 Retrieval process flow of the Submersion method

2.2.3. Partial submersion method Option (RPV filling and solidification)

Partial submersion method option (RPV filling and solidification) is a method that stabilizes inside the pedestal, outside bottom of the pedestal, inside RPV, reactor well etc. by liquid filling materials which will be solidified after certain period of time, and then retrieves fuel debris and reactor structures by remote operated equipment through relatively small opening at an operating floor. The solidified part is recovered by drilling equipment etc., and unsolidified part is recovered by an appropriate remote operated jig.

Filling materials are injected into the inner bottom of the pedestal by a side access to stabilize and solidify fuel debris, and then the filling materials are injected into the space where solidification is deemed appropriate below the reactor well (Lower part of PCV head, inside RPV, remaining part inside pedestal, etc.) by a top access for stabilization.

As for the retrieval operations, a remote operated jig is inserted from the operating floor through the opening, and retrieval operations are carried out by drilling fuel debris and filling materials to the bottom of the pedestal. For the fuel debris retrieval through unfilled spaces, casing is set to carry out drilling and recovery operations.

The spaces to be filled and solidified are where temporary stabilization is urgently needed, drilling retrieval is deemed efficient and reduction of radiation dose due to shielding effect against γ-rays by the filling materials is expected etc. The extent of filling and solidification will vary depending on the results of the internal investigations and the situations inside reactor that will be confirmed after the commencement of the retrieval operations. There will be various cases including the partial filling scenarios such as filling the entire space below the reactor well, only a small part of RPV, the entire space inside RPV, the entire pedestal space or the only small part of pedestal, etc. Evaluations will be made as appropriate based on the results of internal investigations and accessibility for drilling retrieval etc.

For drilling filling materials, two retrieval options can be considered – one is to retrieve as a solid such as core boring or crushing and the other is to circulate drilled cuttings with water and retrieve by filter container.

Since a cell with the containment functionality, equipment for retrieval etc. and a cell cover will be installed on the operating floor, a gantry will be newly required to support their loads.

A double-layered containment barrier is constructed for suppression of radioactive dust dispersion and spread of contaminations during retrieval operations. As with the Partial submersion method, the primary containment barrier consists of the PCV, and the secondary containment barrier consists of the reactor building. However, compared to the Partial submersion method, suppression of radioactive dust dispersion and spread of contaminations will be enhanced since fuel debris is covered by filling materials. In addition, a gas-phase containment system is installed in the primary/secondary containment barriers, and dynamic containment is implemented by the pressure difference inside and outside the containment barriers.

Regarding transfer and storage of fuel debris stored in the recovery container, a study should be conducted referring to the concept of the Partial submersion method and the Submersion method.

