Technical Strategic Plan 2015 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company

Towards Amendment of the Mid-and-Long-Term Roadmap in 2015

April 30, 2015

Nuclear Damage Compensation and
Decommissioning Facilitation Corporation

A Message to Our Readers

Four years have passed after the break of the accident at the Fukushima Daiichi Nuclear Power Station (Fukushima Daiichi NPS) of Tokyo Electric Power Company (TEPCO), and situations at the Fukushima Daiichi NPS have greatly improved compared to the time immediately after the accident. The removal of fuels from the spent fuel pool in Unit 4 was successfully achieved along with other improvements thanks to the incessant efforts of all the people involved. Proper and steady delivery of decommissioning is the essential basis in the recovery of Fukushima prefecture, and there is a growing interest in and expectations of the local communities for the smooth progress of decommissioning work. On the other hand, there still are a lot of challenges to overcome in order to promote the decommissioning work for the reactors which experienced the unprecedented severe accident.

Over the past years, personnel responsible for decommissioning of the Fukushima Daiichi NPS have been occupied with emergency responses, and the mid-and-long-term issues have not been adequately addressed. Under these situations, former Nuclear Damage Compensation Facilitation Corporation transformed into a new organization, Nuclear Damage Compensation and Decommissioning Facilitation Corporation (NDF) in August 2014, as an organization specializing in formulation of strategies and provision of technical support by gathering the knowledge and experiences from all over the world with the objectives of safe and steady decommissioning of damaged reactors. Since then efforts have been made to study the specific strategies to address major challenges of decommissioning from the mid-and-long-term viewpoint, and we have now formulated the first version of the “Strategic Plan.”

The goals of this “Strategic Plan” are to provide a firm technical basis for the government’s mid-and-long-term Roadmap and to serve as an aid for smooth and steady implementation of decommissioning.

The policies for the formulation of the Strategic Plan are

- to provide clear technical basis, such as the latest information on the plant conditions and R&D achievements, and
- to provide technically accurate reports with an intention to keep the expressions easy to understand.

Decommissioning of the Fukushima Daiichi NPS is a continuous challenge to reduce the risks posed by the radioactive materials generated by the accident that do not exist in ordinary nuclear power plants. In that sense, it can be said that this Strategic Plan is a scheme for risk reduction from mid-and-long-term strategic perspective. The Five Guiding Principles for the formulation of the Strategic Plan, “Safe, Proven, Efficient, Timely and Field-oriented” were formulated, and future actions are identified based on the prioritization of risk reduction.

For making this report, we incorporated advice from the Decommissioning Strategy Board, Expert Committee, International Special Advisors, etc., as well as the meetings and discussions with Ministry of

Economy, Trade and Industry (METI) and Ministry of Education, Culture, Sports, Science and Technology (MEXT), TEPCO, Japan Atomic Energy Agency (JAEA), International Research Institute for Decommissioning (IRID), etc. I would like to acknowledge the cooperation of these organizations.

We intend to continuously review this Strategic Plan by incorporating the results of the plant inspections and other detailed studies.

We, NDF, will make the best endeavors to promote safe and steady decommissioning of the Fukushima Daiichi NPS to meet the expectations of the people of Fukushima prefecture and of Japan. We greatly appreciate your understanding and continued support in fulfillment of our responsibility.

April 2015

Hajimu Yamana
Vice President
NDF

Overview of the Technical Strategic Plan for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company (The Strategic Plan)

The position of the Strategic Plan

The purpose of the Strategic Plan was developed to contribute to the steady implementation and studies on the revision of the "Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1-4" (hereinafter referred to as "the Roadmap") developed by the Japanese government in order to facilitate appropriate and steady decommissioning of the Fukushima Daiichi Nuclear Power Station and to provide firm technical basis to the Roadmap. Specifically, an implementation plan for retrieval of molten and solidified fuels (hereinafter referred to as "fuel debris") and waste management which are the key issues in decommissioning of the damaged reactors is outlined. It has to be subject to the continuous assessment and review in accordance with future progress in understanding of the site conditions and achievements in R&D. It is stated in the Roadmap that the fuel debris retrieval method is to be determined in the first half of FY2018.

The fuel debris retrieval methods will be narrowed down from multiple scenarios before the timing specified in the Roadmap. It is also stated that the basic approaches to the processing and disposal of solid radioactive waste are determined in FY2017. These strategic plans will be revised in line with the schedule specified in the Roadmap.

Since the Strategic Plan deals with a wide range of subjects, "logic tree" style is used for explanation of logics throughout the document in order to ensure that every detail is covered comprehensively and to serve as an aid to understand the logical development.

Basic concept of the Strategic Plan

The basic concept of the Strategic Plan is to continuously and promptly reduce the risks associated with the radioactive materials in the Fukushima Daiichi NPS, and risk reduction strategy is formulated for the risks which are represented by the significant effect (hazard potential) and the likelihood of loss of containment function due to radioactive materials (risk sources) such as fuels, contaminated water and waste.

The major risk sources are categorized into three levels depending on the order of priority and the measures are already being taken for those risks that require immediate actions. Therefore this Strategic Plan focuses on the areas of study, the fuel debris retrieval which requires thorough preparations and has a number of challenging issues, and the waste management that requires to be addressed on a long-term basis.

The technical studies on the fuel debris retrieval and the waste management are set out based on the following Five Guiding Principles to risk reduction; 1) Safe- Reduction of risks posed by radioactive materials and work safety, 2) Proven- Highly reliable and flexible technologies, 3) Efficient- Effective utilization of resources (human, physical, financial, space, etc.), 4) Timely- Awareness of time axis, 5)

Field-oriented- Thorough application of Three Actuals (the actual place, the actual parts and the actual situation).

Strategic plan for fuel debris retrieval

- Approaches to the study on the fuel debris retrieval

  Although the fuel debris is in a certain stable condition at present, it needs to be retrieved as soon as reasonably achievable by careful preparations and proven technologies, and store it in a stable condition in the site to reduce further risks.

  This should proceed with the following steps: (1) maintaining and management of the fuel debris in stable condition until it is retrieved; (2) safe retrieval of the fuel debris; and (3) storage of the retrieved fuel debris in a stable condition after being collected and transported. Especially among these steps, (2) safe fuel debris retrieval requires to be evaluated based on the following major issues of "identification of the location, amount, properties of fuel debris and FP distributions," "ensuring the safety during the fuel debris retrieval work" and "the fuel debris retrieval method."

  The studies on "ensuring the safety during the fuel debris retrieval work," and "the fuel debris retrieval method" correspond to the technical requirements for the fuel debris retrieval method and consist of the following nine items:1) securing the structural integrity of the PCV and the R/B, 2) criticality control, 3) maintaining the cooling function, 4) establishment of the containment function, 5) reduction of exposure to the workers during operation, 6) development of fuel debris retrieval equipment and device, 7) establishment of access routes to the fuel debris, 8) establishment of the system equipment and working areas, and 9) ensuring the work safety.

- The features of retrieval methods

  Full submersion/Submersion method: A retrieval method by filling to the top of the PCV with water to submerge the fuel debris. This method enables cooling of the fuel debris, radioactive shielding, and prevention of dispersion of radioactive dusts, but there are some difficulties in prevention of leakage of the PCV, seismic resistance, and criticality control.

  Partial submersion/Dry method: A method to retrieve the fuel debris exposed in the air and without filling the PCV with water. The entry from both the top and the side is possible in this method, but there are some difficulties in preventing the dispersion of radioactive dusts and radioactive shielding.

- The options of the retrieval method and plan for selecting the scenario in accordance with the options.

  This strategic plan describes possible options for the fuel debris retrieval method based on the water level of the PCV which can be filled with water and the direction of accessing the fuel debris for each of the Submersion method and the Partial submersion method. After the selection of the methods to be focused on, the current status and the future actions for the nine technical requirements for the Submersion and Partial submersion methods are discussed. In addition, this plan proposes several scenarios with combinations of different methods and the plan for selecting the scenario in accordance with the conditions of each unit.

The scenario of application to the actual plant is to be selected in stages in accordance with the technical development which will be a key to the success in the fuel debris retrieval method, improvement of estimation accuracy of plant conditions such as the locations and distributions of the fuel debris in each unit. The investigation required to determine the application scenario for each unit and review of the R&D plans are carried out as necessary.

After the selection of the fuel debris retrieval scenario, the next objective is to make thorough preparations for the application of the scenario to the actual plants. The comparative evaluation is to be conducted for the items of Safe, Proven, Efficient, Timely and Field-oriented to select priority scenario based on the Five Guiding Principles if some of them are feasible.

Strategic plan for waste management

- Approaches to the study on the strategic plan for waste management

  Toward the decommissioning of the Fukushima Daiichi NPS, the necessary measures for risk reduction and optimization of overall facility have to be carried out promptly and effectively. Safe and steady storage of solid radioactive waste generated by the accident is required for waste management, and it is important to study the processing method and disposal concept from the mid- to long-term perspective.

  In the current Roadmap, the basic concept of solid radioactive waste processing and disposal is to be established in FY2017 and prospect for safety for the processing and disposal are to be confirmed in FY2021 as holding points (hereinafter referred to as “HP”) for the next step. The studies described in the Strategic plan are carried out aiming at the HP set in the Roadmap as a target.
- Reduction and storage of generated waste

  The amount of the solid radioactive waste generated is to be reduced by controlling carry-in materials and promoting reuse within the site. It must be noted that the volume reduction and disposal of the waste have a certain level of impact such as generation of secondary radioactive waste. For the storage and management, the limited space of the site must be effectively utilized in a well-planned manner based on the estimated amount of waste to be generated from the constructions and other operations.
- Characterization and formulation of processing and disposal measures

  For the waste from which samples has not been taken such as the sludge accumulated in the basement of the reactor building (R/B), sampling works must be carried out in accordance with the plan. It will be especially important to establish a system for characteristics analysis and capacity enhancements.

  It is crucially important to formulate safe and optimal processing and disposal method from comprehensive perspective taking into account of the properties of the solid radioactive waste, suitable disposal method, and treatment method with the disposal method in mind.

  In addition, it will be necessary to actively provide the regulatory authorities with required information so that the regulatory system is organized smoothly.

Approach to R&D and its overall plan

The R&Ds conducted by a number of organizations should be managed integrally and overall optimization should be performed based on the features of each organization and expected results.

- R&D to support the site needs

  R&Ds based on the specific needs toward the fuel debris retrieval and waste management are to be conducted mainly by International Research Institute for Nuclear Decommissioning (IRID) and are reviewed continuously in accordance with the changes in the plant conditions and schedule and achievements of the research institutions, universities, etc.

- Importance of the R&D foundations

  Research and developments which will serve as the foundation for decommissioning technologies by the research institutions such as Japan Atomic Energy Agency (JAEA) and universities are encouraged to carry forward. The results of their researches, and knowledge and experiences are to be applied to decommissioning site and further R&D aiming for actual applications at the site.

  In order to promote R&D by gathering resources, knowledge and experiences from Japan and abroad, active cooperation is to be provided for the development of R&D centers such as the mock-up testing facility, analysis and research facility for radioactive materials, Collaborative Laboratories for Advanced Decommissioning Science. Also development and securing of manpower that will take the role in the mid-and long-term decommissioning is to be addressed in cooperation with the government, nuclear industries and the academic organizations.

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1. Introduction

In response to the accidents occurred at Tokyo Electric Power Company (hereinafter referred to as "TEPCO")'s Fukushima Daiichi Nuclear Power Station (hereinafter referred to as "Fukushima Daiichi NPS"), decommissioning work has begun based on the "Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1-4" (hereinafter referred to as "the Roadmap") developed by the Japanese government in December 2011. For three years since the establishment of the Roadmap, measures have been taken for the most urgent issues such as the contaminated water management. However, for the damaged reactors of the Fukushima Daiichi NPS, development of a mid- and long-term decommissioning strategy is essential "to reduce the risks posed by radioactive materials and to carry out decommissioning over a long period of time." For this reason, Nuclear Damage Compensation and Decommissioning Facilitation Corporation (hereinafter referred to as "NDF") was established on August 18, 2014 by reorganizing the former Nuclear Damage Compensation Facilitation Corporation, as an organization responsible for technical studies to deliver decommissioning properly and steadily from mid- and long-term perspective.

NDF launched the "Technical Strategic Plan for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company (hereinafter referred to as "the Strategic Plan")" as part of its statutory obligations "to provide advice, guidance and recommendations for ensuring an appropriate and steady conduct of decommissioning of the Fukushima Daiichi NPS" and of "R&D for technologies required for decommissioning" based on the Nuclear Damage Compensation Facilitation Corporation Act.

In order to gather knowledge and experiences from in Japan and abroad for the formulation of the Strategic Plan, the Decommissioning Strategy Board was established for decision-making by a group of experts from various technical areas as well as the Expert Committee for hearing the opinions from experts and representatives of related institutions on specific subjects. Overseas experts, appointed as the International Special Advisors, are invited to the Decommissioning Strategy Board, reinforcing the international cooperation with relevant organizations and research institutions.

Figure 1-1 shows the roles of the organizations involved in the decommissioning project of the Fukushima Daiichi NPS and role of NDF.

NDF examines the key issues presented by the Japanese government and reports back the results to the Government. For TEPCO, NDF provides technical advice and guidance in order to realize steady progress of decommissioning. It is also expected to play a central role in technical areas, such as to establish a close alliance with R&D institutions such as International Research Institute for Nuclear Decommissioning (hereinafter referred to as "IRID") and Japan Atomic Energy Agency (hereinafter referred to as "JAEA") and share the progress and challenges for successful advancement of R&D projects.

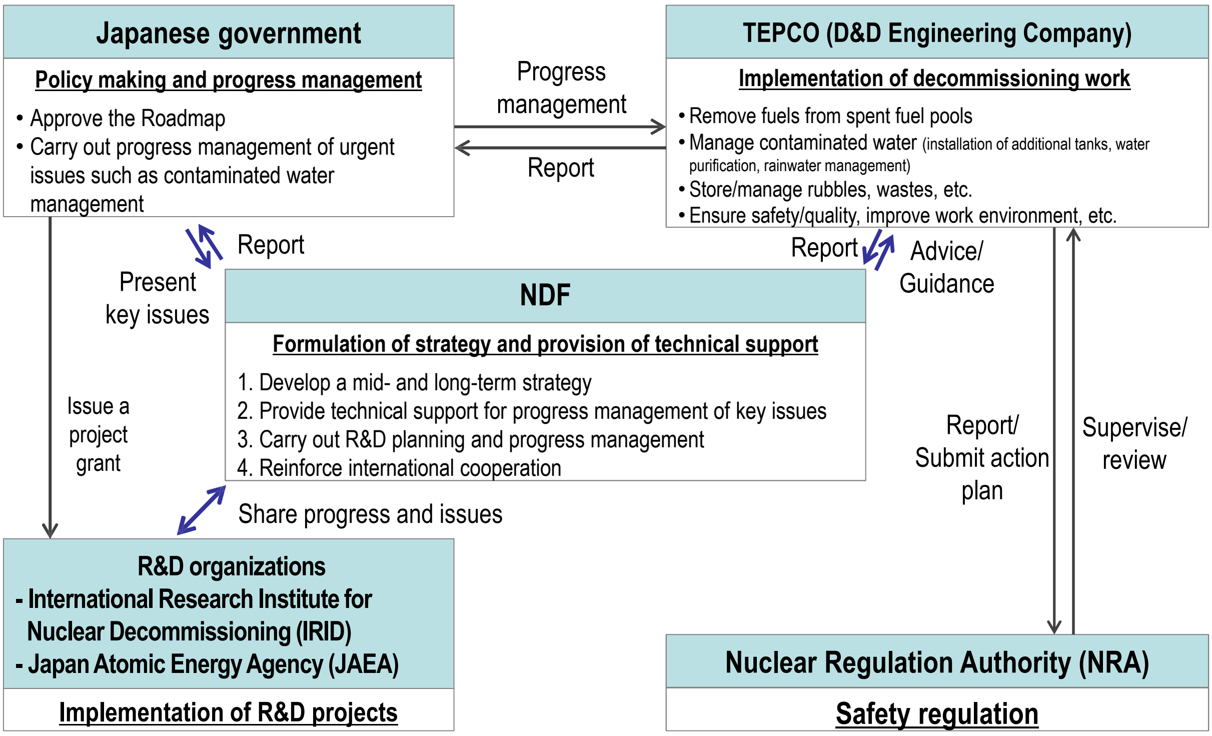

Figure 1-1 Roles of the organizations involved in the decommissioning project of the Fukushima Daiichi NPS

2. The Strategic Plan

2.1 The purpose of the Strategic Plan

The purpose of the Strategic Plan is to contribute to steady implementation and revision of the Japanese governments' Roadmap in order to facilitate appropriate and steady decommissioning of the Fukushima Daiichi NPS. That is, it was developed to provide a firm technical base to the Roadmap.

Specifically, the Strategic Plan identifies challenges and approaches associated with the retrieval of molten and solidified fuels (hereinafter referred to as "fuel debris") and waste management, which are the key issues from mid- and long- term perspectives for the decommissioning of the damaged reactors. It also provides an overall action plan including the division of the roles among relevant organizations. (Figure 2-1)

Important viewpoints, concepts (and logics) and key issues for the decision of fuel debris retrieval method are presented, introducing multiple possible scenarios (options) based on the actual site conditions. Based on the fact that the access into the R/B is limited due to high radioactivity and the internal conditions of the Primary Containment Vessel (hereinafter referred to as "PCV") and reactor vessels are not adequately understood, it is necessary to clarify how the decision on the retrieval method should be made under such uncertain circumstances. It will also be important to make adjustment to the selected method by incorporating the latest site conditions into studies.

For the waste management, basic approaches to processing and disposal are presented, followed by the assessment of the current status on the measures taken so far and discussion on the issues to be addressed in the future with regards to waste reduction, storage, and characterization and as well as waste processing and disposal methods. Furthermore, tasks including R&D and technical investigations which are required to be taken based on the above studies are explained as well.

The Strategic Plan was compiled as of the end of February of 2015 under circumstance still encompassing a lot of uncertainties at the site, bearing in mind the upcoming revision of the Roadmap in spring of 2015. Therefore, it has to be subject to the continuous assessment and review in accordance with future progress in understanding of the site conditions and achievements in R&D. It is stated in the Roadmap that the fuel debris retrieval method is to be determined in the first half of FY2018, and accordingly, the Strategic Plan assumes that the fuel debris retrieval method will be narrowed down from multiple scenarios before the timing specified in the Roadmap. It is also stated that the basic approaches to the processing and disposal of solid radioactive waste are to be determined in FY2017. The Strategic Plan will be revised in line with these schedules specified in the Roadmap.

Figure 2-1 "Strategy/Strategic Priority," "Strategic Specification," "Integrated Plan" and the Strategic Plan

2.2 The status and issues of the Strategic Plan

2.2.1 The development of the Roadmap

The decommissioning of the Fukushima Daiichi NPS has been conducted in accordance with the Roadmap, a document that encompasses the policies established by the Japanese government. The first document to illustrate the mid- and- long- term plan of the Fukushima Daiichi NPS was a report titled "Results of Deliberation to Formulate a Mid- and Long-Term Strategy for Cleaning Up the Fukushima Daiichi Nuclear Power Plant" (dated December 7, 2011) produced by Advisory Committee for Formulating Mid- and Long-term Strategies to Clean up the Fukushima Daiichi NPP of TEPCO (hereinafter referred to as "Advisory Committee") established in Japan Atomic Energy Commission. Subsequently, the first edition of the Roadmap was issued on December 21, 2011 and there have been two revisions since then. (Table 2-1)

The main features are as follows:

- The fuel debris retrieval method assumed in the Roadmap is the Submersion method which was used for the core of the Three Mile Island Unit 2 in the U.S. (hereinafter referred to as "TMI-2"), following the report by the Advisory Committee.
- A study on the Dry method was also referred, which is a method to retrieve the fuel debris without filling the PCV with water, but this method was treated only as a backup and there is no specific R&D plan considered.
- For waste management, a schedule for the study on the basic concept of solid radioactive waste processing and disposal was presented, but it was regarded as an issue for future challenge.

Table 2-1 History of the Roadmap

Results of Deliberation to Formulate a Mid- and Long-Term Strategy for Cleaning Up the Fukushima Daiichi Nuclear Power Plant December 7, 2011	Report issued by the Advisory Committee. The first document to study and explain the mid-and long-term plan of the Fukushima Daiichi NPS.
The Roadmap (the first edition) December 21, 2011	The Government and TEPCO's Mid-to-Long Term Countermeasure Meeting developed the first edition of the Roadmap on December 21, 2011 in response to achievement of the Step 2 objective*[1] of " the Roadmap towards Restoration from the Accident at Fukushima Daiichi Nuclear Power Station." This Roadmap was developed by TEPCO, Agency for Natural Resources and Energy, and the Nuclear and Industrial Safety Agency based on the report of the Advisory Committee. *1 The objective of Step 2 is "release of radioactive material has been controlled and the radiation dose has been significantly reduced."
The Roadmap (the first revised edition) July 30, 2012	The first revised edition of the Roadmap was issued on July 30, 2012. It reflects the progress of the actions taken and the detailed mid-and long-term plan on the priority issues for improvement of reliability (hereinafter referred to as "Reliability Improvement Program"). The Reliability Improvement Program was set out by TEPCO after completion of Step 2.
The Roadmap (the second revised edition) June 27, 2013	The Council for the Decommissioning of TEPCO's Fukushima Daiichi NPS was established in the Nuclear Emergency Response Headquarters on February 8, 2013. In order to accelerate the decommissioning project, it was decided that the progress of field work and R&D will be managed in an integrated manner by the Japanese government and TEPCO as well as with the participation of relevant organizations. This Council formulated the second revised edition of the Roadmap on June 27, 2013.

In terms of the decommissioning strategy of the Fukushima Daiichi NPS, the basis of the current Roadmap is the report of the Advisory Committee which was compiled when the plant conditions were not yet clearly understood. Therefore it did not reflect the recent progress in the field work, plant conditions that have become gradually clear, and the issues identified through R&D. Under such background, the need for formulation of the Strategic Plan incorporating the new issues and findings of plant conditions has become stronger and stronger.

2.2.2 Background of the Development of the Strategic Plan

The background to the development of the Strategic Plan is as follows.

(1) Changes of the situation

With the beginning of fuel assembly removal from the spent fuel pool (SFP) of Unit 4 in November 2013, the project has entered Phase 2 of the Roadmap (up to commencement of fuel debris retrieval which is aimed to be completed within 10 years form the completion of Step 2), and it is now necessary to examine more specifically the strategy for the fuel debris retrieval method.