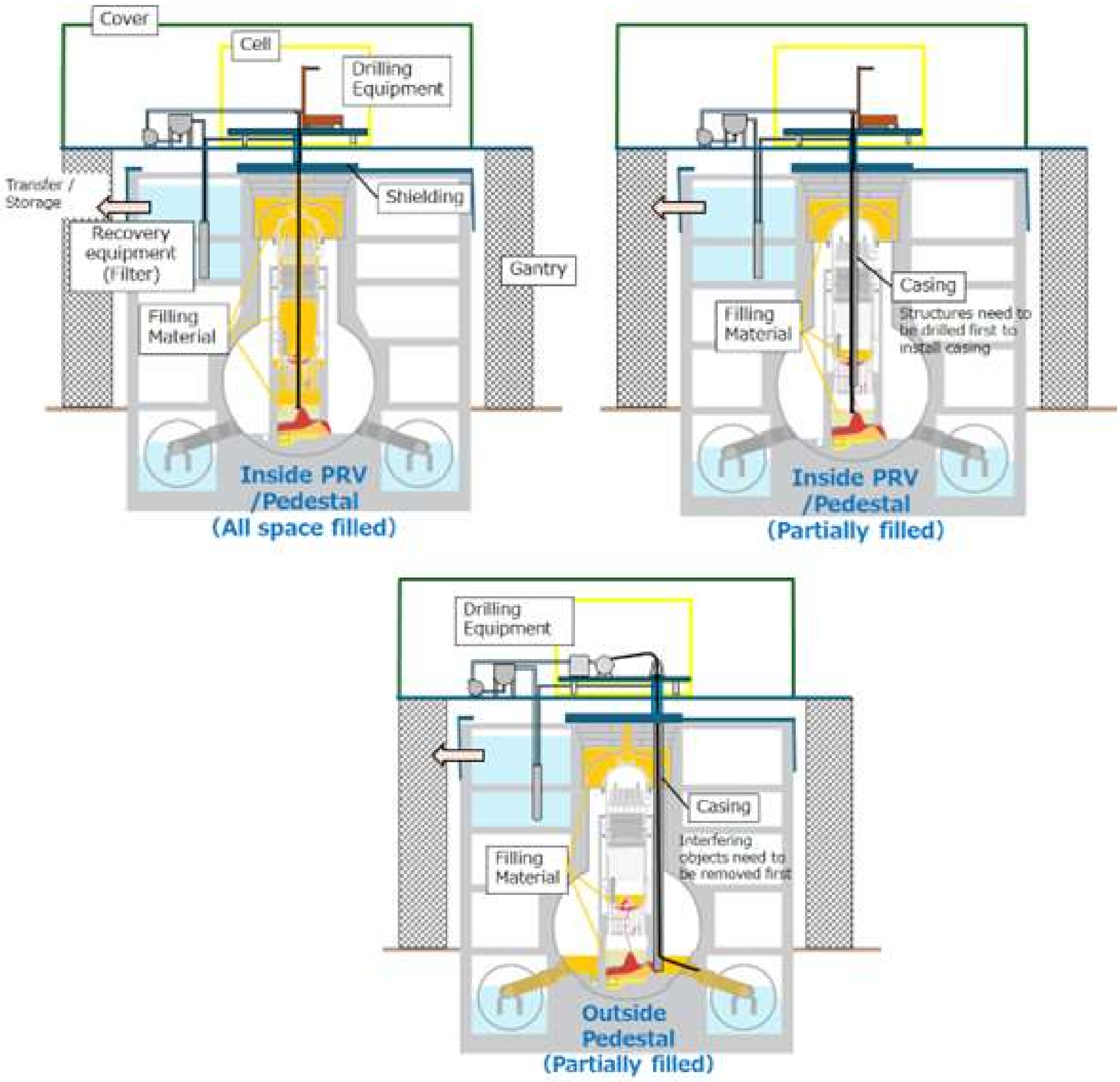

Figure 3 Overview of Partial submersion method Option

3. Evaluation of Retrieval Methods

3.1. Prerequisites for the Evaluation

In carrying out the evaluation of the retrieval methods, the Sub-committee has set out the following conditions.

- Unit 3, which is expected to be the first reactor for a large-scale retrieval, will be the scope of this evaluation. For Units 1 and 2, the retrieval concepts will be examined and selected based on individual conditions with reference to the results of this study.
- Retrieval method will be evaluated based on the assumptions of fuel debris distribution
- The scope of this study is up to retrieval and transferring of fuel debris, excluding storage of retrieved materials. Dismantling of reactor buildings and the process and disposal of waste will be examined after scrutinizing the status and properties of the retrieved waste materials.
- For the public exposure dose level at the site boundary, current regulatory system is referred as the initial setting for this study.

Regarding fuel debris distributions, it is possible that new issues that are different from the above prerequisites are identified from the information obtained through future internal investigations. In such a case, it is possible to change the retrieval scenarios or even to revisit the selection of retrieval method itself in the middle of the engineering study.

3.2. Basic policy for ensuring safety

The special characteristics of the Fukushima Daiichi NPS include: a large amount of radioactive materials are in a various state in various forms (atypical); there is a large uncertainty in on-site information on the status of radioactive materials and containment barriers; Prompt actions are required because the current radiation dose levels are high and there are concerns about further deterioration of the containment barriers. On the other hand, the intrinsic energy that causes the release of radioactive materials is low, so the progress of an event is generally considered to be slow. In considering retrieval methods, the priority should be given to the safety with the full recognition of these special characteristics. Based on the above, we have established the following basic policy for ensuring safety.

< Basic policy for ensuring safety >

- Bring on-site conditions more stable state as promptly as possible and reduce the residual risks as low as possible.

- Ensure to meet safety standards for radiation effects during decommissioning and try to reduce radiation effects as low as reasonably practicable (Special focus should be given to ensuring safety of workers as unusual radiation work conditions are expected)
- Take all possible measures to prevent negative radioactive effects as well as any psychological or social negative impact on local residents and governments.

3.3. Evaluation Approach

The evaluation items shown in Table 1 were set out from 5 basic concepts (Safe, Proven, Efficient, Timely, Field-oriented).

Table 1. Criteria used in this evaluation

Items	Evaluation criteria based on 5 basic concepts
Safe	Compliance with approach and criteria for ensuring safety such as containment, shielding, criticality, and seismic resistance
Proven	Reliability (technological maturity)
	Flexibility against uncertainty
Efficient	Efficiency
Timely	Time consciousness (Early start of fuel debris retrieval and time period for implementations), this criterion is evaluated based on time required for construction, operations and maintenance
Field-oriented	Easiness of installations, operations and manipulations for equipment
	Maintainability

In addition, resources to be required, time (construction, operation and maintenance), flexibility of changing to another retrieval method and possibility of applications to Units 1 and 2.

3.4. Evaluation and issues of each retrieval method

Three retrieval methods presented in Section 2.2 were evaluated based on the evaluation criteria above. Although the study period for the Submersion method is relatively short and the study period for the Partial submersion method Option is even shorter compared to the Partial submersion method which has been studied for a long time, the evaluations were carried out based on the information obtained at present and countermeasures to the issues that are assumed reasonable.

Each retrieval method was evaluated by analyzing the series of work processes from preparations, constructions, fuel debris retrievals, transfer/storage to maintenance, with identifications of the issues and countermeasures. As a result of the evaluations, it was concluded that there was no retrieval method that is deemed technically unfeasible at this stage, although all methods still have issues to be addressed. The main issues are shown in Table 2. Table 3-1 and Table 3-2 shows the results of the comparative evaluations of each method for resources, time (construction, operation and maintenance), flexibility to change to other methods, and the possibility of deployment to Units 1 and 2 are also considered.

Table 2 Main issues

Criteria	Partial submersion method	Submersion method	Partial submersion Option
Compliance with approach and criteria for ensuring safety	・Protection of workers ・Feasibility of seismic isolation structures for the gantry ・Countermeasures to deterioration of existing structures ・Sorting of fuel debris and waste	・Protection of workers ・Feasibility of the liquid-phase system in a boric acid solution environment ・Measures to maintain subcriticality under normal water conditions ・Feasibility of the emergency boric acid injection system ・Sorting of fuel debris and waste	・Protection of works ・Seismic resistance of the equipment installed on reactor buildings ・Sorting and storage scenario of fuel debris and waste
Reliability (Technology Readiness Level)	・Troubleshooting and recovery ・Further studies required on equipment and operations for criticality control ・Adequate demonstrations of remote operated devices	・Troubleshooting and recovery ・Further studies required on equipment and operations for criticality control ・Verifications on operations for remote operated equipment under water	・Troubleshooting and recovery ・Further study required on equipment to be newly installed ・Further studies required on equipment and operations for criticality control ・Method for filling evaluations ・Examinations on water circulation and recovery systems
Flexibility to uncertainties	・Internal investigation is required in advance	・Internal investigation is required in advance	・Internal investigation is required in advance ・Examinations on countermeasures to decay heat
Efficiency	・Selection of fuel debris processing and recovery methods ・Reduction of loads on upper structures (weight of shielding) ・Optimization of new gantry structure design	・Ensuring visibility ・Examination of retrieval operations outside the pedestal ・Optimization of new structure design ・Amount of waste generated during the preparation work	・Study on retrieval methods other than drilling ・Method of treating the water used for drilling and recovery ・Amount of fuel debris and high-level waste generated ・Process of sludge waste due to drilling

Workability and operability	・Properties of fuel debris are unknown ・Measures to prevent water level reversal during ground improvement ・Installation procedure for interface design between new structures and the operating floor ・Emergency recovery method when installing access facility	▪ Properties of fuel debris are unknown ▪ On-site workability of shell structures (including ground stability in case earthquake occurs during construction, measures to prevent water level reversal, and constructions with contaminations) ▪ Handling leakage of water from the shell structure ▪ Transfer site of the stabilization equipment other than the turbine building, method of rerouting, and operation (including during construction period)	・Properties of fuel debris are unknown ・Method of installing a filling hose inside the pedestal ・Examination of filling materials and filling methods ・Interface design between new structures and the operating floor
Maintenability	・Maintenance and troubleshooting of interface new facilities and existing facilities ・Troubleshooting and recovery method by full remote operations	・Detection of water leakage between containment barriers and subsequent restoration measures	・Prevention of drilling water leakage into or out of a cell