Based on the proposals made in the report of the Advisory Committee, the current Roadmap assumes the Submersion method for fuel debris retrieval, which is the same method used at TMI-2.

The plant conditions of each unit became somewhat clear before reaching Phase 2, and there has been progress in R&D and the project in accordance with the Roadmap. As a result, technical difficulties and challenges are now better understood with regards to decontamination of the R/B, water leak blockage, PCV repair, and introduction of small circulation cooling loops.

One of the recent examples of new findings in the water leak was found in the sand cushion drain pipe in Unit 1 which has aroused concern for damage on the PCV shell. It is anticipated that the repairing of PCV may be difficult if the damage is too severe, and the Submersion method will not be possible in such case. Therefore it is now necessary to pursue the Dry method as a more realistic option for retrieval of fuel debris, not merely as a backup plan.

Furthermore, there has been a gradual change in the environment which is crucial to the project to progress. For instance, a decision on decommissioning of Units 5 and 6 has been made, and the understanding of the local communities has been changing through dialogues.

As described above, understanding on the conditions inside the reactor vessels has been progressed resulting in identification of further technical issues, field work and R&D have been progressed, data on the applicability of the developed equipment is obtained, investigations on the related technologies in Japan and abroad are ongoing, and there are changes in the social environments. Under these circumstances, there is a growing necessity to make the judgments based on the latest technologies by implementing the PDCA cycle.

That is, it is necessary to carry out strategic investigations and judgments with firm technical basis in accordance with the latest conditions in order to successfully retrieve fuel debris retrieval despite various technical challenges.

(2) Response to the uncertainty

Decommissioning of the Fukushima Daiichi NPS is different from decommissioning of a normal nuclear power plant and is an unprecedented project to date in Japan as well overseas. There are four plants that experienced core damages and/or hydrogen explosions, and they are under severe environment where the risks from the radioactive materials are already evident. (Even when compared to TMI-2 which experienced a similar accident in the light water reactor, the condition of the Fukushima Daiichi NPS is far severer in terms of the extent of core damages, number of units involved, the environments, etc.)

The assessments on the various risks from different perspectives are essential because the plant conditions are still largely unknown (especially the internal condition of PCV) and with so many uncertain factors. Moreover, since some of these risks are in a trade-off relationship, strategic judgments will be required to deal with these risks.

(3) Response to severe site conditions

The Fukushima Daiichi NPS remains to be under a severe environment even after four years since the accident, and there are a large number of work items to be carried out. Since there will be more operations anticipated under severer environment inside the R/B in the future, it will be increasingly important "to ensure the safety of the work place" and "to secure human resources for site operations over a long term." Especially for human resources, it is important to bear in mind not only the number of workers and technical leaders such as engineer, but also that there is a cumulative dose limitation of the managers/supervisors who understand the site conditions of the Fukushima Daiichi NPS. In addition, it is necessary to think about the limited space within the Fukushima Daiichi NPS available for the storage of solid radioactive waste and treated water as well as the working areas for site operations.

Thus, in order to make the most effective use of the limited resources based on the fact that there are restraints on technologies and resources (human, physical, financial, space, etc.), it is necessary to formulate a feasible Strategic Plan with clearly defined priorities.

(4) Awareness of time axis

Decommissioning and waste management of the Fukushima Daiichi NPS involve two kinds of approaches; short term approaches such as contaminated water treatment where major works are carried out over one to two years and long term approaches of several to about 40 years in span. The approaches must be taken with the course of the future in perspective, and a strategy that covers from short-term to the future approaches must be formulated.

It should be noted that these approaches are strongly interrelated on a time axis and could impact one another. That is, if the short-term approaches are not adequately addressed, it may affect the mid- and-long- term and future approaches and predetermination of the future may restrict the conditions or actual works to be implemented over mid- and- long- term. An optimized strategic plan must be formulated on a time axis because, for example, that treatment of retrieved fuel debris and radioactive waste generated from fuel debris retrieval must be considered in line with the studies on the fuel debris retrieval plan, since it affects the decommissioning scenarios.

(5) Sharing of the strategy

There have been a number of revisions on the Roadmap since the first edition was issued, but it focuses on resolving issues rather than risk assessments. The basic position of the current Roadmap "to remove high hazards as soon as practicable," "to carry out necessary technical development in a planned manner," and "to address urgent and important issues such as contaminated water management" is reasonable, but now that almost two years have passed since the issuance of the current version and more than a year since entering into Phase 2 of the Roadmap, it is considered to be the time to reformulate the decommissioning strategy from the perspective of 1) reflecting the latest plant conditions that have gradually become clear, 2) improving the concept of risk reduction more strategically in line with the time axis, and 3) providing feedbacks of the results of PDCA to the progress of the technical development.

For the reformulation of the decommissioning strategy in response to 1) to 3) above, it is extremely important to share the strategic concept of the overall decommissioning project and technical understanding among the Japanese government, NDF, TEPCO, relevant R&D organizations and contractors, etc. From now on, R&D for highly technical issues such as fuel debris retrieval, technical studies on the site constructions and site operations will be carried out in full scale. Therefore site conditions and R&D progress must be fully understood and a practical strategic plan with firm technical basis and flexibility to the changes must be specified so that the procedures and concepts for decision of the technologies are shared among the relevant parties and workers.

The situation in the UK demonstrates that it is inevitable to share the strategy and make common decisions between Nuclear Decommissioning Authority (hereinafter referred to as "NDA") and the Site License Companies (SLC) who carry out the operations for the decommissioning of the sites.

The relationship with the local communities and society and the impacts on funds are the factors that must be examined, but in terms of the views and scopes of the Strategic Plan, the technical studies will be focused in accordance with the roles of NDF to develop a strategy and provide technical support as described in Chapter 1. The Strategic Plan will not be limited to plans for the field work but cover an overall decommissioning plan including necessary R&D and technical studies into the site constructions as well.

The scope of studies includes the actions carried out in the Fukushima Daiichi NPS as well as the R&D centers being developed by JAEA near the Fukushima Daiichi NPS (mock-up test facility and radioactive material analysis and research center). The demonstration and training using Units 5 and 6 are also discussed as part of the study.

3. Basic Concept of the Strategic Plan

3.1 Fundamental policy

As the Specified Nuclear Facility, the Fukushima Daiichi NPS has been taking necessary safety measures as obligated by the Nuclear Regulation Authority and a certain level of stable condition has been maintained.

However, since the Fukushima Daiichi NPS is in the state different from the normal nuclear power plants in terms of degree of building damage, presence of fuel debris and spent fuels, contaminated water containing radioactive materials and various types of radioactive waste, the risks associated with radioactive materials may arise in the course of the future decommissioning work. Therefore it should be recognized that the decommissioning of the Fukushima Daiichi NPS has higher risks posed by radioactive materials than that of normal nuclear power plants.

If no actions are taken, the risks from the radioactive materials continue to exist. Even though the risks may gradually be reduced by radioactive decay, there may still be increase of risks resulting from degradation of the facilities over mid- and long-term. Therefore it cannot be necessarily stated that the risks simply decrease over time.

For this reason, the basic policy for decommissioning of the Fukushima Daiichi NPS is to continuously and promptly reduce the risks associated with the radioactive materials generated by the accidents. Therefore, the Strategic Plan can be called as “the design of risk reduction strategy” on a mid- and long- term basis.

Moreover, there are possible “operational risks” anticipated with the field works for the fuel debris retrieval or “project risks” which may jeopardize the success of the project itself and these risks should be fully taken into consideration as well.

The main “project risks” are

- Risk of failure in technical development
- Risk of incapability of securing human resources
- Risk of incapability of securing space
- Risk of substantial increase in cost
- Risk of rework due to uncertain regulations

Section 3.2 presents the Five Guiding Principles of the Strategic Plan taking into account of the operational and project risks. Section 3.3 explains the strategy for reducing risks from radioactive materials in the Fukushima Daiichi NPS, and based on Section 3.4 which describes the current action status, Section 3.5 gives the outlined policy for the development of the Strategic Plan.

3.2 Five Guiding Principles

This section presents the five principles of risk reduction in decommissioning of the Fukushima Daiichi NPS.

Principle 1: Safe- Reduction of risks posed by radioactive materials and work safety

Principle 2: Proven- Highly reliable and flexible technologies

Principle 3: Efficient- Effective utilization of resources (human, physical, financial, space, etc.)

Principle 4: Timely- Awareness of time axis

Principle 5: Field-oriented- Thorough application of Three Actuals (the actual place, the actual parts and the actual situation)

(1) Principle 1: Safe- Reduction of risks posed by radioactive materials[1] and work safety

Needless to say, safety is the first priority. The safety fundamental set out by regulatory authorities such as International Atomic Energy Agency (hereinafter referred to as "IAEA") obligating "protection of humans and environments against risks from radioactive materials" can be applied to the decommissioning of the Fukushima Daiichi NPS as well.

However the Fukushima Daiichi NPS is the Specified Nuclear Facility under "the Act on the Regulation of Nuclear Source Materials, Nuclear Fuel Materials and Reactors." The damaged reactors of the Fukushima Daiichi NPS do not meet the safety standards normally required for operating nuclear plants and the approaches to safety and decommissioning processes of the Fukushima Daiichi NPS are not necessarily consistent with those for normal operating plants. Thus, it is expected to facilitate decommissioning based on the idea that any necessary actions are permitted to be taken in light of the situations and site conditions.

Accordingly, recognizing the high level of risks posed by the damaged reactors, priority should be given to "immediate risk reduction to achieve a safe and stable condition." While it is important to meet the basic principles of the new regulatory requirements such as defense in depth, which were reviewed as a result of the lessons learned from the accidents at the Fukushima Daiichi NPS, it is also important to make effort to effectively secure safety and reduce risks with the awareness of total risk reduction in light of the time axis.

With regards to safety of the workers, it is necessary to pay sufficient attention to their work to prevent accidents and injuries since the site is not easily accessible and the work space is also limited. In addition, field work has to be done under the highly radioactive environment therefore management of work hours, setting up of radiation shielding, and use of protective equipment must be ensured in an effort to reduce their exposure.

(2) Principle 2: Proven - Highly reliable and flexible technologies

The decommissioning of the Fukushima Daiichi NPS is an unprecedented project involving tremendous technical difficulties and a large number of elements for R&D.

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[1] Environmental impacts and exposure to the workers

For measures to be carried out in a relatively short term, further developmental work should be minimized in order to make steady progress by minimizing the risks of failure in developments.

For that purpose, feasible technologies and knowledge with high Technology Readiness Level (TRL) available in Japan and abroad should be adopted and applied, by improving them so that they meet the site conditions at the Fukushima Daiichi NPS (e.g. by systematization). They also need to be verified and demonstrated in advance to confirm their performance under severe site conditions.

There is a high degree of uncertainty in the site conditions, and robust technologies should be selected to enable flexible application to unexpected situations or changes of situation. The works should also be carried out step by step and the course of actions should be adjusted as necessary. The alternative plans need to be in place in case that the selected technologies cannot be applied at the site.

On the other hand, development of entirely new technologies may become critical over the course of decommissioning work. For mid- and long-term developmental issues for such technologies, it will be necessary to formulate a R&D plan based the needs, objectives, roles of relevant organizations (university, public research institution, private organization, etc.) including basic and generic technology researches.

For example, target of operations under severe radiation environment may require a combination of (1) remote handling technologies, (2) robot technologies, (3) decontamination or shielding using newly developed technologies, (4) direct operation by humans and (5) related basic technology research. If the TRL of (1), (2), (3) and (5) are relatively low, a question related to technical strategy is how much development will be further required and how the operation should be conducted in combination with direct operation by humans (4).

Definitions and the purpose of use of the remote handling technologies and robot technologies are as follows:

- Remote handling technologies: self-standing and large fixed type remote manipulation used for operations
- Robot technologies: mobile and remotely controlled robots used for investigations

(3) Principle 3: Efficient- Effective utilization of resources (human, physical, financial, space, etc.)

Decommissioning of the Fukushima Daiichi NPS involves implementation of a large amount of complicated works and developments over a long period of time. Therefore, shortage in resources, such as human, physical, financial and space may become the restraints to the project. Reasonable and effective use of these resources will be a key factor in successful decommissioning.

As for human resources, it is necessary to plan and manage the total exposure of each of the construction workers during the period of construction in order to secure manpower over a long period of time for the works under highly radioactive environment. In addition, because the project requires various R&D and technical studies for site construction, impracticable and unnecessary work should be avoided and efficient operation must be pursued. Securing necessary human resources for successful decommissioning such as researchers, engineers and workers in conjunction with human resource development and technology succession are important.

As for physical resources, any facility and equipment brought into the Fukushima Daiichi NPS are highly likely to be treated as radioactive waste. A rational way should be developed in order to reduce the amount of waste by effective utilization (reduce, reuse and recycle), and not to carry in unnecessary goods but fully use them once they are carry in with keeping “3R rule” in mind.

As for financial resources, all activities must always be carried out considering the cost effectiveness of the works and the effect of investment against technical development and facilities including effective use of manpower, since a large amount of work and developments are required over a long period of time to successfully implement the project.

The space of the Fukushima Daiichi NPS has a relatively large compared to the other domestic nuclear power stations, but a vast area of the land is already occupied by the contaminated water tanks and waste storage facilities. Considering that such facilities may further increase in the future and constrain the working areas, the available space must be used in an effective way along with the preparation and securing of the transport route.

For efficient uses of the resources (human, physical, financial and space), it is important to optimize individual work and each development activity, but to avoid partial optimization, it is also important to determine the order of priority to achieve overall optimum results in the long run taking into account the consequences on the future procedures.

(4) Principle 4: Timely - Awareness of time axis

To take unnecessarily long time for decommissioning of the Fukushima Daiichi NPS means continuation of high-risk situation associated with radioactive materials. Therefore, it is important to be aware of “timeliness” in prompt risk reduction. “Timeliness” and certainty are in a trade-off relationship, but putting off the judgment and leaving the high-risk situation unattended is not a reasonable way to deal with the risks. Works need to be carefully carried out in parallel with the studies, and optimal judgments must be made at necessary timing.

In order to be aware of “timeliness,” it is important to set a certain target time for each of the “actions to be taken promptly,” “actions that require steady implementation” and “actions to be carried out over a long time.” Moreover, the process of the fuel debris retrieval can be divided into three phases; “beginning phase,” “intermediate phase” and “completion phase,” and it is also necessary to set an intermediate target for each step of work in addition to targets for overall achievement of “beginning phase” and the “intermediate phase.” The “beginning phase” is a phase when the preparation for reliable method is complete and retrieval work starts, making this phase a significant point both technologically and socially. Even in the “intermediate phase,” it is extremely important to have actual sense of accomplishments and to demonstrate steady progress.

In addition, multilayered preventive measures against project risks are also important to avoid time loss and additional rework. In planning preventive measures, judgments on what risks should be addressed, to what degree preventive measures should be taken, and to what degree the measures should be multilayered will be important as well. Prior clarification on details and level of safety assessment is also required to avoid time loss and additional rework.

On the other hand, "timeliness" is not the focal point of long-term issues such as waste management and decommissioning. However, new regulatory systems and standards may need to be established for the treatment of the damaged nuclear power station and the generated waste which has never been handled in the past. This process may take a considerable time, therefore sufficient lead time should be taken into account when planning the long-term measures.

(5) Principle 5: Field-oriented- Emphasize the Three Actuals (the actual place, the actual parts and the actual situation)

Decommissioning of the Fukushima Daiichi NPS is the risk reduction activities associated with the radioactive materials at the site, therefore it is important to carry out the tasks in accordance with the "Three Actuals" concept thoroughly and in a field-oriented manner.

The Three Actuals means to understand the precise needs based on the actual site conditions, actual structures, systems and components, and what is actually happening at the site, and to choose technologies focusing on the applicability at the site. Special attention should be paid to risks posed by gaps in understanding between engineers and field workers who apply the developed technologies to the site, as well as between design/project management personnel and field workers.

The site applicability is to assess whether the technologies under feasibility study (hereinafter referred to as "FS") is actually applicable to the site conditions and the environment of the Fukushima Daiichi NPS. Assessment of site applicability should be made based on the following points:

- Environmental resistance (radiation, temperature and humidity, light intensity, etc.)
- Accessibility and transportability (narrow routes, obstacles such as rubbles, lifting device, dose rate, etc.)
- Work space (inside the buildings, yard, etc.)
- Infrastructure development (electricity, air, communication, water, etc.)
- Necessity of liquid and solid radioactive waste treatment
- Maintainability and capability to respond to troubles
- Onsite operability

Understanding of site conditions may also provide information to enhance the safety of existing light water reactors. It is originally not within the scope of the decommissioning of the Fukushima Daiichi NPS, but it is expected to keep that in mind throughout the project.

On the other hand, regardless of the Three Actuals or the safety enhancement for the light water reactors, there are great difficulties and exposure accompanied through the investigation of the site conditions under highly radioactive environment of the Fukushima Daiichi NPS. Spending time to execute a thorough investigation is a trade off with safety from the total risk reduction point of view, therefore it may be necessary to make a plan based on a certain level of assumptions. In such case, multilayered measures should be prepared to deal with unexpected situations.

For the decommissioning of the Fukushima Daiichi NPS, it is important to manage the project by comprehensive assessment of various risks taking into account of the balance of all risks that are in the trade-off relationship. Therefore, risk-informed decision making should be applied in assessment of the risks with participation of various relevant parties.

The decommissioning project depends heavily on safety regulation. The regulatory authorities also consider the use of the safety risk information, therefore the risk-informed decision making should also be applied to meet the regulatory requirements. In addition, it is essential to have consultation with the regulatory authorities from the R&D stage concerning how to address safety issues.

It is also important to explain to the society that utmost effort is being made although various risks and restrictions exist, that is, so-called risk-informed communication is necessary.

The accident at the Fukushima Daiichi NPS was that the world has never seen in history in terms of a scale and seriousness. The technologies to be used in decommissioning of the Fukushima Daiichi NPS are far beyond the knowledge accumulated through construction, operation, maintenance and decommissioning of the light water reactors in Japan. On the other hand, there are many experiences of large-scale decommissioning of contaminated facilities and facilities that caused accidents overseas. Learning from of these similar experiences will be helpful for the acceleration of the decommissioning project and ensuring the safety at the Fukushima Daiichi NPS. Thus, it is very important to make use of their experiences of decommissioning of reactor facilities, reprocessing plants and fuel fabrication plants, and cleanup work for nuclear weapon manufacturing facilities. In order to do so, cultivation of relationships with the relevant overseas organizations who have these experiences needs to be actively established. Their experiences are valuable not just because of their technologies but also because of their experiences of taking dynamic actions and countermeasures at the decommissioning sites in response to unexpected and extraordinary situations. It is necessary to plan and take actions so that such overseas decommissioning technologies and project experiences can be acquired smoothly in the systems and mechanisms of Japan that supported the excellent technologies of light water reactors. That is, creating an optimal environment to facilitate the introduction of excellent experiences and technologies from overseas should also be encouraged.

It should also be noted that there is a strong international demand for taking the precautions for handling of fuel debris and spent fuel assemblies from the physical protection viewpoint.

While individual areas of work are studied in accordance with the Five Guiding Principles, it is extremely important to be always aware of the interrelationship of all the areas of work and their position within the entire project from the total optimization viewpoint.

3.3 Strategy for reducing risks of radioactive materials

Since the containment function of the Fukushima Daiichi NPS was lost by the accident, it is necessary to identify the radioactive materials as the risk sources that require countermeasures. The order of priority of the risk reduction must be determined based on the risk analysis, and action policy to each risk source should be decided.

In the subsequent section, the terms and definitions and the basic concepts necessary for the formulation of risk reduction strategy are provided followed by the explanation of the risk reduction strategy based on the results of risk analysis.

It must be noted that the risk analysis explained below is for the purpose of trying to understand the whole image of the existing risks of the Fukushima Daiichi NPS, and more detailed analysis is planned in the future. Also the changes in risks over time and the operational risks are not taken into account therefore these will be subject to the further study as well.

3.3.1 Terms and definitions

The general terms on risks identified based on JIS Q 31000:2010 Risk Management Principles and Guidelines which is compliant with ISO 31000:2009 and terms used for the risk assessments are defined below.

(1) Level of risk

The “level of risk,” or the magnitude of the risk, is indicated by the combination of “consequence” and “likelihood” of certain “events” . With regards to the impacts of radioactive materials, an “event” may be the loss of containment function as a result of earthquakes, tsunami, malfunctions or erroneous operations. A “consequence” may be the impacts on humans and environment, and the “likelihood” may be how likely an “event” may occur. In this Strategic Plan, “hazard potential” and “likelihood of the loss of containment function” are used as the equivalent terms for the “consequence” and “likelihood” respectively.

(2) Impacts of radioactive materials

In case of loss of containment function, a risk source could result in the following external impacts:

- Direct impact of radiation
  - ➢ Impact on the environment
    - ✓ Public exposure (external exposure and internal exposure)
    - ✓ Environmental contamination and wide-area dispersion
- Exposure to the workers (external exposure and internal exposure)
- Social disorder (domestic and overseas experts, media, etc.)
- Reputational damages (local industries, etc.)
- The Strategic Plan mainly studies the direct impacts of radiation.

(3) Hazard potential

Normally “consequence” is assessed by the impacts on humans and environment by migration/dispersion of a certain amount of radioactive materials released to the environment as a result of an “event.” However, the amount of radioactive materials released into the environment when the event occurs is not evaluated in this Strategic Plan. Instead, “hazard potential” is used as an equivalent terminology to a “consequence,” and is defined as the total amount of radioactive materials on the safe side which is contained in the risk source taking into account the properties of radioactive material based on the likelihood of leakage or migration. The actual possibility for the entire amount of radioactive materials contained in the risk source to be released to the environment is thought to be extremely small.

The term used for the amount of radioactive materials is inventory (Bq). Effective dose (Sv) may also be used instead to indicate an impact to human bodies more directly.

Typical properties of radioactive materials are gases, liquids and solids, and depending on the property, likelihood of leakage or migration/dispersion differs in the event of loss of containment function, and the likelihood decreases in the order of gases, liquids and solids. Other properties include powders and sludge[1] and they are in an intermediate position in terms of the likelihood of leakage/dispersion.

It should be noted that the “hazard potential” does not take into consideration of the “likelihood” of “events.”