Table 3-1 Other evaluations (except for flexibility for changeover to other retrieval methods)

Criteria	Partial submersion method	Submersion method	Filling and solidification method
Resources	・Preparation works: Removal of interfering buildings is required ・Construction works: Installation of a working platform / extension building is required ・Waste: Removal of interfering buildings is required	・Preparation works: Removal of interfering buildings is required ・Construction works: Installation of shell structures is required ・Waste: Removal of interfering buildings is required	・Preparation works: Removal of interfering buildings is required ・Construction works: Installation of a working platform is required ・Waste: Removal, etc. of interfering buildings is required
Work period (Constructions, operations and maintenance)	・Preparation works: Medium-term ・Construction works: Medium-term ・When retrieving: Assumed to be the same level for all methods ・Recovery in case of remote control device failure: Long-term	・Preparation works: Long-term ・Construction works: Long-term ・When retrieving: Assumed to be the same level for all methods ・Recovery in case of remote control device failure: Short-term (Manual works inside a cell is possible)	・Preparation works: Medium-term ・Construction works: Short-term ・When retrieving: Assumed to be the same level for all methods ・Recovery in case of remote control device failure: Short-term (Manual works inside a cell is possible)
Changeover to other method	Described in the following table (A summary of the contents and degree of impact to change one retrieval method to another in each operational status)		
Application to Unit 1 and 2	Application to single unit: Possible Simultaneous application for unit 1 / 2: Possible	Application to single unit: Possible Simultaneous application for unit 1 / 2: To be examined	Application to single unit: Possible Simultaneous application for unit 1 / 2: Possible

Table 3-2. Other evaluations (Flexibility for changeover to another retrieval method)

Original retrieval method	Status before the change	New retrieval method after change: Partial submersion method		Submersion method		Partial submersion method option	
		Details	Impact	Details	Impact	Details	Impact
Partial submersion method	Removing interference buildings	-	-	Changeable	Small	Changeable	Small
	After the start of new construction	-	-	New equipment needs to be removed	Large	Changeable	Small
Submersion method	Removing interference buildings	Changeable	Small	-	-	Changeable	Small
	After the start of new construction	Same facility can be used for top access; if side access is required, interference facility needs to be removed.	Middle	-	-	Same facility can be used for top access; if side access is required, interference facility needs to be removed.	Middle
	After submersion	After draining water, same as above	Middle	-	-	After draining, same as above If filling and solidification is possible underwater, it may be left submerged.	Middle
Partial submersion method option	Removing interference buildings	Changeable	Small	Changeable	Small	-	-
	After the start of new construction	Additions and modifications to the platform should be considered in designing	Middle	New equipment needs to be removed	Middle	-	-
Partial submersion method option (no gantry)	Removing interference buildings	Changeable	Small	Changeable	Small	-	-
	After the start of new construction	New equipment needs to be removed	Small	New equipment needs to be removed	Small	-	-

(1) Evaluation of the Partial submersion method

< Advantages >

- Since the retrieval operations will be conducted without significant changes on the current conditions, it is possible to mitigate concerns on changing the status of the reactor.
- Fuel debris retrieval works can be commenced earlier than the Submersion method.
- Suitable processing and retrieval method can be selected from multiple options of top access as well as combinations of top access and side access depending on the status of the reactor.

< Issues to be addressed >

- A wider variety of remote operated equipment are required compared to other methods due to high-level radiation dose environment, which would require a long period for design, development and demonstration. Furthermore, there is a possibility that design changes are required after installations at the site. In addition, significant amount of time would be needed for rescue of remote operated equipment in case of failure, recovery methods under a high-level radiation dose environment and/or prevention measures against an increase in radiation levels inside a cell will need to be considered.
- In order to retrieve fuel debris and waste that have high radiation dose from the top opening, it is necessary to install a heavy cell and retrieval equipment on the operating floor, therefore, the gantry structure to support them with sufficient seismic resistance becomes large in scale.

(2) Evaluation of the Submersion method

< Advantages >

- Radiation level at operating floor can be reduced by water shield against strong gamma rays from inside the reactor, which makes remote operations from top easier and margin for worker exposure will be extended. Prevention of dust scattering can also be expected.
- A rigid containment barrier (the shell structure) allows complete isolation from the outside.
- Manual recovery operations of remote operated equipment from the operating floor is possible in case of failure

< Issues to be addressed >

- Verifications of workability at the site in the basement of reactor building (e.g., ground stability in case earthquake occurs during constructions, countermeasures to inflow of groundwater and quality assurance on large-scale constructions of the shell structure) and secure transfer locations for the stabilization facilities outside the turbine building.
- Careful criticality management as well as management of a large amount of retained water (water quality control, leakage prevention, corrosion control, etc.),
- The shell structure is extremely large in scale.
- The longest preparation period is required therefore the commencement of the fuel debris retrieval work is the latest.

(3) Evaluation of Partial submersion method Option

< Advantages >

- The fuel debris on bottom of RPV and pedestal can be stabilized by solidifications with filling materials. Also handling of fuel debris can be standardized and simplified by solidification.
- Reduction of radiation level can be expected due to shielding effect by a filling materials and the relatively small opening to access the reactor, etc. As a result, it is possible to simplify the cell to be installed in the operating floor, the cell cover, and the gantry structure to support them. In addition, manual recovery operations in the operating floor would be possible in case of equipment failure.
- The drilling equipment is simple and remotely operated with vertical movement in one axis. In addition, it is flexible as a bit or jig can be changed depending on the object to be drilled.
- Compared to the Partial submersion method and the Submersion method, equipment is smaller in scale, and it is likely that the fuel debris retrieval work can be commenced at the earliest timing.

< Issues to be addressed >

- The selection of the filling materials (Fluidity, adjustment of curing time, mechanical properties after solidification, thermal conductivity, chemical stability, degradation by radiation, etc.), and the establishment of the filling method and the filling evaluation method are required.
- It is necessary to select and verify the bit for the object to be drilled.
- The larger the extent of filling and solidification becomes, the more amount of waste will be generated. Special considerations will be required for handling sludge.

4. Recommendations for the Selection of Retrieval Methods

From the evaluations of retrieval methods in Section 3.4, it was confirmed that all retrieval methods have advantages and issues to be solved, and that the technical elements in each retrieval method are accompanied by uncertainties (in terms of engineering, fundamental data, demonstration, etc.). It is difficult to make a clear judgment on three retrieval methods unless certain engineering study and research and development (Trial design and manufacturing, and demonstration of useful technology etc.) are carried out.

On the other hand, given that delays on commencement of fuel debris retrievals could increase the overall risks in the decommissioning project, it is deemed adequate to present a retrieval method for which the focused engineering study should be commenced, based on the current evaluations of technical characteristics for each retrieval method. It is desirable not to stick to one retrieval method, but to consider the scenarios in which the strengths of each retrieval method are combined to complement the weaknesses (Hereinafter referred to as “retrieval scenario").

Internal investigation, sampling and analysis are essential to promote more realistic engineering studies. Information such as damages on existing structures, the amount and distributions of fuel debris (including existence of stump-shaped damaged fuels in the RPV) and radiation maps inside a reactor will be provided by internal investigations. That information can be reflected in the engineering studies for the establishment of access routes to fuel debris, retrieval methods and equipment for them. In addition, properties of fuel debris can be obtained through sampling and analysis, and can be utilized as inputs for engineering studies of fuel debris processing, criticality management, packaging, transfer and storage, waste management, and inventory management, etc.

The direction of retrieval methods and scenario that should be focused on in the future were examined according to the following concepts.

< Basic Concept of Retrieval Method Selection >

A retrieval method or scenario should:

① Be simple without an excessive scale of facilities and equipment at the initial stage and can be modified to reflect information and experience that will be obtained.

② Be flexible to change the direction of retrieval method or scenario as necessary based on internal investigations.

③ Put emphasis on efficiency of the entire decommissioning project to avoid the situation in which continuity and feasibility of the project might become unstable due to protracting fuel retrieval period.

④ Provide better confidence on engineering, research and development to address important technical issues that are key to technical feasibility.

⑤ Have simple remote operated equipment which is easy for maintenance and allow both remote operated operations and manual works in a complementary way.

⑥ Be able to minimize the radiation exposure risk to the public, as well as easily implement the measures to reduce worker exposures.

⑦ Be able to present an approach of ensuring safety with confidence and not require excessive safety margins.