(4) Likelihood of loss of containment function

The “likelihood” refers to the “likelihood of loss of containment function” with the impact of an event on the integrity of a facility that contains the risk source discussed. It depends on the frequencies of initiating events (internal events and external events) and vulnerability of facility (e.g. buildings and equipment) containing the risk source to damages:

- Internal events: loss of power supply, internal fire, inundation, hydrogen explosion, malfunction, erroneous operation (human error), internal missile, sabotage, etc.
- External events: earthquake, tsunami, volcanic activity, tornado, external fire, typhoon, heavy rain, flooding, external missile, illegal intrusion, etc.

The “level of risk” depends on the “hazard potential” and “likelihood of loss of containment” as shown in Figure 3-1, and it is higher in the upper right side and lower in the lower left side. Risk reduction consists of the following two ways;

- Lowering of the “likelihood of loss of containment function,” for example by retrieving the fuel debris from PCV and reactor pressure vessels (hereinafter referred to as “RPV”) and storing them in a safe and sound conditions.

[1] Sludge refers to the semi-solid materials containing radioactive materials.

- Lowering of the “hazard potential” due to reduced inventory resulting from radioactive decay and changes of properties of the risk sources.

In the risk reduction strategy, the order of priority and approaches are determined based on the combination of the “level of risk” and “hazard potential.” More specifically, the risk level of the risk sources in the upper right hand corner of the below figure is to be reduced, then the lower right and upper left corners next and finally the lower left hand corner is to be lowered.

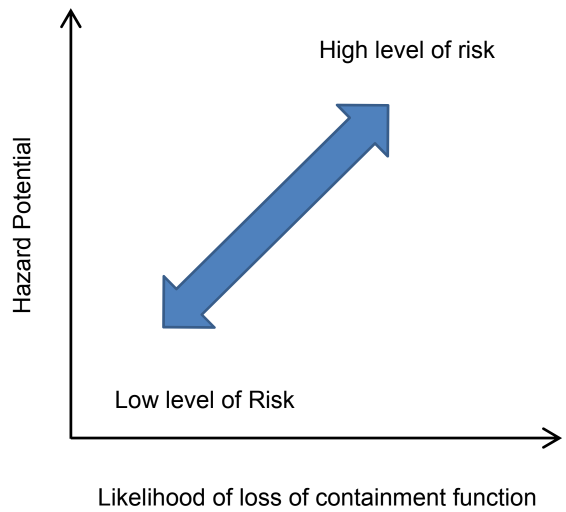


Figure 3-1 Level of risk

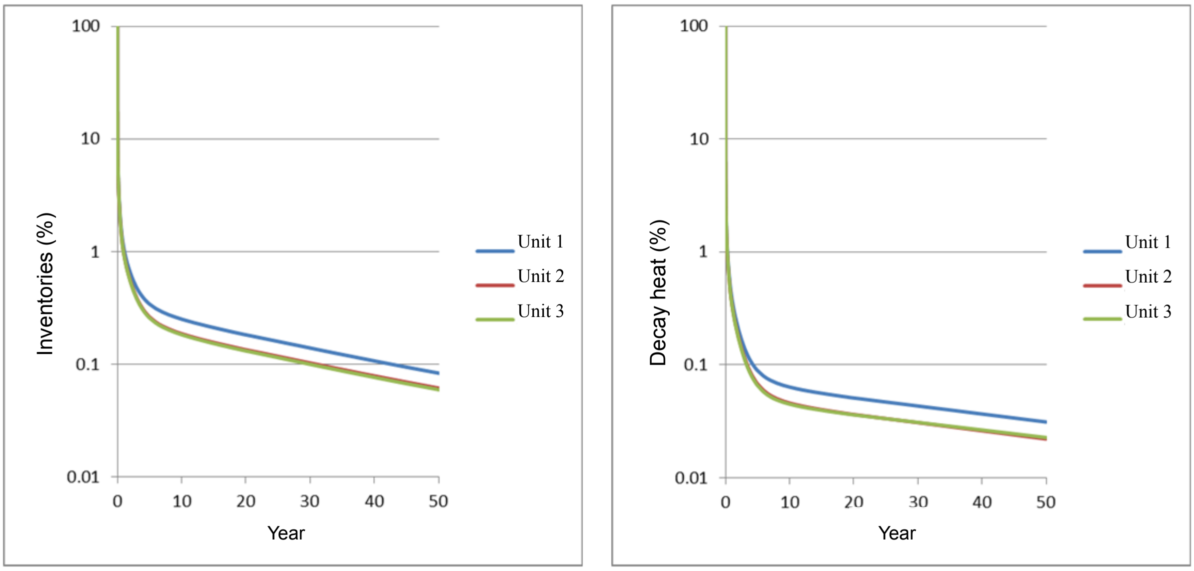
3.3.2 Procedure of risk analysis

There are no established methods of risk analysis and risk management for the damaged reactors and such methods are yet to be developed. However, the following procedures may be taken according to the definitions in section 3.3.1.

(1) Identification of risk source and evaluation of inventory

Actinide nuclides such as uranium and plutonium (herein after referred to as “heavy nuclides”), fission products (hereinafter referred to as “FPs”) such as cesium which are easily released into the environments, and activation products accumulated in the reactors over a long period of operation (Co-60, Fe-55, etc.) are typical radioactive materials for which the external impacts should be considered. It is important to identify the inventory, properties and locations of the risk source that contains these radioactive materials, and the risk source can be fuel debris, contaminated or activated reactor structural materials, spent fuel assemblies in the pools, contaminated water, other contaminated areas and equipment in the buildings, and various types of radioactive waste.

It should also be taken into consideration that four years have already passed since the accident and the radioactivity and decay heat have decreased over the years. The radioactive materials will further decay over the course of future decommissioning work. Core inventory and decay heat are shown in Figure 3-2 for each unit. All values are relative to the values at the time of the accident and the release of radioactive materials into the environment is not taken into account. As can be seen in Figure 3-2, the current inventories and decay heat have decreased to less than 1% and to approx. 0.1%, respectively.



Reference: JAEA-Data/Code 2012/018

Figure 3-2 Inventories (left) and decay heat (right) of the reactor cores

(2) Characterization of radioactive materials

The above-mentioned risk sources have different properties; solids such as fuel debris and pellets in fuel rods, liquid such as contaminated water, and gases such as noble gases in fuels. There are also other various properties of risk sources, such as sludge, complex radioactive compounds on the surfaces of equipment and buildings (surface deposits), materials having potential chemical reactivity, mixtures of chemical and radioactive materials (mixed waste), and environmental pollutants in the site (rocks which adsorbed clay particulates and radioactive materials). If the risk source is currently contained, the likelihood of its leakage depends on its property in the event of loss of containment function, and if the risk source is already released into the environment, the likelihood of migration or dispersion depends on its property.

(3) Evaluation of containment function

For the above-mentioned risk sources, the likelihood of loss of containment function are evaluated on the imperfect containment functions at present such as continuous leakage of radioactive materials from PCV, leakage of highly contaminated water accumulated in the R/B and damages of the facilities, assuming the external events (earthquakes and tsunami) and internal events (operational errors) as the initiating events.

3.3.3 Analysis of the risks of radioactive materials at the Fukushima Daiichi NPS

The major risk sources in the Fukushima Daiichi NPS are analyzed in accordance with the above procedure. Currently, the inventories of the fuels in reactors have decreased to below 1% compared to the amount immediately after the accident, and safety measures for the containment function obligated for the Specified Nuclear Facility have been implemented. The following section describes relative analysis if the risks still present under current condition where the level of risks has decreased considerably compared to aftermath of the accident.

(1) Identification of risk sources

Among major risk sources present at the Fukushima Daiichi NPS, the following are attributable to the fuels and contain radioactive materials of heavy nuclides and FPs:

- Fuel debris in the PCV;
- Fuel assemblies stored in the SFP of each unit;
- Fuel assemblies stored in the common pool;
- Fuel assemblies stored in the Dry casks.

The following contaminated water and waste containing radioactive FPs:

- Highly contaminated water accumulated in the R/B and seawater piping trenches (hereinafter referred to as “contaminated water in the buildings” and “contaminated water in the trenches,” respectively);
- Contaminated water stored in tanks to be decontaminated (“contaminated water in the tanks”);
- Secondary waste generated from cesium and second cesium adsorption system (“waste adsorption column of water treatment system”)
- Secondary waste in the sludge storage tanks of decontamination equipment (“waste sludge from water treatment system”)
- Rubbles and fallen trees and solid radioactive waste generated by operations (including waste generated during normal operation before the accident which mainly consists of corrosion products such as Co and Mn)
- Other waste such as contaminated soils and stagnant water

The following structures and buildings contain radioactive materials such as FPs and activation products:

- Equipment in RPV/PCV which contains activation products are contaminated with dispersed FPs (e.g. steam driers, steam separator, core shrouds, upper grid plates/core support plates, piping, valves, etc.)
- Equipment, piping and parts of buildings which are contaminated by dispersed FPs in the buildings.

Among the above, following are the major risk sources that need to be studied:

- Fuel-related: fuel debris and fuel assemblies in the pools
- Contaminated water-related: contaminated water in the buildings, trenches and tanks

- Waste-related: waste adsorption column of water treatment system and waste sludge from water treatment system and solid radioactive waste.

There were 1,535 fuel assemblies stored in the SFP of Unit 4 at the time of accident, but their transfer to the common pool is already complete therefore they are no longer regarded as the risk sources in the above analysis.

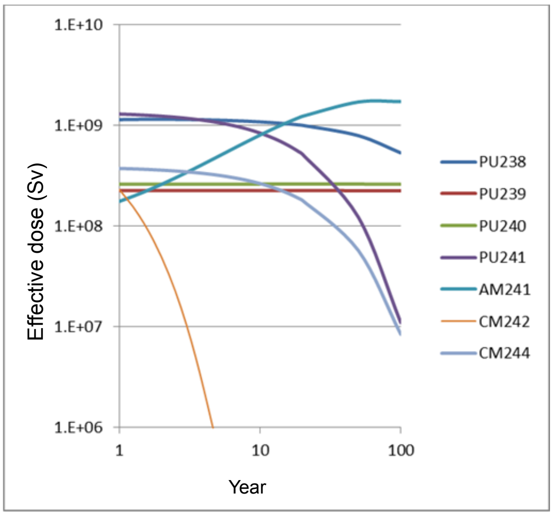
In addition, with regards to the fuel assemblies stored in the common pools and dry casks, the integrity of their facilities as well as the inventories of activation products of the structures and buildings are generally at the same level as those in the normal plants. Therefore even though there is a considerable amount of contamination by FPs, the measures for these fuel assemblies will be the extension of normal decommissioning work. They do however need to be studied at some point in the future.

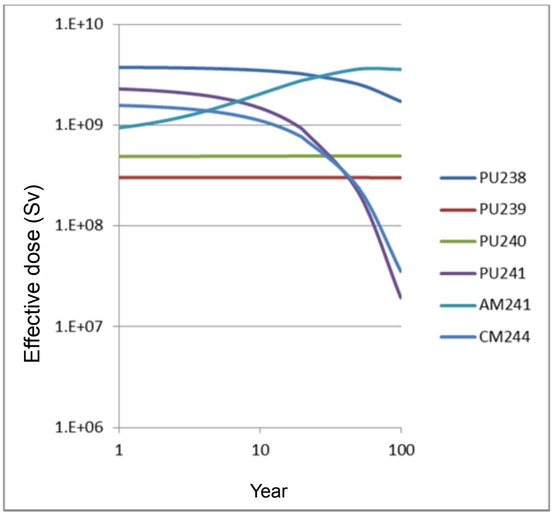
(2) Selection of isotopes for evaluation

Among the identified risk sources, some of the isotopes have a large impact on human bodies even if quantitative change over the time of study is taken into account. Such isotopes are selected for the evaluation of effective dose.

Figures 3-3 and 3-4 (reference of inventories: JAEA-Data/Code 2012-018) shows, as example, the effective doses of heavy nuclides and FPs of the reactor core and fuels in the pool of Unit 2 over a hundred year period since the accident including a few decades necessary to complete the decommissioning work. Here, the isotopes with more than 1% of contribution to the total amount of effective dose are selected. The selected isotopes and their features are provided in Table 3-1. The figures for internal exposure caused through ingestion are used for dose factors.

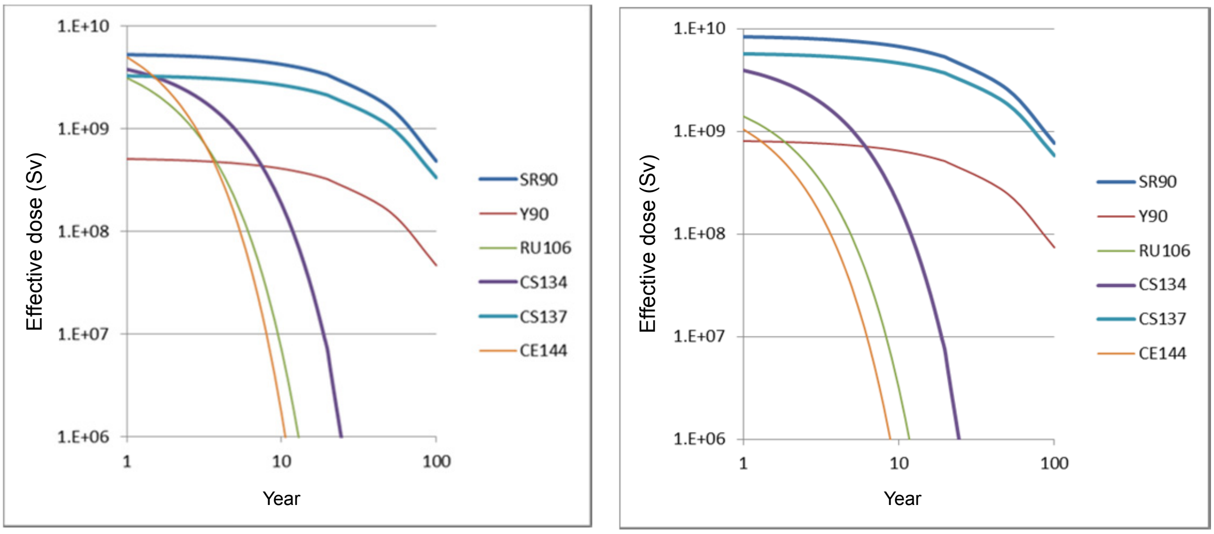
Pu-238, Pu-239, Pu-240, Pu-241, Am-241 and Cm-244 are selected for heavy nuclides and Sr-90, Cs-134 and Cs-137 are selected for FP evaluation focusing on their contributions from the accident to after a few years. This shall apply to both the reactor core and the fuels in the pools.





Reference: JAEA-Data/Code 2012-018

Figure 3-3 Effective doses of heavy nuclides (Left: Unit 2 reactor core, Right: Unit 2 fuels in the pool)



Reference: JAEA-Data/Code 2012-018

Figure 3-4 Effective doses of FPs (Left: Unit 2 reactor core, Right: Fuels in the pool)

Table 3-1 Radioisotopes with more than 1% contribution to the inventories and their features

Isotope	Half-life		Dose factor (Sv/Bq)		Features
			Ingestion	Inhalation	
Pu-238	87.7	years	2.3×10^{-7}	1.1×10^{-4}	–
Pu-239	2.41×10^{4}	years	2.5×10^{-7}	1.2×10^{-4}	–
Pu-240	6.54×10^{3}	years	2.5×10^{-7}	1.2×10^{-4}	–
Pu-241	14.4	years	4.8×10^{-9}	2.3×10^{-6}	–
Am-241	4.32×10^{2}	years	2.0×10^{-7}	9.6×10^{-5}	Produced by Pu-241 decay
Cm-242	163	days	1.2×10^{-8}	5.9×10^{-6}	–
Cm-244	18.1	years	1.2×10^{-7}	5.7×10^{-5}	–
Sr-90	29.1	years	2.8×10^{-8}	1.6×10^{-7}	Deposited in bones, significant impact to human bodies
Y-90	2.67	days	2.7×10^{-9}	1.5×10^{-9}	Produced by decay of Sr-90, radioactive equilibrium
Ru-106	1.01	years	7.0×10^{-9}	6.6×10^{-8}	–
Cs-134	2.06	years	1.9×10^{-8}	2.0×10^{-8}	Highly volatile, easily released to the environment
Cs-137	30.0	years	1.3×10^{-8}	3.9×10^{-8}	Highly volatile, easily released to the environment
Ce-144	284	days	5.2×10^{-9}	5.3×10^{-8}	–

Reference: ICRP Publication 72

(3) Assessment of the "hazard potential"

The inventories and effective doses of the radioactive materials are evaluated for each risk source, and the hazard potential is evaluated based on its property.

Table 3-2 shows the inventories, effective doses and properties of the risk sources. For the inventories of the contaminated water, secondary waste generated from the water treatment system, and solid radioactive waste, there is only a limited amount of samples and the figures vary depending on the samples, therefore the rough values are shown in the table. Cs-137 is an especially important isotope among FPs, but Sr-90 is also noteworthy for contaminated water even though the amount is insignificant in the secondary waste from the water treatment system and solid radioactive waste.

For the effective doses, the larger of the dose factors of internal exposure by ingestion and inhalation is used for evaluation of the maximum impacts[1]. The dose factor of heavy nuclide is greater for inhalation, so that the effective doses of the fuel debris and fuels in the pools is considerably higher than those of the other risk sources.

With regards to the properties of the risk sources, contaminated water is liquid, and fuel debris, fuel assemblies in fuel pools, waste adsorption columns of water treatment system and solid radioactive waste are solids. Waste sludge from the water treatment system is of a property between solid and liquid.

The hazard potential is evaluated in accordance with the effective doses for the solids so that the fuel debris and fuels in the pools are categorized as high and the waste adsorption columns of water treatment system are medium, and solid radioactive waste is low. For other risk sources, the hazard potential is evaluated based on the properties, therefore the contaminated water as a liquid is medium and the waste sludge is low.

Note that there is a noble gas of Kr-85 (half-life of 10.7 years) remaining in the fuels in the pools but this does not affect the above evaluation. The possibility of fuel debris reaching recriticality is not taken into account because it is considered that subcritical state can be stably maintained unless the water level or the property of fuel debris is changed which may happen during fuel debris retrieval work.

Table 3-2 Assessment of hazard potential

Risk source		Inventory*			Effective dose (Sv)	Property	Potential impact
		Timing	Heavy nuclides (Bq)	FP (Bq)			
Fuel Debris	Unit 1	Mar. 2015	2×10^{17}	4×10^{17}	5×10^{12} (Total of Unit 1-3)	Solid	High
	Unit 2	Mar. 2015	2×10^{17}	5×10^{17}			
	Unit 3	Mar. 2015	3×10^{17}	5×10^{17}			
Fuels in pools	Unit 1	Mar. 2015	2×10^{17}	3×10^{17}	1×10^{13} (Total of Unit 1-3)	Solid	High
	Unit 2	Mar. 2015	5×10^{17}	8×10^{17}			
	Unit 3	Mar. 2015	4×10^{17}	7×10^{17}			
Contaminated water in the trenches		Nov. 2014	—	up to 10^{15}	up to 10^{8}	Liquid	Medium
Contaminated water in the buildings		Nov. 2014	—	up to 10^{15}	up to 10^{8}	Liquid	Medium
Contaminated water in the tanks		Nov. 2014	—	up to 10^{16}	up to 10^{9}	Liquid	Medium
Waste adsorption columns of water treatment system		Sep. 2014	—	up to 10^{17}	up to 10^{10}	Solid	Medium
Waste sludge from water treatment system		Sep. 2014	—	up to 10^{15}	up to 10^{7}	Sludge	Low
Solid radioactive waste		Nov. 2014	—	up to 10^{15}	up to 10^{8}	Solid	Low

* Fuel debris and fuels in the pools: JAEA-Data/Code 2012-018
Waste adsorption columns and waste sludge from water treatment system: Technological development in IRID related to the decommissioning of the Fukushima Daiichi Nuclear Power Station (5) Technological development related to the processing and disposal of radioactive waste presented in AESJ 2014 Fall Meeting Overview Reports (September 10, 2014)
Others: Estimated based on the data on METI and TEPCO websites

1 *NDA Prioritisation – Calculation Of Safety and Environmental Detriment Scores*, EGPR02, Rev, 6, April 2011.

(4) Evaluation of the likelihood of loss of containment function”

In order to fully evaluate the “likelihood of loss of containment function,” studies on the frequency of the initiating event and the probability of damages to the facilities are necessary. A simplified comparison of the “likelihood of loss of containment function” of the risk sources based on the condition of the damages to the buildings and facilities and necessity for management was conducted and the result is shown in Table 3-3. There are three categories from I to III, and the waste adsorption columns of water treatment system and the solid radioactive waste are categorized as the least likely (I) since they are designed to store the waste and no additional management is required.

Table 3-3 Evaluation of the “likelihood of loss of containment function”

Risk source	Feature	Likelihood of loss of containment function
Fuel debris	No significant damages were confirmed on PCVs, and criticality control, cooling and prevention of hydrogen explosion are implemented in combination so that the loss of containment function is unlikely to occur. However taking into account of the uncertainties, the evaluation should be made with margin.	I to II
Fuels in the pools	The loss of containment function of SFP in Unit 1 is moderately likely due to the fallen rubbles and heavy objects, damaged ceiling of the building, and seawater injection.	II
Contaminated water in the trenches and the buildings	The containment of the contaminated water in the buildings and trenches is maintained by the balance of water level with the ground water, and the loss of containment function is relatively likely compared to the other risk sources.	III
Contaminated water in the tanks	There have been events of operational errors in the contaminated water tanks, and the flange type tanks are still used although they are being replaced by the welded type, and the loss of containment function is relatively likely compared to the other risk sources.	III
Waste adsorption columns of water treatment system	The waste adsorption columns are carbon steel containers filled with Cs absorbed zeolite. They are put into the shielding containers and placed in dikes or on storage racks. No management such as decay heat removal is required.	I
Waste sludge from water treatment system	Waste sludge is stored in agglomeration pits in the main process building, and leakage monitoring, decay heat removal and hydrogen discharging are carried out so that the likelihood of loss of containment function is relatively low.	I to II
Solid radioactive waste	The highly radioactive rubbles are collected in the containers and stored in the solid radioactive waste storage building. No special management is required.	I

(5) Risk analysis

Figure 3-5 shows the levels of risks for major risk sources in the Fukushima Daiichi NPS based on the “hazard potential” and “likelihood of loss of containment function.”