Based on <Basic Concept of Retrieval Method Selection> above, we consider as follows:

The Partial submersion method does not require significant changes on current status for fuel debris retrieval, hence it can avoid concerns on the changes in current conditions. In addition, suitable processing and retrieval methods can be selected such as combinations of a top access and a side access depending on the status of the reactor. On the other hand, however, due to large system in scale and complete dependence on remote operated equipment, there are great concerns over conflicts with yard planning, feasibility of the retrieval sequences and overall performances of remote operated equipment such as operability and operating rate. To address these concerns, it is necessary to conduct engineering study for the Partial submersion method with realistic conditions and constrains. Furthermore, there is a chance to resolve some of the issues in the Partial submersion method by partially introducing concepts of the Partial submersion method Option. For example, it is expected that applying some of concepts of the Partial submersion method Option would reduce the radiation dose at an operating floor and improve some of issues identified in the Partial submersion method to some extent. For engineering study going forward, it is appropriate to seek options to combine the Patial submersion method and the Partial submersion method Option in complimentary way.

As for the Submersion method, although this method has a potential to solve various issues associated with high radiation dose at the site due to the effect of water shielding, there are issues regarding to: large scale of equipment and construction works, the longest time required to commence retrieval operations, its irreversibility as a project, uncertainty in the site workability of constructing shell structures, and the difficulty of handling large amounts of water. Therefore, it is deemed difficult to select the Submersion method for a full-scale retrieval option at this stage. On the other hand, however, there is great advantages of handling materials with high-radiation dose under water which may make fuel debris retrieval operations easier in the areas where it is difficult to retrieve by the Partial submersion method, and considering the work efficiency, a future transition from the Partial submersion method to a retrieval method that can utilize water shielding functionality is deniable. Therefore, an option that can utilize water shielding functionality should continue to be examined in parallel with the Partial submersion method including the ground investigations around and below reactor buildings.

As for the Partial submersion method Option, entire facility is smaller in scale and the equipment is simple, and the effect of filling and solidification can be expected to temporarily stabilize the fuel debris. However, it cannot be denied that technical examinations have not been sufficiently conducted yet, e.g., the selection of the filling materials to meet requirements has not been completed, the technical examinations have not been matured yet on how to fill the spaces in reactor, and conceptual designs regarding to drilling the solidified areas and handling of the recovered materials have not been sufficiently explored. In addition, the overall operation sequence and retrieval works need to be more specified, hence it is considered too early at this stage to judge the feasibility of this retrieval method alone. If a certain level of confidence can be obtained on the selection of filling materials and the recovery method through engineering study and research and development to demonstrate the feasibility of this retrieval method, this would enable to improve Partial submersion method further by applying the functionality of filling and solidifications. The retrieval scenario that combines Partial submersion method and Partial submersion method Option should be investigated going forward.

For the evaluation of three retrieval methods, special focuses were given to criticality control, seismic resistance and waste management in terms of realistic safety measures in response to the magnitude of risks. For criticality, the premises of the evaluations is that fuel debris retrieval will be conducted in subcritical conditions by motoring and detection of status that are close to criticality. For seismic resistance, given that inherent energy is low and too conservative assumptions would increase the overall risks by protracting the period of fuel debris retrieval, it is necessary to conduct optimum seismic resistant design in line with site specific conditions from the view point of the impacts to the site boundary and workers if containment is lost. For waste management, the amount of waste would not be a decisive factor for comparative evaluations although it will be aimed to minimize the amount of waste generated as much as possible. On the other hand, however, it should be noted that characteristics of wastes (such as sludge) would impact on feasibility and technical issues of each retrieval method.

In addition, for any retrieval method, an enough understanding of situations inside PCV / RPV is a prerequisite for engineering and safety assurance. The internal investigations that have been carried out so far have provided some information on a part of bottom of PCV, but little information is available on the top of the PCV and inside the RPV. Accelerating progress of internal investigations are quite important for the selection of the retrieval method, however, considering the targeted time frame, it is deemed inevitable to make parallel progresses on the engineering study for fuel debris retrieval and internal investigations.

An "access to the inside of the RPV through a small opening on the well shield plug" in the Partial submersion method Option is similar to the operational concept of internal investigations of the RPV by top access. A series of tasks in a top access is composed of: establishment of an access route to the inside of the RPV with partial filling and solidifications as necessary through a small opening that allows manual works, and internal investigations with small camera and fuel debris sampling by core boring. These tasks are expected to enable smooth transition to fuel debris retrievals while expanding the extent of filling and solidifications and core boring recovery.