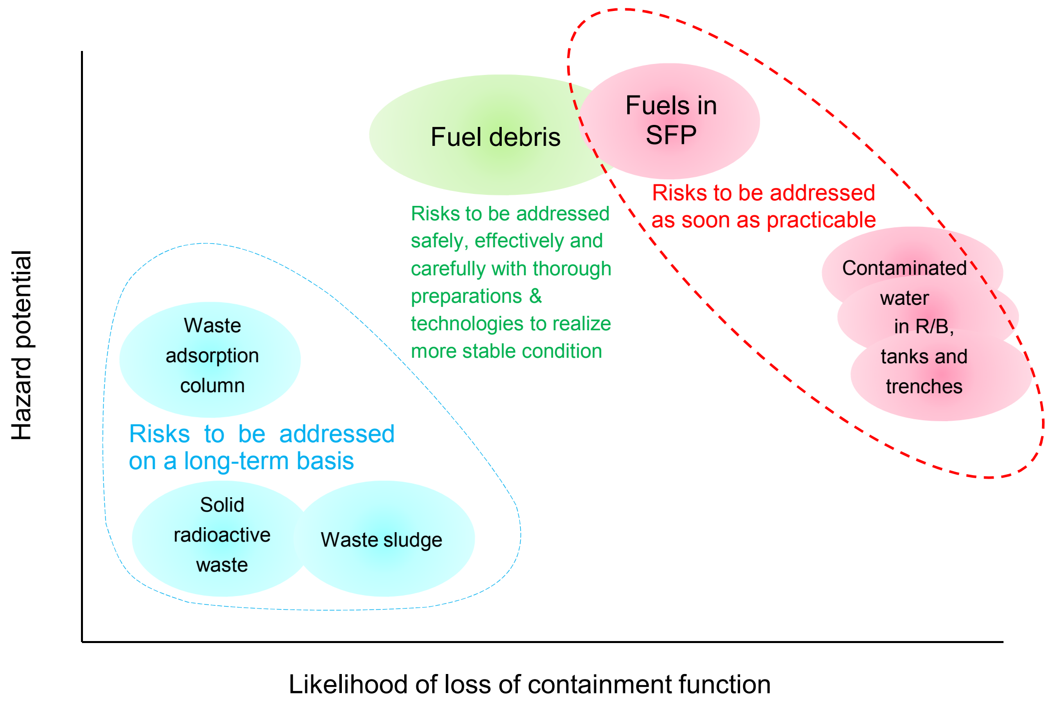


Figure 3-5 Image of risks of the Fukushima Daiichi NPS

3.3.4 Risk reduction strategy

The risk reduction strategy is formulated based on the analytical results. Firstly the order of priority is determined based on the levels of risks and the risk reduction policy is determined. Then the operational risks and risk communication with the local communities are explained as the issues to note when risk reduction strategy is actually implemented.

(1) Order of priority of risk reduction

In order to ensure the reduction of risks posed by radioactive materials, it is necessary to identify the risk sources, analyze those risks, and determine the order of priority of the measures for risk reduction. Major risk sources in the Fukushima Daiichi NPS can be divided into three levels based on the level of risks, and they should be addressed as explained below.

- Risks to be addressed as soon as practicable
  - ➢ Contaminated water in the trenches
  - ➢ Contaminated water in the buildings
  - ➢ Contaminated water in the tanks
  - ➢ Fuel assemblies in the pools
- Risks to be addressed safely, effectively and carefully with thorough preparations and technologies to realize more stable condition
  - ➢ Fuel debris

- Risks to be addressed on a long-term basis
  - Waste sludge from water treatment system
  - Waste adsorption columns of water treatment system
  - Solid radioactive waste

The risk reduction strategy in Figure 3-6 shows the order of priority of the above risk sources, and it illustrates that the risks are reduced in phases as the actions are taken.

In phase 1 of risk reduction, actions are taken against the risk sources with comparatively high level of risk which is indicated in the upper right hand corner in Figure 3-5. These actions will be challenging but there are no mid-and long-term R&D issues therefore risk reduction should be conducted as soon as practicable.

In phase 2, the target of risk reduction is the fuel debris which is currently in a certain level of stable condition but has considerable amount of inventories. Various issues are to be studied in parallel with the phase 1 and system has to be established by thorough preparations to take actions safely, effectively and carefully. It is important to reduce the risks associated with the retrieval work and to achieve a more stable condition of the fuel debris by carefully carrying out the investigations and samplings.

In phase 3, the risks are reduced not only for the stored waste but also for other waste generated from the actions taken in phases 1 and 2. These are also referred to as residual risks because they are risks that arise as a result of taking an action against a risk, and they require long-term strategy for waste management. It should be noted that the waste sludge from water treatment system has a property between solid and liquid and needs careful management in the future.

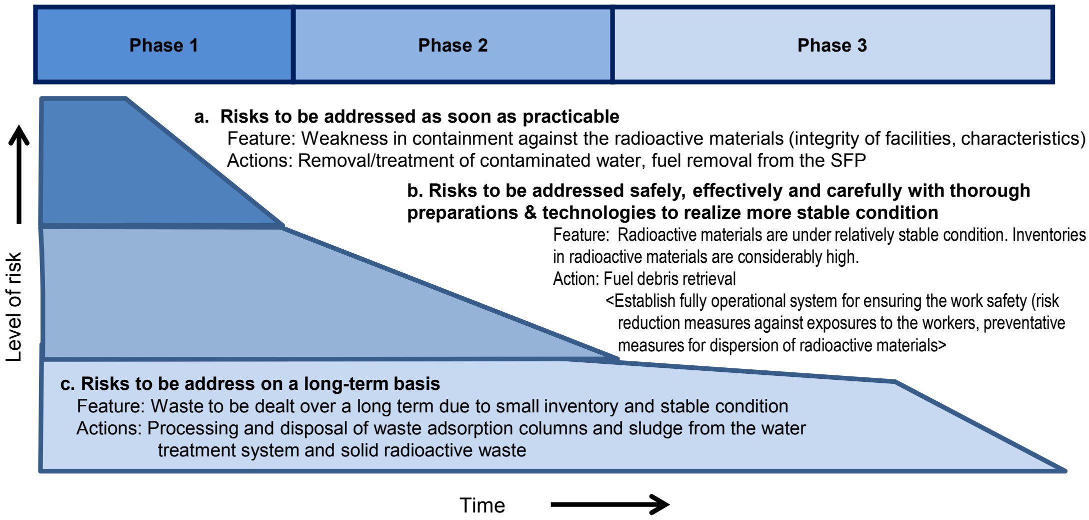


Figure 3-6 Risk reduction strategy

(2) Risks caused by the radioactive materials to be considered during operation

Among the works done during phases 1 and 2 of risk reduction, retrieval of fuel debris and fuel assemblies will require caution against risks to be caused by the radioactive materials. The major risks are summarized in Table 3-4, and dust dispersion during removal of the highly radioactive rubbles, which is to be carried out before fuel debris retrieval, is also included in the table as a risk related to retrieval work. The longer the removal work takes, the higher the possibility of the risks to become evident and the higher the project risks (such as failure in securing workers) may be.

Table 3-4 Major risks during operation

Risk source	Exposure to the workers	Dust dispersion	Damages due to fall	Recriticality	Dust dispersion during rubble removal	Required period
Fuels in the SFP	Low	None	Medium	Low	High	Up to a year
Fuel debris	High	High	Medium	Medium	Low	Up to ten years

(3) Sharing risk information with the local communities

Progress in decommissioning of the Fukushima Daiichi NPS is deeply connected with the return of the evacuees to their homes. Even minor troubles or environmental impacts may affect the residents of the surrounding areas seriously by reputational damages. Therefore, it is essential to make a clear explanation to the society about the prospect of decommissioning work and to ensure reduction of risks on the local residents and the environment. As an organization responsible for technical strategies, NDF is expected to explain the risk status at every milestone of the decommissioning process and to establish common understandings on the target level of risks through risk communication. It is expected that the target level meets the regulatory requirement and is in line with the international standards of safety objectives, and it is believed that it will certainly help the local residents obtain peace of mind.

The fuel debris containing large amounts of inventories is kept under a certain level of containment. If safe and reliable removal methods become available, risks can be reduced without causing serious troubles. However, if the retrieval work is performed too hastily without making thorough preparations, it will remain to be susceptible to unexpected problems until the completion of the retrieval work. Thus the risk reduction strategy involves trade-off between promptness and carefulness. With that in mind, risks should be divided into those to be addressed as soon as practicable and those to be addressed carefully and it is important to share this understanding with the local communities.

3.4 Current action status

The current status of actions taken for the evaluated risks is listed below. It shows the status of actions already taken for the contaminated water and the fuel assemblies in the pools and the current status and action policies for the fuel debris and waste in preparation stage which are being evaluated as risk sources at the present.

(1) Management of contaminated water

No environmental impact has been observed outside the harbor of the Fukushima Daiichi NPS. However, it is considered as a risk with high priority since if the groundwater continues to flow into the buildings and there is a concern of environmental impacts in case the contaminated water leaks from the storage tanks. In response to the preventative and multi-layered measures developed by the Committee on Countermeasures for Contaminated Water Treatment, TEPCO has been taking a series of measures based on the following three policies.

a. Removing the contamination source
   - i) Water purification using the nuclide removal system, reverse osmosis water treatment system, etc.
   - ii) Removal of highly contaminated water in trenches, etc.

b. Isolating the groundwater from the contamination source
   - iii) Pumping out of groundwater through groundwater bypassing system
   - iv) Pumping out of groundwater from wells (sub-drain) near buildings
   - v) Establishment of the land-side impermeable walls by freezing the soils
   - vi) Construction of waterproof pavement to prevent rainwater from permeating into the soils

c. Preventing contaminated water leakage
   - vii) Building higher, double-walled dikes around the tanks
   - viii) Improvement of the foundation by sodium silicate
   - ix) Establishment of the sea-side impermeable walls
   - x) Additional installation of tanks (replacement with welded type tanks)

Among the above, (b) iii), (c) vii) and viii) are already completed or currently being carried out, and purification and removal of contaminated water in (a) i) and ii) are underway, and the other measures are currently being prepared or arranged, therefore the risk reduction against the highly contaminated water is steadily in progress. Especially, as a result of treatment of contaminated water by the nuclide removal system, the amount of contaminated water in storage tanks as of March 2015 has decreased to less than half the amount at the time of the assessment of Table 3-2 conducted in November 2014. In addition, the secondary waste such as the precipitated materials and spent absorption agents generated by the water treatment is stored in the highly efficient containers and are managed in a condition of low risk level in terms of the properties and containment function.

On the other hand, the issues with comparatively low risks, such as drainage of rain water, are becoming relatively important and comprehensive review of the risks is currently being carried out.

(2) Removal of fuel assemblies from the pools

The removal of the fuel assemblies stored in the SFPs is underway according to the planned order of Units 4, 3, 1 and 2. The order of removal was determined by the order of priority of risk reduction based on the amount of inventories of radioactive materials, heat generation rate, and damages to the buildings due to hydrogen explosion and fallen rubbles of each unit.

a. Unit 4

Removal of the fuel assemblies from the pool was completed on December 22, 2014.

b. Unit 3

The removal of rubbles on top of the building is complete, currently preparing for fuel removal while removing the rubbles in the pool, decontaminating the operating floor, and installing additional shielding.

c. Unit 1

Risk reduction for dispersion of radioactive materials during the removal of the building cover is prioritized, and the condition of the scattered rubbles inside the building cover is being analyzed. The covers will be taken off and the rubbles will be removed in parallel with the preventative measures for scattering of the rubbles.

d. Unit 2

Since no hydrogen explosion occurred, the risk posed by the fuels in the SFPs is not largely different from normal nuclear power plants. In preparation for fuel removal in the future, a low risk plan is being formulated, considering the use of the roof of the R/B for fuel removal and possibly for fuel debris retrieval as well, and in the meantime the establishment of the yard is in progress.

(3) Fuel debris

The current heat generation of fuel debris in the PCV of Units 1−3 is approx.0.1MW, which is less than one-hundredth of the amount immediately after the accident, and it is kept at adequately low temperature by the multi-layered cooling systems. Also, since the fuel debris is once a molten fuel, there is no remaining gaseous FPs, and dust dispersion is sufficiently controlled by the PCV gas monitoring system. This system is constantly monitoring a noble gas (xenon) generated in case of criticality, and no recriticality has been confirmed so far. Since fuel debris is assumed to have been solidified by cooling and in a relatively stable condition, the risk for criticality is thought to be low.

However, to retrieve the fuel debris, PCV needs to be opened to reach the fuel debris that emits extremely high radiation. Sufficient time and caution must be taken for planning and preparations to minimize the risks to workers and the environment caused by radioactive materials.

(4) Waste

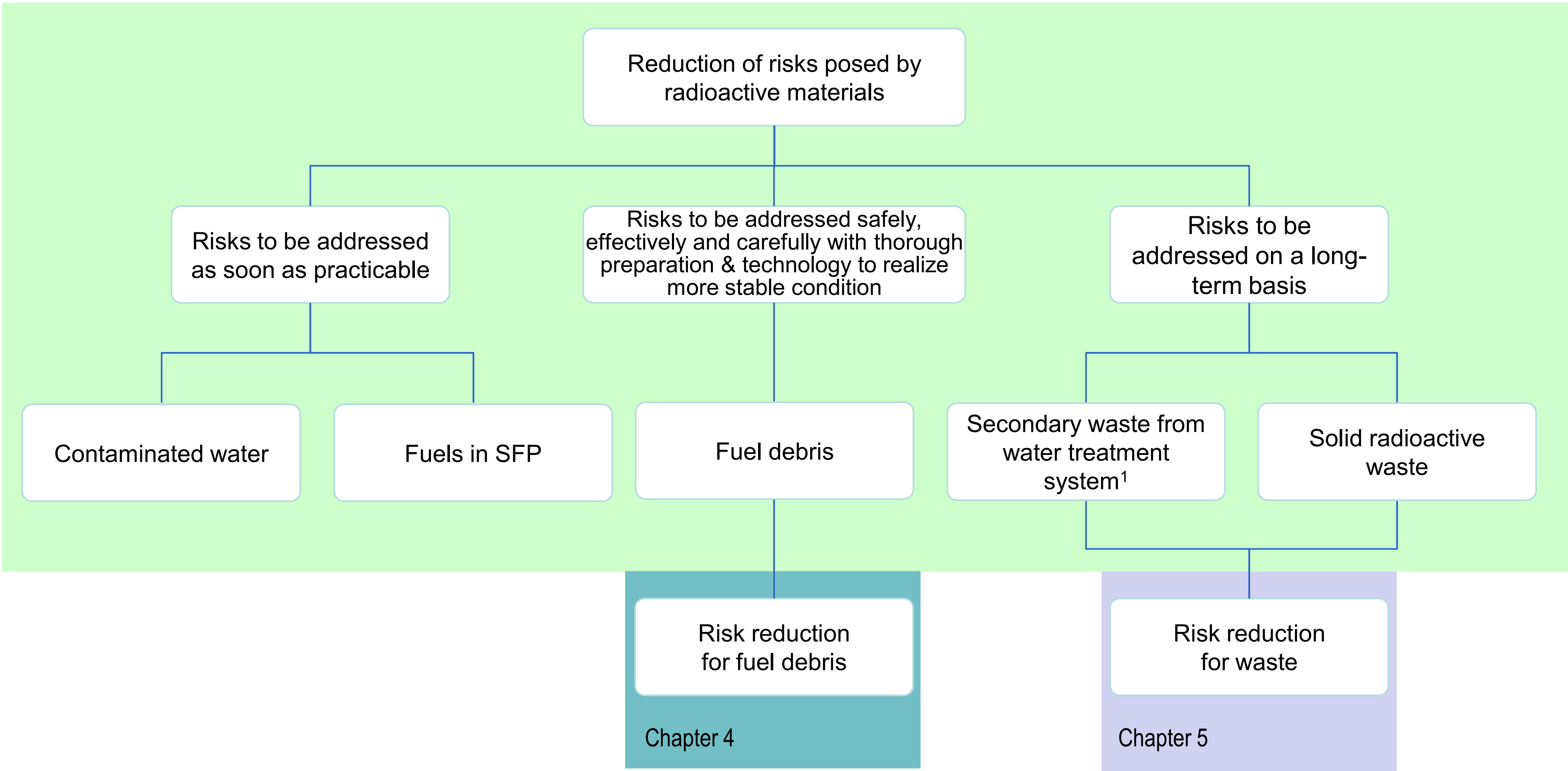
The generated waste is stored in the storages facilities or temporary storages, or kept in the segregated storages according to the property and dose rate and facilities for more appropriate storage or incinerators for waste reduction are being constructed. For waste sludge and waste adsorption columns of the water treatment system and the solid radioactive waste, it is necessary to identify their properties and characteristics and to develop a processing and disposal methods based on the study. From mid- and long-term perspective, safe storage will be required, and it must be done in a way that meet the disposal method.

3.5 Overview of approach to development of the Strategic Plan

The risks caused by the radioactive materials are analyzed and the risk reduction strategy was formulated for the risk sources of the Fukushima Daiichi NPS. The formulated strategy is summarized in Figure 3-7 which is a chart that illustrates the skeleton of the strategy (hereinafter referred as the "logic tree"). The major existing risk sources are categorized into three levels depending on the order of priority and measures are already being taken for those risks that require immediate actions, but there are various issues in the actual implementation and NDF provides technical support in such cases.

For safe and steady retrieval of fuel debris, thorough preparations will be required and there is a number of challenging issues that lies ahead. Chapter 4 goes into details of the strategic plan for fuel debris retrieval and the logic tree regarding the implementation of the retrieval work is shown in Figure 3-8. Chapter 4 assumes that the current target is the retrieval and safe storage of the fuel debris and the work is divided into three phases, the preparation period, retrieval, and storage after retrieval.

The details of secondary waste generated from the water treatment system and solid radioactive waste is dealt in Chapter 5 as a strategic plan on the waste from a long-term perspective. In the Strategic Plan, storage/management and processing/disposal methods are explored as immediate issues as shown in the logic tree in Figure 3.9.



1. Waste adsorption column and waste sludge from water treatment system

Figure 3-7 Logic tree for reduction of risks posed by radioactive materials

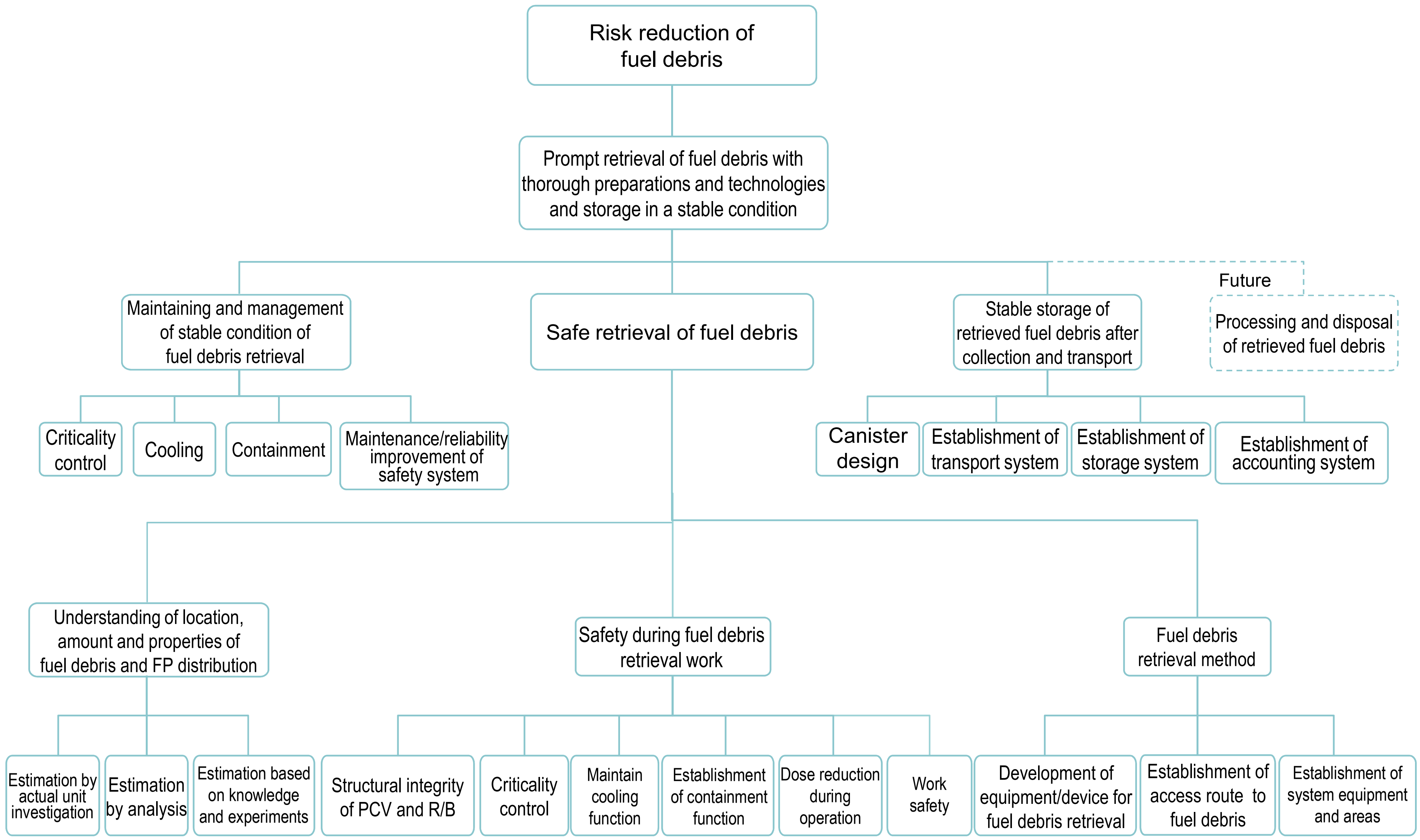


Figure 3-8 Logic tree on risk reduction for fuel debris

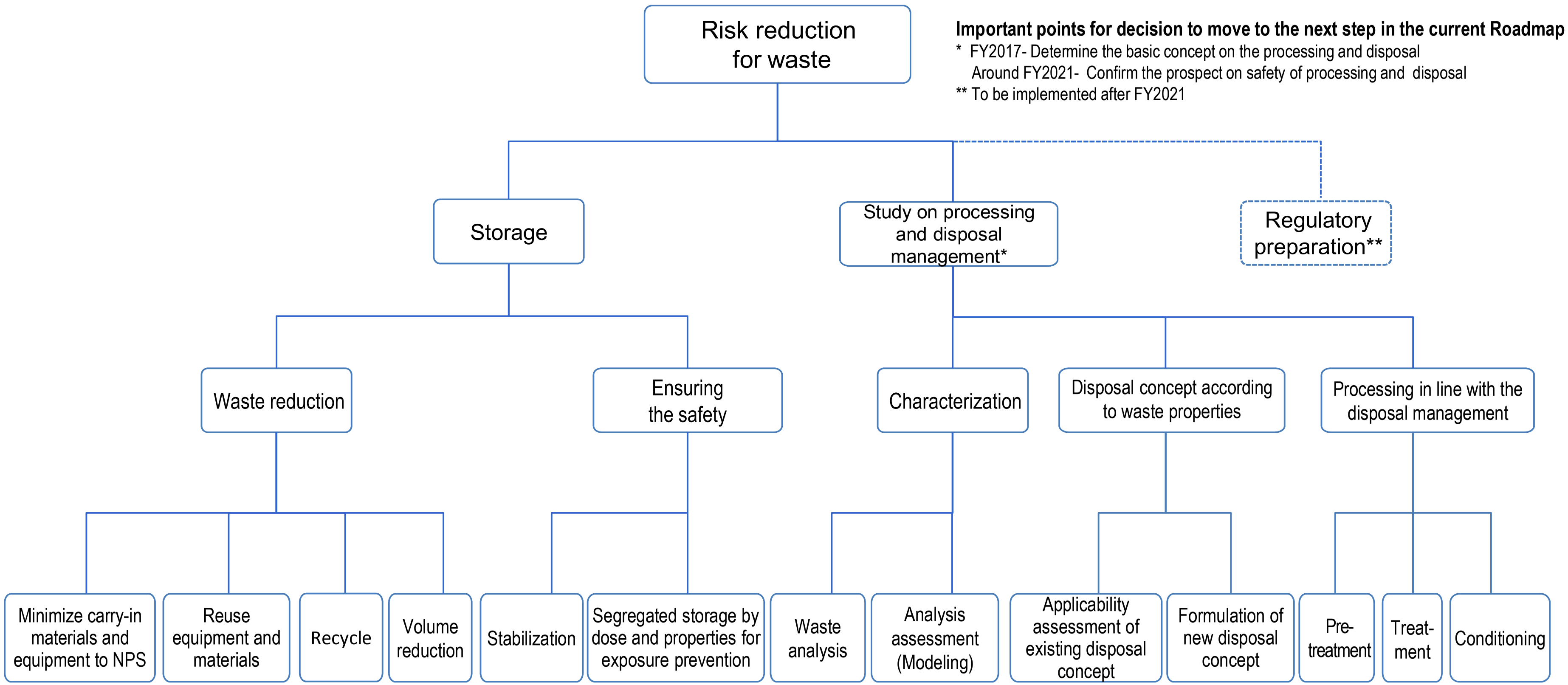


Figure 3-9 Logic tree on risk reduction for waste

4. Strategic plan for fuel debris retrieval

4.1 Study on the strategic plan for fuel debris retrieval

This section describes the policy of studying the strategic plan for the retrieval of the fuel debris, which should be addressed safely, steadily to be stabilized with proven technologies through careful preparation.

In specific, the approach to the study of fuel debris retrieval, application of Five Guiding Principles to the fuel debris retrieval method and application technology evaluation, and role sharing of fuel debris retrieval are described.

4.1.1 Approaches to the study on the fuel debris retrieval

Although the fuel debris is in a certain stable condition at present, it needs to be retrieved as soon as reasonably achievable with proven technologies through careful preparations and, store it in a stable condition in the site in order to reduce further risks. This should proceed with the following steps: (1) maintaining and management of the fuel debris in stable condition until it is retrieved; (2) safe retrieval of the fuel debris; and (3) storage of the retrieved fuel debris in a stable condition after being collected and transported. Especially among these steps, (2) safe fuel debris retrieval requires to be evaluated based on the following major issues of “identification of the location, amount, properties of fuel debris and FP distributions,” “ensuring the safety during the fuel debris retrieval work” and “the fuel debris retrieval method.” Since the studies cover a wide range of issues, the structure of requirements which is the backbone of the approaches is shown in Figure 4.1-1 in order to illustrate the entire image.

“Identification of the location, amount, properties of fuel debris and FP distributions,” which is important input information for studying the fuel debris retrieval method, is carried out by the estimation based on available information such as actual mechanical investigations, analyses, and past knowledge and experiments. The studies on “ensuring the safety during the fuel debris retrieval work” and “the fuel debris retrieval method” correspond to the technical requirements for the fuel debris retrieval method and consist of the following nine items:

- Securing the structural integrity of the PCV and the R/B
- Criticality control
- Maintaining the cooling function
- Establishment of the containment function
- Reduction of exposure to the workers during operation
- Development of the fuel debris retrieval equipment and devices
- Establishment of access routes to the fuel debris
- Establishment of the system equipment and working areas
- Ensuring the work safety

In the current Roadmap, it is currently aimed to start retrieval of fuel debris in the first unit by the Submersion method from the top of the PCV by the end of 2021. The technical developments of equipment and facilities for remote-controlled decontamination, investigation, and operation to realize the retrieval method as well as field work and investigation are conducted. Assuming that it will be difficult to fill the PCV with water to the top, an alternative method, such as Partial submersion method is going to be studied as well.

This strategic plan describes possible options for the fuel debris retrieval method. After the selection of the methods to be focused on, the current status and the future actions for the nine technical requirements for the Submersion and Partial submersion methods are discussed. In addition, this plan proposes several scenarios with combinations of different methods and the plan for selecting the scenario in accordance with the conditions of each unit.

The scenario applicable for each unit is to be selected in a phased manner by determining the feasibility of each method based on progress of technical development and studies which will be the key to the realization of the retrieval method, and in accordance with the improvements in accuracy of the estimation on the plant conditions, such as location and distribution of the fuel debris in each unit obtained by the investigation into the internal conditions of the PCV (PCV internal investigation).

The scenario for the fuel debris retrieval method should be studied so as to be determined in the first half of FY2018 as it is established as a decision point in the Roadmap.

The whole image towards fuel debris retrieval is shown in Figure 4.1-2. At present, a conceptual study is being carried out, and FS and element tests are being carried out partially. After the selection of the scenario of the retrieval method, a basic and detailed design for the first unit, and its application and verification test of the equipment and facilities will be implemented towards the application to the actual unit.

However, in reality, information regarding the following items are not obtained sufficiently and there are difficulties in setting up the conditions; (1) objectives (fuel debris, etc.), (2) method (application technologies), (3) requirements (regulatory requirements, necessary conditions, etc.) and (4) target (image of final target).

Therefore, the conditions of the objectives are to be estimated based on the maximum likelihood method by combining the simulations and theoretical predictions obtained from confirmed site information or the information on the subject and then, the technical specifications need to be set provisionally considering the margin of estimation. It is necessary to update the provisional specifications as required based on further information obtained as well as to revise the technical specifications of the methods and the application technologies.

For provisional specifications, it is important to foresee and reflect the requirements in those specifications in order to conform to safety regulations and other site conditions in addition to the viewpoint of ensuring engineering probability. The regulatory requirements are to be assumed when the regulatory authority's judgment is not yet determined. Therefore, more practical requirements need to be assumed through the communication with the regulatory authorities.

Several options are proposed based on the engineering judgment, and a relative option comparison is carried out for conceptual methods or application technologies, in accordance with the provisional specifications. Evaluation is carried out for each provisional option based on the viewpoint of Five Guiding Principles as shown in Section 4.1.2, and comparative evaluation is carried out based on “strengths, weaknesses and other characteristics” as “basic characteristics” of each option.

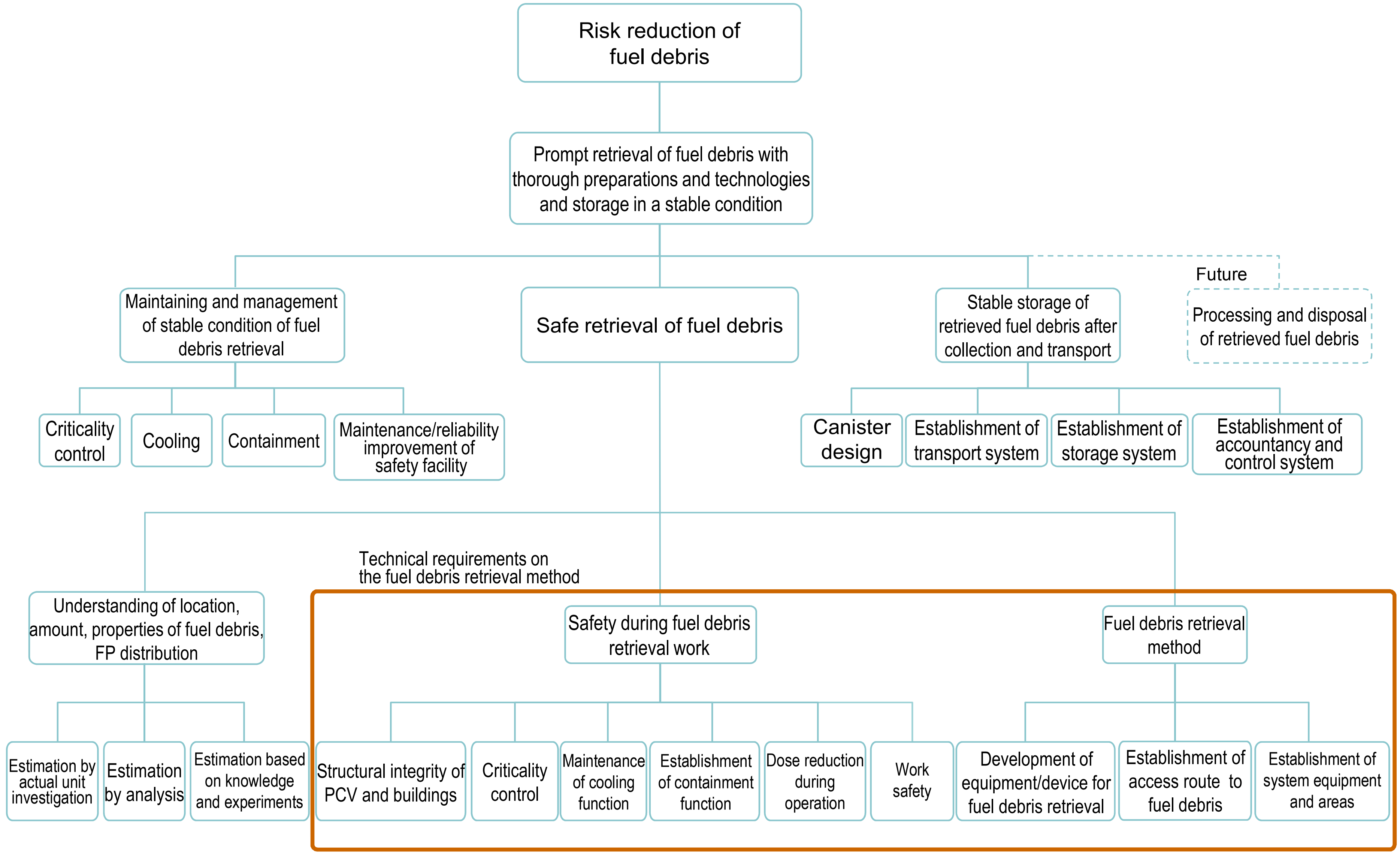


Figure 4.1-1 Logic tree on risk reduction for fuel debris

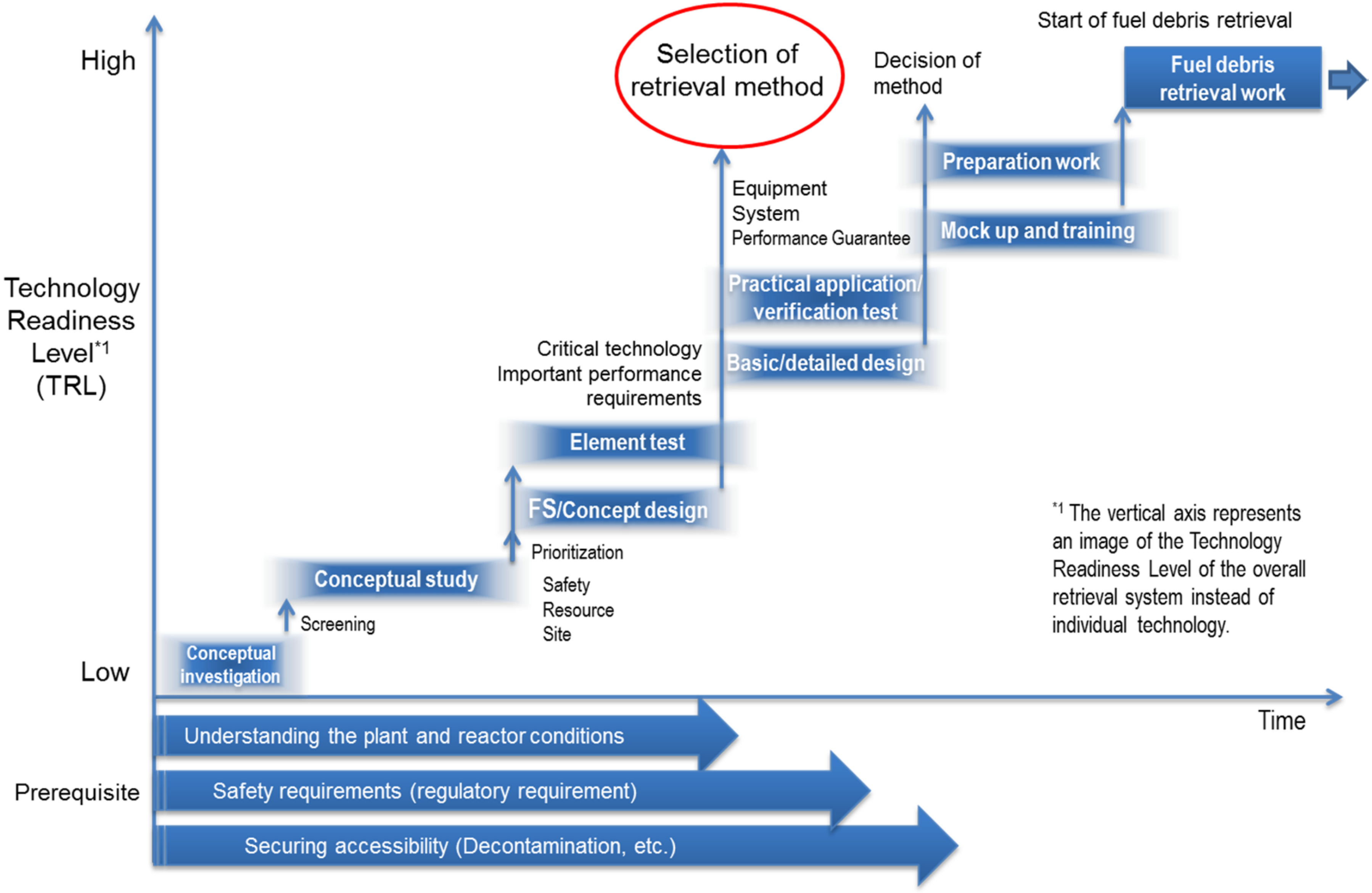


Figure 4.1-2 Processes toward fuel debris retrieval

4.1.2 Five Guiding Principles in evaluation of methods and application technologies of fuel debris retrieval

When the methods and application technologies of fuel debris retrieval are evaluated and judged, the following issues should be noted and addressed based on the Five Guiding Principles.

“Safe” should be evaluated as the highest priority. A target level foreseen from the viewpoint of safety regulations or independent safety ensuring should be set up for the safety, and it is first required to carry out a conceptual design to satisfy the target conservatively. Realistic constraints for the resources (human, physical, financial, space, etc.) required for realization of this conceptual design are sought from two viewpoints (that is, “efficient” and “field-oriented”), and only the concepts judged feasible by the coordination with the field work are considered to be a “priority option.” The options of which feasibility is judged to be “poor” from the two viewpoints of “efficient” and “field-oriented” should be ranked as a low grade and excluded from the objectives to be preferentially tackled. However, since it is possible that a technical innovation and an epoch-making improvement of site conditions may occur in the future, it is meaningful to continue the FS for the concept within a necessary range. Since the notion of “timely” should basically be used for priority setting in the options where the conditions of “safe,” “efficient” and “field-oriented” are satisfied, it is not desirable that safety, efficiency and site conditions are disregarded as a result of “timely” being preferred.

The notion of “proven” requires caution. The feasibility of the option strongly depends on a success of technical development because it is an unprecedented effort. On the other hand, attention should be paid to the occurrence of a rework risk that if a critical technical development fails, all the investment and time required for the development will be in vain. Especially, for a development for which a great deal of investment and time are needed from the beginning, it is appropriate to carry out the development while thoroughly confirming the validity of the development by setting many PDCA steps to frequently evaluate the progress in achievements of development and feasibility. Basically, it is desirable to adopt the technologies with high technical maturity and high applicability. Therefore, the maturity of application technologies should be thoroughly evaluated by comparing and checking various conditions to overcome, which are needed for putting assumed methods into practice. Moreover, it is very important to carry out a mock-up test to improve its realization in the field. A scale is to be specified appropriately covering “from small scale to the actual scale,” and for the technical issues to be determined, efforts must be put into the identification of unknown problems in conditions as similar to the actual plant as possible. In this case, when setting the scale of a mock-up test, careful considerations will be required including the validity of investment in a mock-up test.

Examination of the methods and application technologies of fuel debris retrieval is advanced using the evaluation indicators shown in Table 4.1-1, from the viewpoint of the Five Guiding Principles.

Table 4.1-1 Items of assessment based on Five Guiding Principles

Five Guiding Principles		Items of assessment
Safe	Reduction of risks posed by radioactive materials and ensuring the work safety	Contain (impact to the environment)
		Exposure to the workers (working hours and environment)
		Ensuring the work safety
		Effect of risk reduction
Proven	Highly reliable and flexible technology	Level of difficulty of technical development and TRL
		Conformity to requirements
		Flexibility and robustness* to uncertainties
		Alternative plans
Efficient	Effective utilization of resources (human, physical, financial, space, etc.)	Securing human resources (researchers, engineers, workers)
		Reduction of generated waste
		Costs (technical development, design, field work)
		Securing working and storage areas
		Impact on the subsequent processes of decommissioning
Timely	Awareness of time axis	Early commencement of fuel debris retrieval
		Time required for fuel debris retrieval
Field-oriented	Emphasize the Three Actuals (actual field, actual things and actual situation)	Workability (environment, accessibility, and operability)
		Conservatism (maintenance, actions against troubles)
		Applicability to each unit

* The capability to maintain the robust function even when the condition is changed to a certain extent from what is expected

For "safe," it is not appropriate to apply the same safety standard as that for a normal NPS to decommissioning of the Fukushima Daiichi NPS, which is a Specified Nuclear Facility. Nuclear Regulation Authority proposed to the Fukushima Daiichi NPS "issues for which a Specified Nuclear Facility operator shall take measures," based on "Law on the Regulation of Nuclear Source Material, Nuclear Fuels Material and Reactors." In response to that, TEPCO has developed "Implementation Plan for the Specified Nuclear Facility" and is promoting risk reduction work for the damaged NPS while ensuring the safety.

The concept on ensuring the safety that should be taken into consideration for fuel debris retrieval work is described as follows:

- It is required to continuously manage so that the functions to "shut down," "cool" and "contain" a reactor, which are the bases of nuclear safety, are stable, by monitoring the plant parameters after the accident.
- For fuel debris retrieval work, although a quick and efficient retrieval work is aimed in order to reduce the risk of the entire facility, standing on the viewpoint of "protecting people and environment from the impact of radiation," the measure for ensuring the safety should be set as an essential problem in the efforts from the early stages such as prior examination and preparation.

- Safety during operation may be ensured based on the safety standard by prediction or assumption at a certain point in time, due to limited information on fuel debris, etc. Safety requirements should be flexibly revised so that safety is ensured more appropriately, by sharing among organizations concerned "safety-related information" which is clarified at each operation step and reflecting it in the retrieval methods or safety management.
- Conformity and response to foreseen safety-related requirements, inspection requirements, etc. should be considered in the development of equipment or construction methods.

It is important that the safety requirements during fuel debris retrieval work are to be established before starting the works and it shall be appropriately reviewed based on the facts which are clarified as the work progresses. In addition, it is necessary to share information closely with regulatory authorities and establish the safety requirements that incorporate the regulatory requirements.

4.1.3 Fundamental views of role sharing on fuel debris retrieval

Because fuel debris retrieval work has a high degree of technical difficulty which has not been experienced so far, not only collaboration with related industries and research institutes, but also acquisition of the knowledge and technologies from the broad range of fields in Japan and abroad including the field other than nuclear engineering and implementation of necessary R&D and application of developed technologies to fuel debris retrieval work in the field are required.

The role sharing towards decommissioning of the Fukushima Daiichi NPS is described in Figure 1-1 of Chapter 1. Here, the fundamental views of role sharing of each organization that participates in fuel debris retrieval are organized below:

(1) TEPCO

- Investigation of plant conditions, basic design, procurement, detailed design, fabrication, construction work plan, training, technical studies on the on-site construction work and field work
- Development and delivery of "implementation plan" on a Specified Nuclear Facility (response to Nuclear Regulatory Agency)
- Presentation of needs for the highly technical R&D projects to be carried out as a subsidized program of the Japanese government, and management of field demonstration tests for review and evaluation for practical application
- Collaboration and ensuring conformity among the technical studies, field works and R&D projects
- R&D carried out by TEPCO itself

(2) Government of Japan

- Policy (such as a basic policies for the Roadmap) decision and progress management of decommissioning
- Budgetary measures for research and technical development with a high degree of technical difficulty

(3) NDF

- Development of strategic plan on policy decision of fuel debris retrieval method
- Provision of support and progress management of technical studies
- Operation of advisory committee for fuel debris retrieval field
- Planning, coordination and management of R&D

(4) Research institutes (e.g. IRID)

- Development and implementation of R&D project implementation plan (e.g. development of equipment and facilities, development of evaluation technology, acquisition of data and information required for these developments)
- R&D progress management, collaboration and ensuring conformity among R&D projects

4.2 Study on maintaining and management of stable condition until start of fuel debris retrieval

The status of the study on maintaining and management of stable condition until the start of fuel debris retrieval is described below.

In specific, the plant and the fuel debris condition based on the information obtained so far and the study items and study approach required for maintaining and managing the stable condition until start of fuel debris retrieval are described.