Based on all discussions made so far, it is considered appropriate to:

- Commence engineering study, research and development combining the Partial submersion method and the Partial submersion method Option.
- In parallel, conduct internal investigations by a top access through a small opening.
- Continue study for a retrieval option utilizing water shielding functionality too, in parallel with the tasks above.

5. Future Course of Action

5.1. TEPCO's engineering study for large-scale retrieval method

As mentioned above, it is necessary for TEPCO to start more detailed engineering study for a large-scale retrieval based on the recommendations in this report. In proceeding the engineering study, the first action will be an establishment of the organization gathering expertise inside and outside TEPCO and it is also necessary to consider the parties to be involved in constructions of facilities and operations for fuel debris retrievals in the future.

In making the recommendations of this report, we narrowed down the direction of the engineering study and identified the issues to be addressed under a great uncertainty. TEPCO is required to tackle the issues presented in this report such as internal investigations and research and development, as well as proceed more detailed engineering studies. In addition, the direction of the engineering studies presented in this report needs to be continuously reviewed at every opportunity that can reduce uncertainties, e.g., internal investigations, research and development, and analysis of fuel debris samples. In case there are any doubts raised based on new information from internal investigations etc., it needs to be considered to revisit the direction of engineering and re-evaluate fuel debris retrieval method.

In addition, it is also recommended not to stick to the original plan due to concerns such as accountability for resources already invested. If new information is obtained through internal investigations etc. that creates need for reconsiderations of a retrieval method, the retrieval method should be reviewed without hesitation of changing the plan.

Furthermore, the studies need to be parallelly conducted to identify incidents that can be assumed in fuel retrieval operations, assess the impact of those incidents (safety assessment) and consider the criteria to resume the works.

5.2. Development of safety assurance concept

Since the fuel debris retrieval is an unprecedent task to be conducted under unusual conditions and environments and risk pictures are different from those in normal reactors, it is necessary to establish safety standards and criteria specific to the Fukushima Daiichi NPS. In carrying out more detailed engineering studies for large-scale retrieval, it is necessary to set out safety standards and criteria by the operator itself for safety functionality such as containment, shielding and subcriticality maintenance.

Safety standards and criteria will greatly affect the scale of equipment and operations and overall time, and therefore need to be appropriately set out to avoid the risk level remains high by protracting engineering process and retrieval operations. To avoid delay on the commencement of fuel debris retrieval, it is recommended to set out safety requirements and criteria by the operator and present them to Nuclear Regulatory Authorities at as accurately and as early stage as possible, then reflect reviews and suggestions of the regulator to basic and detailed design.

Examples of major discussion topics for safety requirements are shown in ① to ③ below.

[Examples of major discussion topics regarding to safety]

① Concept for seismic resistant design for the facilities in large-scale retrieval method

Design basis in line with realistic conditions for seismic resistance for specific engineering study by TEPCO.

② Concept for criticality management during fuel debris retrieval

As a part of safety assessments, identification of the scenarios in which criticality occurs, the assessment of probability of occurrence and impact, prevention measures, monitoring, mitigation measures etc.

③ Concept of waste storage

The storage method with the considerations of hydrogen gas generations and criticality control

5.3. Follow up by the Sub-committee

Since this report presents recommendations based on the evaluations with great uncertainties, TEPCO needs to continuously review the direction of engineering study presented in this report through the engineering, internal investigations, and research and development conducted by TEPCO. Prior to acceleration of detailed engineering for concrete retrieval system and equipment, the assessment on the feasibility needs to be made within one or two years. Therefore, it is recommended to keep this Sub-committee in near future to follow up TEPCO's engineering, research and development activities.

5.4. Communications with local residents and governments

The recommendations in this report were made based on the evaluations with technical and specialized expertise. Indeed, from the viewpoint that the safety is the first priority, this activity should be carried out responsibly by experts who own the technical knowledge and experience. On the other hand, it is important to lead the activities and deliverables in this Sub-committee to the sense of security of local governments and residents.

Therefore, it is necessary to fully explain and share the contents of this report and the implementation status of TEPCO's engineering study by communications with local governments and residents.

End of the Report