4.2.1 Conditions of the plants and fuel debris based on information obtained

In the current Roadmap, field works and investigations are being carried out focusing on the Submersion method with access from the PCV top to retrieve fuel debris, aiming to start fuel debris retrieval of the first unit at an early stage. Moreover, technical developments necessary for practical application of the fuel debris retrieval methods, such as the development of equipment and facilities for remote decontamination, investigation, and work are being advanced. Furthermore, the study of the Partial submersion method has also started assuming it may be difficult to submerge to the top.

Therefore, it is expected that a certain period will be needed until fuel debris retrieval starts.

It is important to maintain the stability and continue to manage and monitor the condition of the plant, fuel debris and FP such as Cs until fuel debris retrieval is started in order to ensure the safety.

However, at present, since it is difficult to observe the condition of fuel debris directly due to high radiation and only indirect observation of the temperature and gas composition in the PCV has been possible.

Nevertheless, because the temperatures in the PCV and the RPV indicate a stable downward trend, it is confirmed that the fuel debris is continuously cooled and the condition is stable. In addition, because injection of nitrogen gas to the PCV and the RPV are continued and the hydrogen concentration in the PCV of each unit is also low and stable, it can be said that the possibility of hydrogen explosion is negligible. The stagnant water in the building is stable, since it is managed so that the water level of the building lower than the underground water level by a circulation water discharge line to prevent leakage.

4.2.2 Study items and approaches for maintaining and management of stable condition of fuel debris

From the view point to "reduce the risks of radioactive materials, and manage and monitor them stably," the study required for maintaining and managing stable condition of fuel debris are summarized in the following four items based on the logic tree shown in Figure 4.2-1.

(1) Criticality control

Although it is assumed that the fuel debris is in a stable condition at present, it cannot be denied that it may become critical due to a certain cause, and so the criticality control is required. The function consists of criticality monitoring and recovery from the criticality.

(2) Cooling

Because fuel debris has decay heat and can release contained radioactive materials when it becomes a high temperature, so it needs to be cooled with water. This function consists of circulation water injection cooling, temperature control and a mobile water injection by fire engines.

(3) Containment

Since release of fuel debris and FPs such as Cs to the outside has a significant impact on workers and general public, it is required to be prevented by the PCV, etc. so that they may not be released to the outside. This function consists of leakage prevention of the PCV (gas-phase part) by a gas control system, prevention of leakage of contaminated water (liquid-phase part) by water level control and prevention of hydrogen explosion by N_2 injection.

(4) Maintenance and reliability improvement of safety system

Maintenance and reliability improvement are required for the facilities necessary for maintaining the current safe condition of fuel debris. This function consists of maintenance of equipment, redundancy of equipment and reduction of exposure due to maintenance work.

Study on the four items is carried out as follows (Figure 4.2-2).

(1) Clarification of requirements

The information necessary for evaluation, or monitoring and management of the plant conditions is organized based on the Five Guiding Principles.

(2) Assessment of current status (understanding what activities have been carried out to obtain information on requirements)

The knowledge obtained from past studies and the current status of investigations and R&D projects are organized for the conditions of plant and fuel debris of each unit.

(3) Future actions

It is examined whether the information obtained in the investigations and the projects shown in (2) above, is necessary for the requirements shown in (1). In addition, the necessary activities to be carried out for managing and monitoring the plants, reactor internals and fuel debris in the future are summarized. Furthermore, the methods for estimation and evaluation to ensure the management and monitoring are examined.

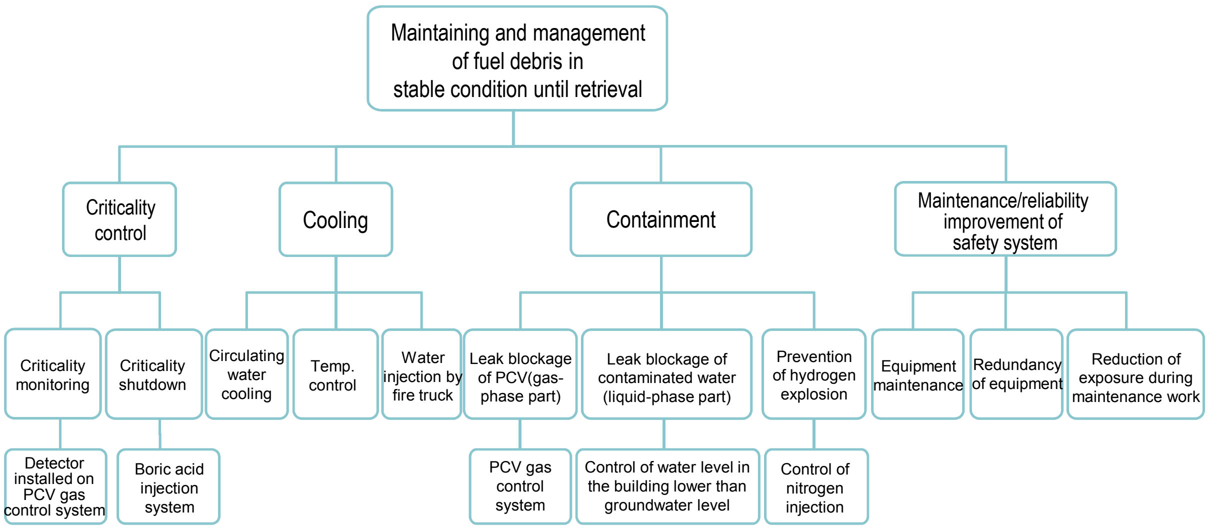


Figure 4.2-1 Logic tree for maintaining and management of fuel debris in stable condition until fuel debris retrieval

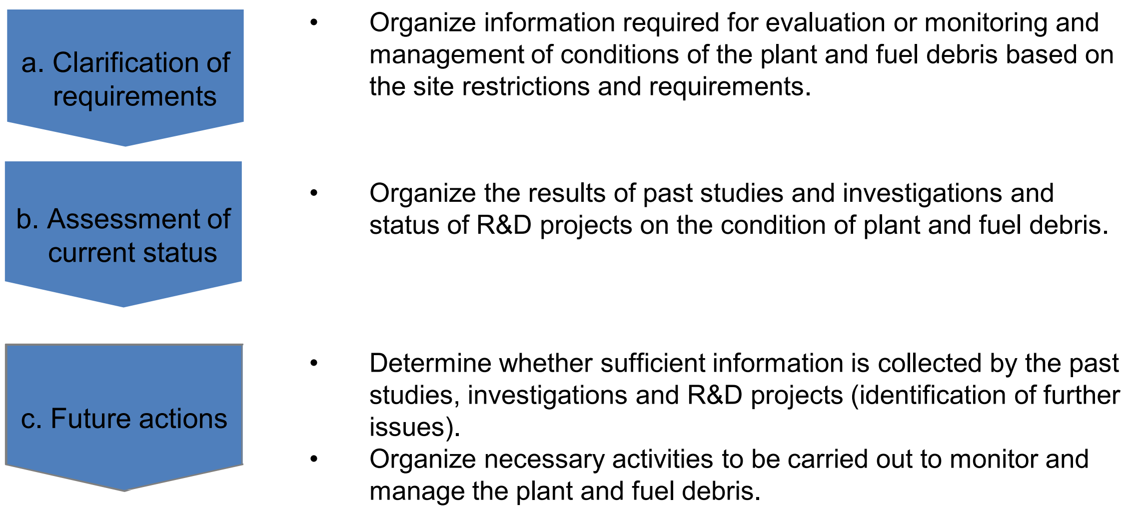


Figure 4.2-2 Evaluation process

4.2.2.1 Criticality control

(1) Purpose

a. To appropriately manage the risks of the occurrence of criticality so that the fuel debris that exists in the RPV/PCV does not reach criticality.

b. To make it subcritical or prevent criticality and to prevent a massive release of radioactive materials to the outside in case that it goes critical, or there is a possibility of criticality.

(2) Major requirements

a. Risk of the occurrence of recriticality is managed appropriately.

b. The exposure dose at the site boundary is sufficiently low even if recriticality should occur.

(3) Current status[1]

a. Continuous monitoring of Xe-135 concentration, a short half-life FP, is carried out by the gas radiation line monitor set up in the PCV gas control system of each unit. While the criticality criterion is set to 1 Bq/cm^3 (approx. 100 times the Xe-135 concentration generated by spontaneous fission), no sign of criticality has been shown. In addition, evaluations have been carried out by using various conditions of composition and shape of fuel debris, deposition shape, composition and mixed amount of structural materials, etc. The results indicate that the possibility of reaching criticality is low.

b. A boric acid water injection system is installed in order to make it subcritical or prevent criticality in case of emergency. Two boric acid water tanks are set up (one is a spare), and alkalescent sodium pentaborate solution which has little effect on structures is injected through the reactor coolant injection system. This system has the capability of achieving the boron concentration of 510ppm which is equivalent to the reactivity of more than 5% Δk. In addition, when boric acid is exhausted, the sea water having the reactivity of 3% Δk is injected. The time required from the occurrence of criticality to the completion of injection is 6 hours at the shortest and 22 hours at the longest.

c. The impact assessment during recriticality is carried out conservatively assuming that the critical state with the output level equivalent to 100 times the criticality criterion for Xe-135 concentration continues for one day, and the evaluated exposure dose at the site boundary was 2.4×10^{-2} mSv. Therefore, it is considered that there is no significant effect on the general public.

[1] TEPCO, Implementation Plan for Specific Nuclear Power Facilities at the Fukushima Daiichi Nuclear Power Station (December 2012; partially amended in August 2013)

(4) Future actions

a. Because the condition of fuel debris in the RPV/PCV of each unit of the Fukushima Daiichi NPS is significantly different from that of a sound reactor core, in which fuel assemblies are orderly arranged in order to maintain criticality, and no sign of criticality has been shown so far, it is considered that the possibility of reaching criticality is low unless the condition of water level and fuel debris significantly changes. However, continuous activities to reduce recriticality risk are expected. If the knowledge of the location, amount, and properties of fuel debris is obtained from the results of investigation in the RPV/PCV, it will be possible to examine the effects on the possibility of recriticality.

b. In addition, if the criticality control technology under development is completed towards fuel debris retrieval, it can be introduced into the actual plant without waiting for start of fuel debris retrieval work. Especially, for the technology under development for improving response speed as sophistication of recriticality detection, although there are issues such as enlargement of system and increase in the number of detectors, it is expected that it can be introduced into the existing PCV gas control system.

4.2.2.2 Cooling

(1) Purpose

To provide cooling for fuel debris and estimate and manage the condition because there is a risk that the radioactive materials in the fuel debris are released if the fuel debris is not sufficiently cooled and the temperature of fuel debris rises.

(2) Major requirements

a. Cooling of fuel debris by cooling water injection is secured.

b. The cooling condition of fuel debris is evaluated and managed.

c. The fuel debris is cooled in the event that a permanent facility cannot cool fuel debris due to events such as earthquake or tsunami.

(3) Current status

a. TEPCO is carrying out maintenance and management of equipment for cooling fuel debris as well as continuous monitoring of the parameters including the temperatures of the reactors. For cooling water injection system, which is a cooling system for fuel debris, operation of condensate storage tank (hereinafter referred to as “CST”) reactor coolant injection system has been started as well as the main water source has been changed from a buffer tank to a CST since July 2013. Thereby, improvement of seismic resistance and increase in capacity are achieved for the tank and the risk of losing water injection function due to reduction of a reactor water discharge line length is reduced.

b. For the parameters including the temperatures of the reactors, because each parameter has lowered since immediately after the accident and an almost constant value has been shown, it can be evaluated that a stable cold shutdown condition is maintained. Because the temperatures in the RPV/PCV stably indicate a downward tendency due to continuous cooling and reduction of decay heat, it also can be evaluated by these parameters that a cold shutdown condition is maintained.

c. In "Fukushima Daiichi NPS, Implementation plan on a Specified Nuclear Facility," December 2012 (amended in August 2013), the reactor core re-damage frequency is approx. 5.9×10^{-5} / year according to the risk assessment of the reactor coolant injection system by probabilistic risk assessment, and it can be confirmed that the risk is reduced compared to the reactor core re-damage frequency of approx. 2.2×10^{-4} / year evaluated in the "Report (Part 1) on facility operation plan (Revision 2) (December 2011)." In addition, according to the evaluation of the reactor coolant injection system in the event of abnormality, even in the case where that the amount of radioactive materials of three plants are assumed to be released due to an event equivalent to a severe accident greatly exceeding an expected level (water injection shutdown for 12 hours), the effective doses are approx. 6.3×10^{-5} mSv / year at the site boundary, approx. 1.1×10^{-5} mSv / year at a 5 km point from the Specified Nuclear Facility, and approx. 3.6×10^{-6} mSv / year at a 10 km point from the Specified Nuclear Facility and therefore, it is considered that there will not be a significant risk of exposure to the general public in the vicinity. [1]

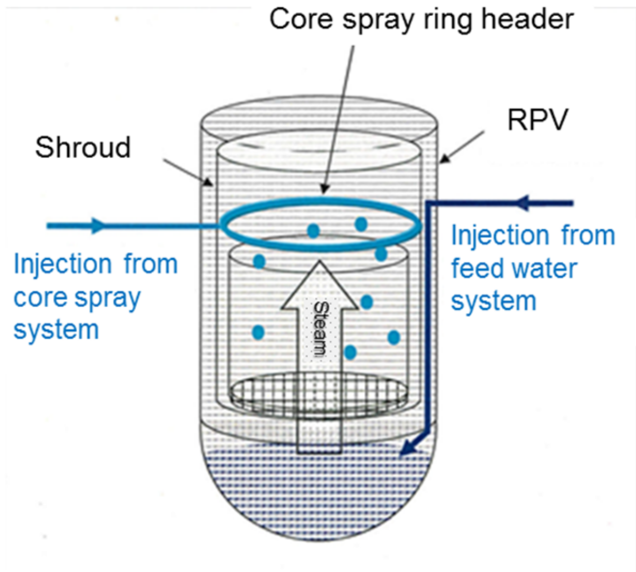
(4) Future actions

a. The cooling water injection is to be continued in order to maintain stable cooled condition.

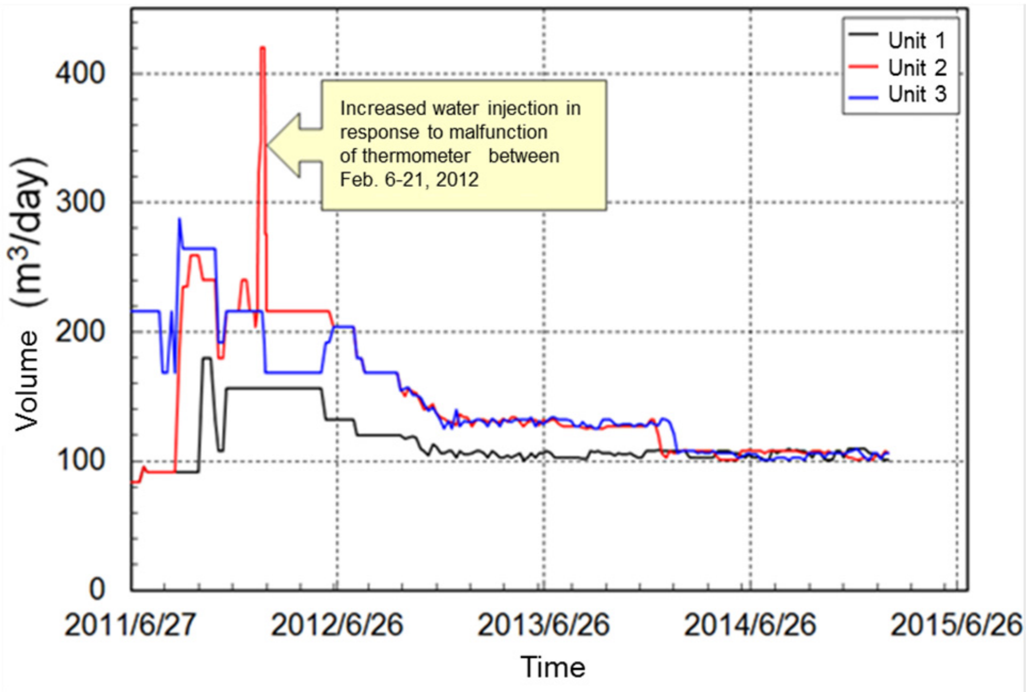
b. Maintenance and reliability improvement of the cooling equipment is to be carried out by operation and management, as well as continuous monitoring of the parameters including the temperature of the reactors.

c. In addition to the measures which have been carried out so far, the measures for improving reliability of quick response using mobile equipment (fire engines, etc.) are to be carried out while considering the evaluation of seismic ground motion and tsunami.

[1] Source: Implementation Plan of the Measures for the Specified Reactor Facilities at Fukushima Daiichi Nuclear Power Station, December 2012 (Revised August 2011), TEPCO.



a. Water injection[1]



b. Volume of water injected into each unit

Figure 4.2-3 Water injection of each unit

[1] Reference: Fukushima Daiichi Nuclear Power Station- Unit 3 Diversification of a Method of Water Injection to Nuclear Reactor by Adding Core Spray System Line (Aug. 23, 2011)

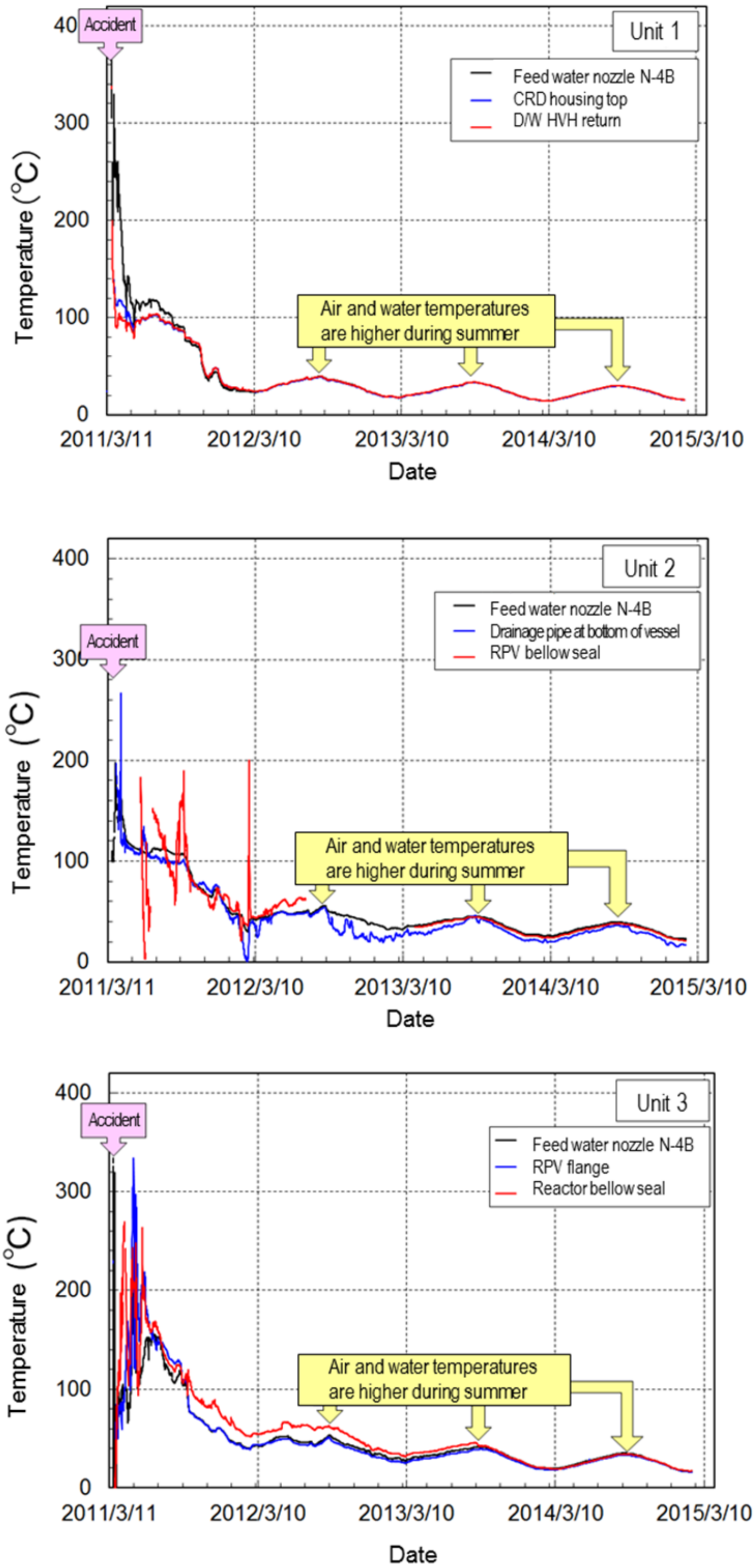


Figure 4.2-4 Trend of temperature around the reactor in the Fukushima Daiichi NPS

4.2.2.3 Containment

(1) Purpose

To prevent PCV failure due to hydrogen explosion as well as to control and prevent leakage of radioactive materials from the PCV.

(2) Major requirements

a. Leakage of radioactive materials from the PCV gas phase part is prevented.

b. Leakage of contaminated water (liquid phase part) from the PCV or the R/B is prevented.

c. Hydrogen explosion caused by the radioactive decomposition of the water in the PCV is prevented.

(3) Current status

a. Prevention of leakage of radioactive materials from PCV gas phase part

The radioactive materials released to the environment are reduced by extracting and filtering the gas in the PCV of Units 1 to 3 using the PCV gas control systems and by monitoring the concentration and amount of radioactive materials using radiation control related equipment.

b. Prevention of leakage of contaminated water (liquid phase part) from R/B

The contaminated water leaking from the PCV of each unit is accumulated in the R/B, etc. The water level gauges are installed to monitor the conditions of the accumulated water in the building and other facilities so that the contaminated water does not leak, and the level of the accumulated water is controlled so that it is kept lower than the underground water level. In addition, the underground water level is checked by the water level gauges installed in appropriate sub-drains in the vicinity of the building.

c. Prevention of hydrogen explosion

i) Nitrogen injection into the RPV/PCV is continued. In the case of nitrogen injection, the hydrogen concentration and the amount of nitrogen gas are monitored so that the hydrogen concentration in the PCV of each unit does not exceed the burning limit concentration (4%).

ii) In addition to these efforts, for Unit 1 where a rise of hydrogen concentration in the PCV was intermittently confirmed, the hydrogen released from the water to the upper part of the suppression chamber (hereinafter referred to as “S/C”) and remaining in the S/C was replaced with nitrogen, and the stable condition is achieved. Because a small amount of hydrogen continues to be released from the accumulated water in the S/C, nitrogen gas injection is carried out in order to maintain the stable condition and the risks due to hydrogen are reduced. For Unit 2 where a rise of hydrogen concentration in the PCV was confirmed by pressure fluctuation, nitrogen gas injection to the S/C was carried out and replacement by nitrogen gas was completed, and the change of the parameters is being checked. For Unit 3, because a rise in hydrogen concentration has not been observed and it is considered that the condition of the closed space in the S/C is stable, the change of the parameters is being checked.

iii) The change of the hydrogen concentration in the PCV is shown in Figure 4.2-5. The hydrogen concentration in the PCV shows a constant value and is controlled at a sufficiently low concentration compared to the burning limit concentration (4%)

(4) Future actions

a. Prevention of radioactive materials leakage from PCV gas phase part

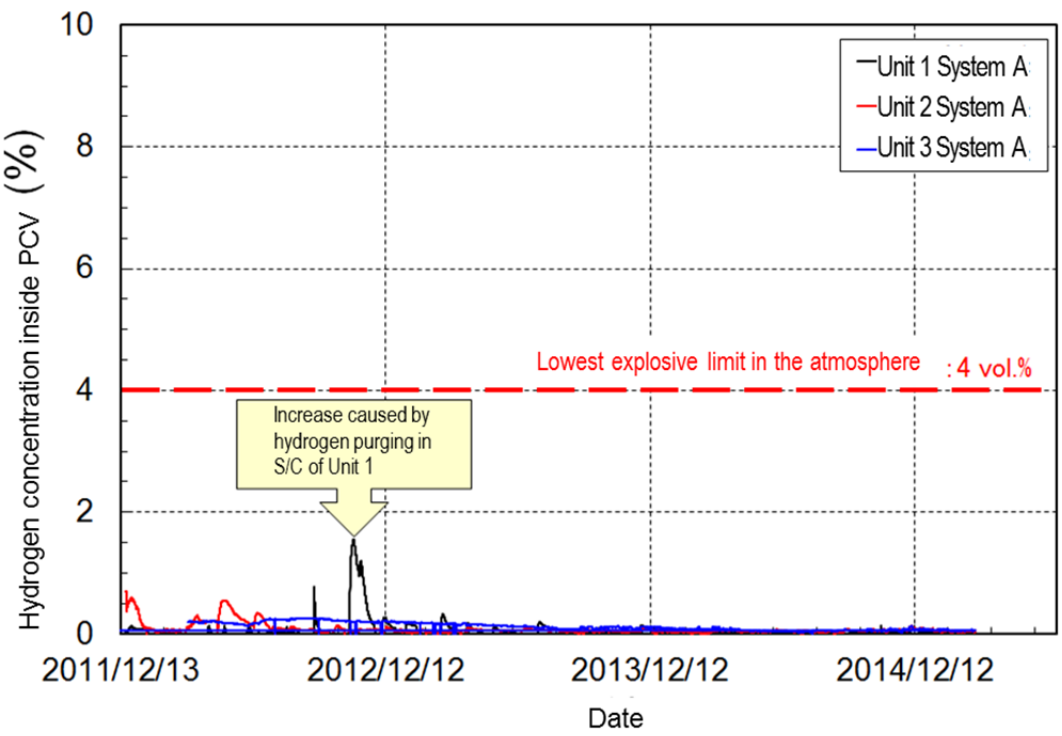
Extraction and filtering by the PCV gas control system are to be continuously implemented and the concentration and amount of radioactive materials is to be monitored by radiation control related equipment, so that the radioactive materials released to the environment is reduced as much as reasonably achievable.

b. Prevention of leakage of contaminated water (liquid phase part)

Leakage of contaminated water to the outside of the building is to be prevented by maintaining the water level in the building lower than the level of the underground water. In addition, the contaminated water is purified by the existing accumulated water treatment system of the circulation water discharge line. In preparation for the completion of retrieval of fuel debris and treatment of the accumulated water in the buildings in the future, a small circulation loop is to be installed in order to reduce the risk of leakage of contaminated water to the outside of the building, and the water source is to be changed from the turbine building to the R/B.

c. Prevention of hydrogen explosion

Because the hydrogen concentration is maintained sufficiently low by filling nitrogen gas in the PCV, risk reduction of hydrogen explosion is achieved. The stable condition is to be maintained by continuing to carry out maintenance in a well planned manner.



(Reference: data released by TEPCO)

Figure 4.2-5 Trend of hydrogen concentration inside the PCV

4.2.2.4 Maintenance and reliability improvement of safety system

(1) Purpose

To aim at maintenance and reliability improvement of safety system for maintaining and managing the stable condition of fuel debris.

(2) Major requirements

a. Continuous maintenance and management for equipment is carried out.

b. Equipment has redundancy so as to prevent loss of its function by a single failure.

c. Exposure due to maintenance work is minimized.

(3) Current status

a. The permanent monitoring instruments are maintained and managed in order to carry out continuous monitoring of the temperatures of the RPV/PCV.

b. For the fuel debris of Units 1 to 3, circulation cooling systems have been set up, and the reliability improvement measures such as installation of multiple equipment also have been taken. For monitoring of the cold shutdown condition of the PCV and the RPV, permanent monitoring instruments are additionally set up. In addition, for cooling water injection, the reliability is improved by having multiple systems as backups to the existing equipment (Figure 4.2-6). The reactor coolant injection systems of Units 1 to 3 are under operation as follows:

i) CST reactor water injection pump: two for each unit (for normal operation)

ii) Reactor water injection pump in turbine building: two for each unit (for normal operation)

iii) Reactor water injection pump located at the elevated place for normal operation: three shared between three units (for normal operation)

iv) Reactor water injection pump located at the elevated place for emergency: three shared between three units (for emergency)

v) Reactor water injection pump beside pure water leak blockage tank: three shared between three units (for emergency)

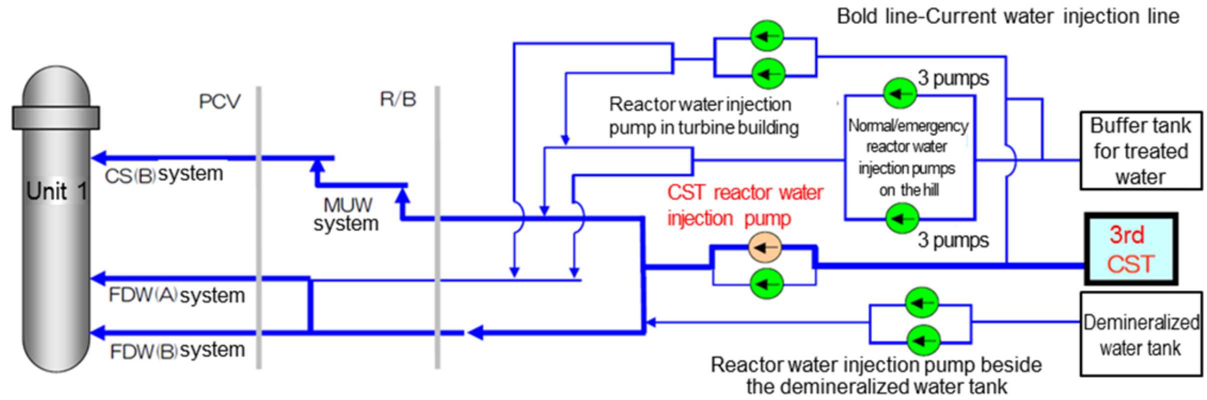
c. The inside of the R/B is still at a state of high dose rate, and rubbles and dusts are scattered making it difficult for the workers to access. As for work environment, space dose rates have been measured inside the R/B of Units 1 to 6.

(4) Future actions

a. Maintenance and reliability improvement of safety system are continuously carried out by operation and management. For the purpose of maintaining and improving the reliability of the power supply facilities, the measures such as changing to a permanent system from a temporary system should be carried out so that they can withstand a long time of use.

b. With respect to the temperature in the PCV, it is necessary to consider installation of a permanent monitoring instrument in the future for Unit 3 as well.

c. It is necessary to conduct internal investigation of the R/B and estimate and assess the condition of contamination for each nuclide. The applicable decontamination technologies shall be used and decontamination equipment capable of remote operation shall be developed as necessary. Decontamination and other activities need to be carried out in order to secure accessibility into R/B.



(Provided by TEPCO)

Figure 4.2-6 Current water injection line to the reactor (Unit 1)

4.2.3 Maintaining and management of stable condition

With respect to the fuel debris, the circulation cooling system have been set up, the measures for improving reliability, such as installation of multiple of equipment, are also taken, and the stable cooling condition is maintained. It is important in terms of safety to continuously maintain and manage the stable condition.

It should be noted that maintaining the stable condition until fuel debris retrieval is related and continuous to ensuring the safety during fuel debris retrieval work.

Therefore, the function to control and manage a radioactive material release, the function to cool a reactor, the function to prevent criticality and the function to prevent hydrogen explosion are maintained and enhanced continuously, and cooling of fuel debris and the concentration and amount of radioactive materials are monitored. In addition, for monitoring, it should be considered to integrate and make databases of plant data so as to effectively manage the plant information, such as temperatures of RPV/PCV and cooling water injection flow rate.

Concrete future actions are shown in Figure 4.2-7.

Figure 4.2-7 Future actions for maintaining and management of the reactor and fuel debris in stable condition until the fuel debris retrieval

4.3 Study on the methods of safe retrieval of fuel debris

This section describes the status of study on the methods of safe retrieval of fuel debris.

Specifically, studies on the identification of the location, amount, properties of fuel debris and the FP distribution, options for retrieval methods, evaluation of each retrieval method based on technical requirements and feasibility, applicability of the method based on the condition of each unit are explained below.

4.3.1 Study on identification of the location, amount, properties and FP

The following section describes the status of the study on the identification of the location, amount, properties of fuel debris and FP distribution.

Specifically, the distributions of fuel debris and FPs, the items and approaches of study that will be necessary for identification of the location, amount, properties of fuel debris and FP distribution, estimated status based on the past studies are explained.

Identification of location, amount and properties of fuel debris and the distribution of the FP will be important for decision on the retrieval method, development of the fuel debris retrieval equipment, and implementation of fuel debris retrieval works with reduced risks from radioactive materials.

4.3.1.1 The conditions of fuel debris and FP distribution

The physical observation of the distributions of the fuel debris in the PCV and FP has not been realized due to high radiation inside.

Therefore, accident progression analysis is used for identification, estimation and evaluation of fuel debris, FP distribution (such as Cs), and internal condition of the PCV and the RPV, but a large part of information that can be obtained in the current situation remains to be uncertain.

4.3.1.2 Items and approaches for identification of location, amount, properties of fuel debris and FP distribution

The following are the ways to estimate the location, amount and properties of fuel debris and the FP distribution based on the logic tree in Figure 4.3.1-1.

(1) Estimation by plant investigation
Investigations of certain structures such as internal conditions of the RPV/PCV and S/C and torus rooms, and the whole image of the fuel debris using of the muon detection system.

(2) Estimation by analysis
Analysis is conducted using accident progression analysis codes.

(3) Estimation based on knowledge and experiments
Estimation from the knowledge and experiments is conducted by studies based on the past accidents and researches and engineering studies on plant data and experiments on simulated debris.

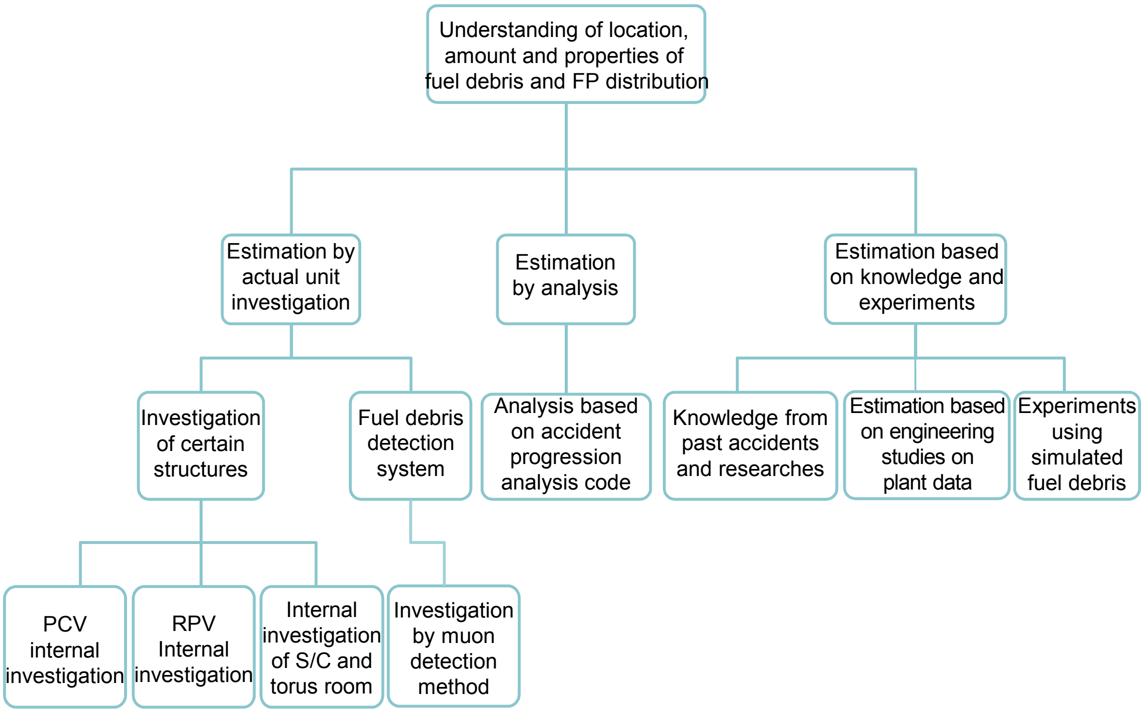


Figure 4.3.1-1 Logic tree for understanding the conditions of reactor vessels and fuel debris

Three types of estimation described above are conducted from the following perspectives.

(1) Requirements

Information required to estimate and evaluate the plant condition is organized.

(2) Current status (activities conducted to obtain information on the requirements)

The results of the past studies, status of the ongoing investigations and R&D projects regarding the conditions of the plant and the fuel debris for each unit are organized.

(3) Future actions

Whether the information on the investigations and projects described in (2) is sufficient for the requirements of (1) is to be assessed. Subsequent actions required to be taken to understand the plant condition and the fuel debris are also clarified.

4.3.1.2.1 Estimation based on plant investigation

(1) Purpose

To investigate the distribution of the fuel debris and the conditions inside the reactor vessels to obtain basic information for studying the fuel debris retrieval methods and condition of the radiation dose inside the reactors.

(2) Major requirements

a. The condition of the fuel debris distribution around the RPV pedestals is identified.

b. Whether there is fuel debris remaining inside RPV is confirmed.

(3) Current status

a. For Unit 1, acquisition of images, measurements of ambient temperature, radiation dose, water level and water temperature, sampling of stagnant water, installation of permanent thermometer were completed by accessing into the PCV through X-100B penetration. For Unit 2, acquisition of images, measurements of ambient temperature, radiation dose, water level and water temperature, sampling of stagnant water, installation of permanent thermometer were completed by accessing into the PCV through X-53 penetration. Unit 3 was examined by ultrasonic method from the outside of X-53 penetration and it was confirmed that inside X-53 penetration is not immersed in water.
   - In FY2015, acquisition of images, measurements of ambient temperature, radiation dose, water level and water temperature, sampling of stagnant water, installation of permanent thermometer is planned for Unit 3 through X-53 penetration.

b. For the PCV internal investigation, the devices to investigate the outside of the RPV pedestal of Unit 1 and the inside of the RPV pedestal of Unit 2 are being developed.

c. Optimization of development plan for RPV internal investigation was carried out as part of R&D in FY2014. What was required in the investigation was clarified and developmental studies for top entry technology, pipe access technology and fuel debris sampling device have begun.

d. A technology for non-destructive measurement of the accumulated amount of radioactive materials inside the S/C is being developed, since temperature increase caused by decay heat, possibility of criticality, and generation of hydrogen as a result of radiolysis of water may be assumed depending on the amount of radioactive materials such as fuel debris.

e. The distribution of the fuel debris is being measured using muon detection technology.
   - In FY2015, measurement and evaluation of the fuel debris inside the RPV of Unit 1 are planned using the transmission method.
   - From FY2015 to FY2016, measurement and assessment of the fuel debris inside the RPV of Unit 2 are planned using the scattering method.

(4) Future actions

The following are the actions to be taken.

a. The PCV internal investigation is to be carried out based on the information obtained from the analysis of the accident. The results should be used in the studies for reactor condition by sophisticated accident analysis. For Unit 3, the water level inside the PCV is high while the place where the investigation device is to be inserted into Unit 2 is submerged in water, therefore the device developed for Unit 2 may not be useable for Unit 3. For the internal investigation of PCV of Unit 3, necessary R&D items should be identified if the existing technology is determined to be inapplicable.

b. For the purpose of optimizing the designs for the fuel debris retrieval equipment and facilities, RPV internal investigations should be conducted focusing on the top entry technologies, and technical developments to realize the investigations will be required which will contribute to the detailed designs of equipment and facilities. It is also necessary to develop a fuel debris sampling technology. It will be required to determine the approaches at an appropriate timing over the period of technical development along with coordination with the site.

c. The necessity for investigation on the amount of radioactive materials remaining in S/C and torus room needs to be considered and determined.

d. A measurement technology to detect the fuel debris using muon will be developed as part of R&D. The results of measurement of Units 1 and 2 will be incorporated into the study on the conditions inside the reactor vessels using sophisticated accident analysis. If favorable results are obtained by the fuel debris detection by muon, application to Unit 3 should be considered as well.

4.3.1.2.2 Estimation based on investigation by analysis

(1) Purpose

To analyze and estimate the location, amount, properties of fuel debris and the FP distribution as they serve as basic information for studying the fuel debris retrieval methods and development of equipment and facilities.

(2) Major requirements

a. The total amount of fuel debris is estimated.

b. The conditions of the fuel debris such as distributions, status of solidification and forms are estimated.

c. The mechanical, chemical and physical features of the fuel debris properties are estimated.

d. The distribution of FPs such as Cs is estimated.

(3) Current status

a. MAAP and SAMPSON, the accident progression analysis codes, are improved and used for analysis. Currently the conditions inside the reactor vessels are being studied, and different results of analysis obtained by different codes will be examined and comprehensive evaluation of the conditions inside the reactor vessels is going to be carried out based on the information obtained from the plants.

b. In BSAF project of OECD/NEA, analyses are conducted using the accident progression analysis codes of different countries.

(4) Future actions

a. In order to identify the amount, distribution and properties of the fuel debris, the accident progression analysis codes is to be continuously improved and the difference in the results caused by use of different analysis codes is to be further examined. Moreover, not only the results of analysis, but also the data and information obtained from plant investigation, achievements made in the fuel debris detection projects and other R&D projects will be used to outline the most probable location, amount, and properties of fuel debris and the FP distribution such as Cs. In parallel, it will be necessary to create an integrated database to efficiently share the information among the related organizations. It should be considered so that users are allowed to handle not only the above mentioned information but all kinds of data required for determining the feasibility of the fuel debris retrieval method such as dose distribution inside the reactor vessels and evaluation of cooling status of fuel debris.

b. The assessment made by Japanese side on the fuel debris and the FP distribution should be provided to BSAF project of OECD/NEA and the knowledge and experiences of all the participating countries should be incorporated.

4.3.1.2.3 Estimation based on investigation based on knowledge and experiments

(1) Purpose

To obtain the data and information for studying the fuel debris properties by carrying out analyses and tests using the simulated debris to help understand the conditions of the fuel debris inside the reactors and study the collection, transport and storage of fuel debris.

Also to develop the technologies required to analyze and measure the fuel debris to be retrieved from the reactor vessels.

(2) Major requirements

a. The features are estimated based on simulated debris.
   - The requirements for fabrication of simulated debris are determined based on the accident progression of the Fukushima Daiichi NPS and with reference to TMI-2.
   - Data on mechanical, chemical and physical properties of the simulated debris is obtained to reflect the information in the designs of equipment and devices used for the fuel debris retrieval.
   - The properties of TMI-2 debris are examined and compared to the data obtained from the simulated debris. The points to be reflected to the fuel retrieval in the Fukushima Daiichi NPS is clarified.

b. Analysis of actual fuel debris properties
   - The analysis flow is formulated for the actual debris analysis, covering from the transport of the actual debris to analysis of individual debris and the necessary elements of technical development are identified.

- Technologies for analysis and measurement such as a dissolution method and chemical form analysis method of the actual debris are studied and developed in order to analyze the composition of the actual debris by chemical analysis.
- Technologies for transport of the actual debris are studied and developed.

(3) Current status

a. Characterization using simulated debris

- The mechanical properties of tetragonal and monoclinic crystal system such as (U, Zr) O_2 and Fe_2 (Zr, U) were measured and evaluated.
- Boring tests on a number of simulated materials with different properties were conducted, and the impacts on the boring performance by each of the properties were observed.
- Reaction tests with U-Zr-O system and cement in an oxidation atmosphere were carried out and the data of debris particles produced under water was acquired.
- Physical property data of composite materials with system of debris presumably produced from the fuel containing Gd and the structural materials (Fe) were measured.
- Collection of past data on properties of the products of molten core concrete interaction (MMCI) from CEA, France, has begun. Solidified molten metal/ceramics were manufactured using UO^2 with the cooperation of NNC, Kazakhstan.
- As a test using the TMI-2 debris stored by JAEA, measurements of Vickers Hardness has begun after fabrication of samples and observation by optical metallography was completed. Evaluation of applicability of alkali fusion for analysis has begun.
- Transport of actual debris samples was studied.
- R&D plan with regards to fuel debris properties which contributes to the collection and storage was developed.
- Tests using porous ceramics were conducted to evaluate the hydrous and dry properties of the debris.

b. Analysis of actual fuel debris properties

- The analysis items and overall analysis flow were studied, technical issues were identified and future development plan was formulated.
- Development of dissolution method and studies on chemical form analysis method as well as development of the actual debris analysis equipment were carried out as part of analysis and measurement technology development.
- Property analysis method necessary for appropriate processing and disposal of waste was planned in case the actual debris are to be treated as waste.
- Equipment necessary for analysis and research facilities were considered.

(4) Future actions

a. Characterization using simulated debris

- By the end of FY2015, based on the knowledge obtained so far (through accident progressions analysis, experience from TMI-2 accident, severe accident research), the properties of fuel debris in each unit are to be estimated and summarized in a property list.
- The progress on the property list is to be confirmed, and solutions must be presented as necessary should there be any problem.
- The fuel debris properties estimated in 2015 is to be confirmed and updated constantly based on the latest site conditions.
- The compiled data and information is provided for selection of fuel debris retrieval method, development of equipment and devices and development of collection and storage technologies. Whether sufficient data is provided is to be assessed and issues are reviewed if any.
- Evaluation of the heterogeneous properties on a large lump of object was not possible in Japan, therefore property evaluation tests on large-size products of MCCI at CEA, France and solidified molten metal/ceramics at NNC, Kazakhstan are to be carried out under the framework of international cooperation.

b. Analysis of actual fuel debris properties

- An overall flow for the actual debris analysis including actual debris transport and individual debris analysis is to be established. Also the technical development elements are to be extracted and the future technical development plan is to be formulated, which is followed by necessary technical development.
- In preparation for the study on the analysis flow, information on the required items and number of analyses is to be obtained as soon as possible in collaboration with development projects for collection, transport and storage of fuel debris.
- Information on the form of fuel debris canisters and containers for on-site transfer which is required for designing the analysis facilities is to be obtained as soon as possible in cooperation with other related projects. It will be reflected to the structural designs of the handling equipment and facilities.
- In preparation for being able to acquire samples of fuel debris before beginning of operation of the analysis facility for characterization (second phase analysis facility), studies on preparation of receiving the samples at the JAEA facility for analysis and the transport casks should be carried out.
- The technical issues that may arise during the actual debris analysis are to be identified and reviewed using small amount of samples which may be taken in the course of the PCV internal investigation.

- In order to reflect the results of the projects in the designing and operation of analysis and research facilities, activities under close cooperation is to be conducted with the facility development project.

4.3.1.3 Distributions of the fuel debris and FPs based on studies

To study the fuel debris retrieval methods, distributions of the fuel debris and FPs estimated based on the information and the results of accident progression analysis obtained so far are described below.

The information on the fuel debris and FP distributions are to be shared among the relevant parties from now on, and studied and updated based on the common understanding of the current status.

(1) Estimated location of fuel debris

The plant condition and estimated location of the fuel debris of each unit that has been investigated so far are shown in Table 4.3.1-1.

The results of the accident progression analysis, the PCV internal investigation, and on-site measurements are comprehensively evaluated by TEPCO to estimate the possible location of the fuel debris.

Table 4.3.1-1 Plant investigation status and estimated locations of the fuel debris

Unit	Results of plant investigation	Estimated locations of the fuel debris
Unit 1	● Water level inside D/W is approx. 3m from the bottom. ● S/C is almost filled with water. ● Leakage from sand cushion drain pipe is confirmed. ● Leakage from the expansion joint cover of vacuum break line in S/C is confirmed. ● High radiation is detected in some areas in southeast on the 1st floor of the R/B (several Sv/h).	● Almost all fuel debris fell to the lower plenum, and very little fuel remaining in the core region. ● Most of fuel debris that fell to the lower plenum fell to the bottom of D/W. ● Fuel debris scattered outside the RPV pedestal (with possibility of shell attack).
Unit 2	● Water level inside D/W is approx. 30cm from the bottom. ● S/C is about half filled and water level is almost the same as the torus room. ● No trace of leakage at upper part of torus room. ● The structure on the lower part of the RPV was confirmed by internal images taken from the opening at RPV pedestal. Damages to the RPV bottom may not be significant.	● A part of the fuel debris fell to the lower plenum, or to the bottom of D/W and some remaining in the core region (there may not be any outside the RPV pedestal).
Unit 3	● Water level inside D/W is approx. 6.5m from the bottom (estimated from the pressure difference between D/W and S/C). ● S/C is almost completely filled with water. ● Leakage around expansion joint of main steam pipe D is confirmed.	● A part of the fuel debris fell to the lower plenum or to the bottom of D/W, and some remaining in the core region (there may not be any outside the RPV pedestal).

(Based on information provided by TEPCO)

(2) Estimated amount of fuel debris

Table 4.3.1-2 shows the amount of fuel debris estimated from the accident progression analysis of each unit.

The amount of fuel debris is estimated by the weight of the fuel and the materials attached or mixed with the fuel. The weight of the reactor core (weight of the loaded uranium) is approx. 69t for Unit 1 and approx. 94t for Units 2 and 3. They are assumed to contain melted fuel claddings and reactor internals.

Table 4.3.1-2 Estimated amount of fuel debris based on analysis

	Unit 1	Unit 2	Unit 3
Amount of fuel debris	App. 160-180t	App. 230-240t	App. 220-230t

(Overview of 2013 achievements, "Identifying conditions inside the reactor vessel by upgraded technology for accident progression analysis," IRID/IAE (May 29, 2014))

(3) Estimated properties of the fuel debris

Sampling of the actual debris has not been conducted yet therefore the fuel debris properties are estimated based on the currently available information.

Figures 4.3.1-2 (1/3) to (3/3) show the features of fuel debris at different locations in Unit 2. The fuel debris distribution in the RPV and PCV is estimated by accident progression analysis and the properties are tentatively estimated based on the examples of TMI-2 and experiments.

Figures 4.3.1-2 (1/3) and (2/3) show the estimated features of fuel debris distributed inside the RPV based on the case studies of TMI-2. At the upper part of the RPV (A) and the core plate (I), melted fuel debris is adhered to the structures. At the upper part of the reactor core, unmelted cladding (B) and molten substances solidified into rock-hard objects (C and D) are observed. In the center of the reactor core, the properties are different according to the speed of solidification of the melted fuel (E and F), and some fuel pellets remain intact (G). There are fuel assemblies in a shape of stubs around the core (H), and there is fuel debris melted and solidified into a rock-hard objects at the lower part of the RPV (J and K).

Figure 4.3.1-2 (3/3) shows the features of the fuel debris accumulated at the lower part of the PCV. The fuel debris in TMI-2 remained in the RPV, therefore the features are estimated based on tests conducted by overseas research institutions. The melted fuels fell to the floor and reacted with the concrete, and various properties of MCCI are formed according to the locations (L, M and N). (O) and (P) show the whole images of MCCI products.

(4) Estimated FP distribution

Figure 4.3.1-3 shows the result of analysis on distributed amount of Cs of each unit for reference. The distribution of FPs such as Cs is estimated based on the results of accident progression analysis which uses data that contains uncertainties, therefore it is subject to review based on further plant investigations and accident progression analysis.

Figure 4.3.1-4 shows the future actions for the identification of the location, amount and properties of fuel debris and FP distribution.

Based on the case of TMI-2, the internal conditions of the reactor vessel of Unit 2 was assumed using the results of analysis by the accident progression analysis code, SAMPSON.
The images shown are from TMI-2 photographs, and the actual condition of Unit 2 may be different. As the internal conditions of the reactor vessels become clear, reassessment may be required.

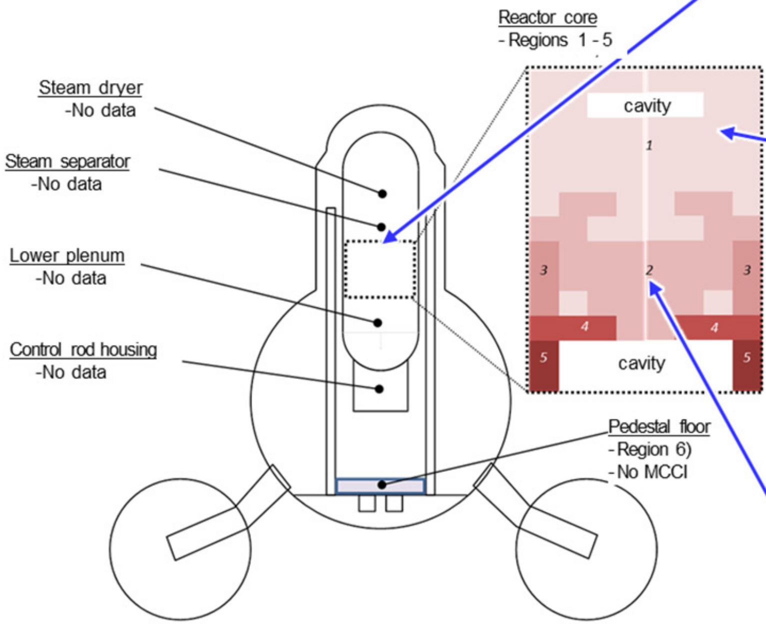
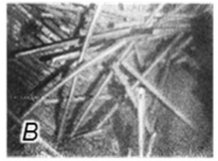
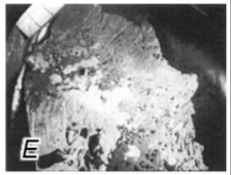
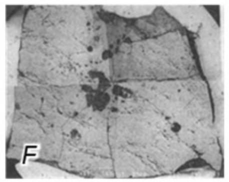
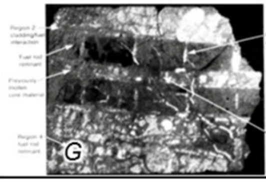


	Image	Features
Molten upper part Plenum	A No image	**[Image A: Structures around the plenum]** Molten or damaged upper plenum (debris attached) **〔Main composition: stainless steel, Zry-2, UO_2 〕**
Loose debris	  C No image	**[Image B: Unmelted fragments]** Unmelted cladding and fuel structural materials **〔Main composition: Zry-2, UO_2, stainless steel〕** **[Image C: Unmelted fragments, small rock-shaped debris]** Unmelted fragments, fragments of re-solidified fuels, melted objects solidified into granular debris after rapid cooling **〔Main composition: Zry-2, UO_2, stainless steel, $(U,Zr)O_2$〕** **[Image D: Small rock-shaped debris]** Small rock-shaped debris **〔Main composition: $(U,Zr)O_2$〕**
Upper crust		**[Image E: Upper curst]** Molten fuels that cooled and solidified into fuel debris relatively quickly
Solidified molten material (Molten pool)		**[Image F: Solidified molten material]** Molten fuels slowly solidified into fuel debris
Lower curst		**[Image G: Fuel pellets in the solidified molten material]** Molten fuel assembly that cooled and solidified into fuel debris relatively quickly **[Main composition: $(U,Zr)O_2$, (U- and Zr- rich phases), boride, metal-containing debris]** ・In TMI-2, upper crust (surface crust of a few centimeters thickness), solidified molten materials (agglomerate), lower crust (crust of 0.1m thickness)

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B : Reprinted with permission from G. R. Eidam, "Core Damage" Chapter 5 of "The Three Mile Island Accident," 1986 American Chemical Society, Volume 293. Copyright 1986 American Chemical Society.

D ~ G : Reprinted from R. K. McCardell, M. L. Russell, D. W. Akers and C. S. Olsen, "Summary of TMI-2 Core Sample Examinations," Nuclear Engineering and Design 118 (1990) 441-449, Copyright 1990, with permission from Elsevier.

(Provided by IRID)

Figure 4.3.1-2 Estimation of fuel debris properties (1/3)

Based on the case of TMI-2, the internal conditions of the reactor vessel of Unit 2 was assumed using the results of analysis by the accident progression analysis code, SAMPSON.
The images shown are from TMI-2 photographs, and the actual condition of Unit 2 may be different. As the internal conditions of the reactor vessels become clear, reassessment may be required.

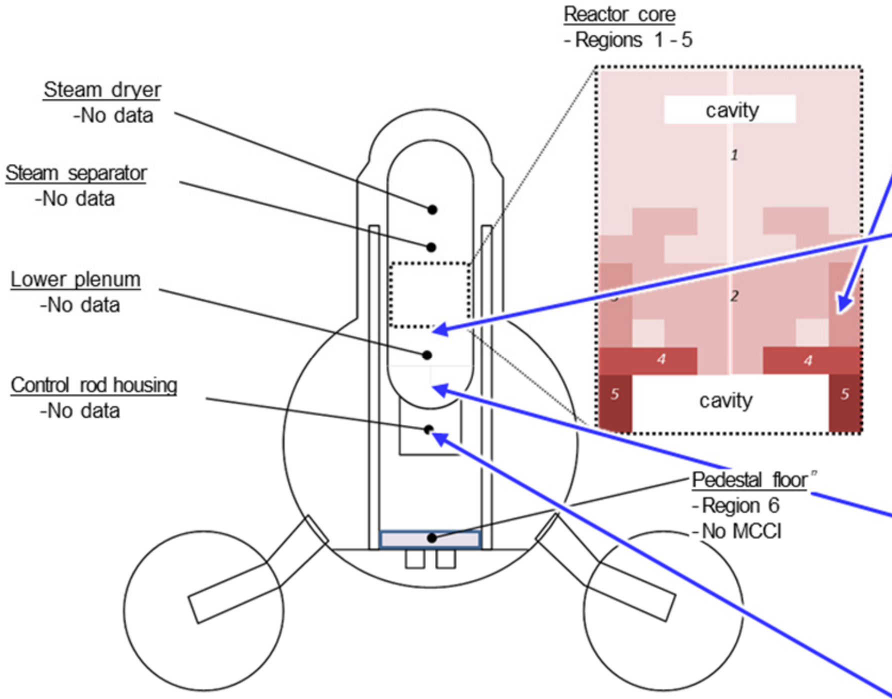
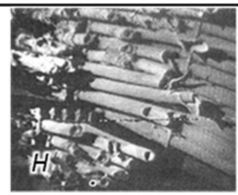
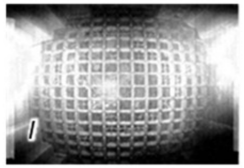
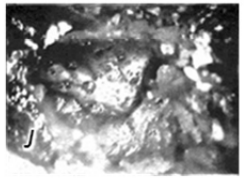
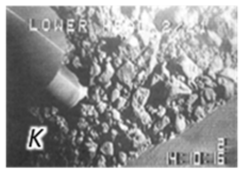


Image		Features
Stub-shaped fuels		**[Image H: Stub-shaped fuels*]** Unmelted or damaged fuel assemblies **[Main composition: Zry-4, UO_2, $(U,Zr)O_2$]**
Core support structures		**[Image I: Core plate]** Debris fell through the grids of the core plate and fuel support(debris attached) **[Main composition: stainless steel, $(U,Zr)O_2$]**
Solidified debris of molten fuels at the lower head		**[Image J: Solidified molten material]** Rock-shaped debris containing damaged molten fuels and control rods **[Main composition: $(U,Zr)O_2$]**
Granules of solidified debris		**[Image K: Small rock-shaped debris]** Molten materials rapidly cooled and solidified into granular debris **[Main composition: $(U,Zr)O_2$]**
CRD, CRD housing and the attached debris	No image	**[CRD, CRD housing and the attached molten debris]** **[Main composition: $(U,Zr)O_2$, stainless steel]**

* *Image H actually shows the damaged upper plenum but the stub-shaped fuels are assumed to be in similar form.*

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H & K : Reprinted with permission from G. R. Eidam, "Core Damage" Chapter 5 of "The Three Mile Island Accident," 1986 American Chemical Society, Volume 293. Copyright 1986 American Chemical Society.
I & J : Reprinted with permission from EPRI NP-6931 "The Cleanup of Three Mile Island Unit 2 A Technical History: 1979 to 1990," (1990).

(Provided by IRID)

Figure 4.3.1-2 Estimation of fuel debris properties (2/3)

Based on the case of TMI-2, the internal conditions of Unit 2 was assumed using the analysis results of the accident progression analysis code, SAMPSON.
The images shown are from photographs of MCCI tests, and the actual conditions of Unit 2 may be different. As the internal condition of the reactor vessel become clear, reassessment may be required.

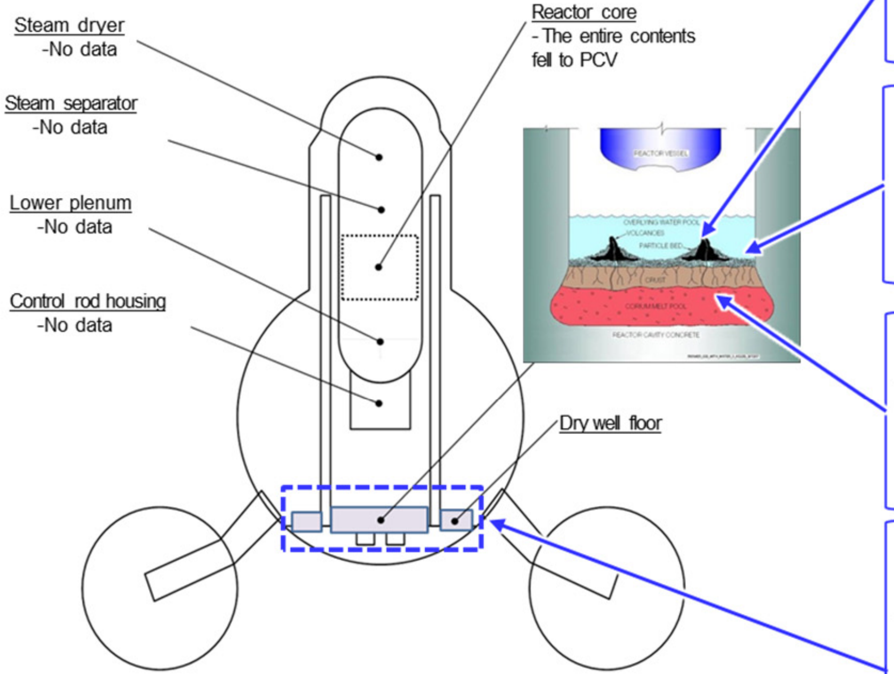
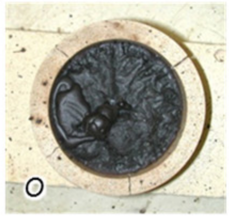


	Image	Features
Volcano-like debris generated from MCCI	 L	**[Image L: Volcano-like debris generated from MCCI]** Debris formed when the molten corium inside streamed out after the solidification of crusts (CEA VULCANO test)
Powder-like debris generated from MCCI	No Image M	**[Image M: Powder-like debris generated from MCCI]** Corium that fell into the water during the initial stage and the molten corium inside streamed out after the solidification of crusts (ANL CCI test)
Agglomerates generated from MCCI	 N	**[Image N: Agglomerates generated from MCCI]** Molten corium inside has solidified (ANL CCI test)
Debris generated from MCCI (upper part)	 O	**[Image O: Debris generated from MCCI (upper part)]** Overall image after the test on silica-rich concrete (ANL CCI test)
Debris generated from MCCI (vertical cross-sectional view)	 P	**[Image P: Debris generated from MCCI (vertical cross-sectional view)]** Overall image after the test on silica-rich concrete (ANL CCI test) [Main composition: $(U,Zr)SiO_4$, $(U,Zr)O_2$]

The images are extracted from the following documents with approval obtained by NDF.

L : Reprinted with permission from C. Journeau, P. Piluso, J.-F. Haquet, S. Saretta, E. Boccaccio, J.-M. Bonnet, "Oxide-Metal Corium-Concrete Interaction Test in the VULCANO Facility," Proceedings of ICAPP 2007, Nice, France, May 13-18, 2007, Paper 7328.

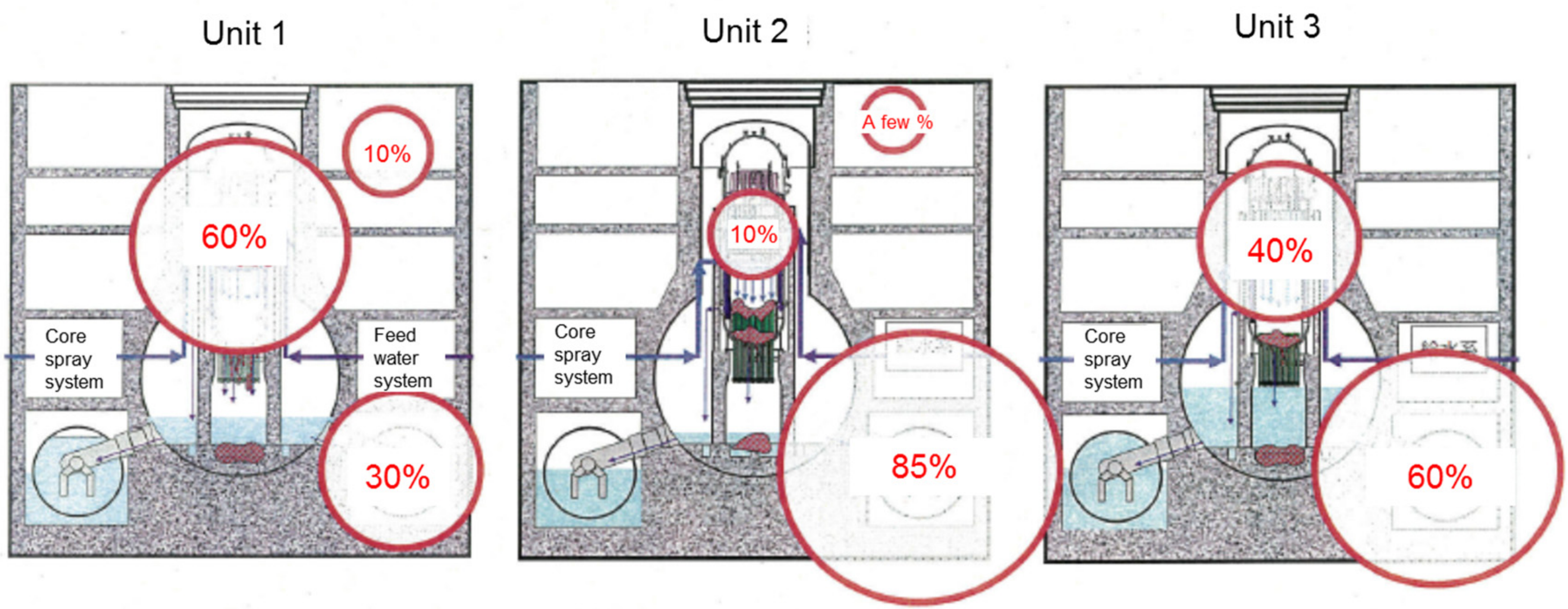
N & P : Reprinted with permission from Argonne National Laboratory
Source: M. T. Farmer, S. Lomperski, D. J. Kilsdonk, and R. W. Aeschlimann, Argonne National Laboratory, S. Basu, U.S. Nuclear Regulatory Commission
Published in: "OECD MCCI Project, 2-D Core Concrete Interaction (CCI) Tests: Final Report," February 28, 2006, OECD/MCCI-2005-TR05, http://www.ipd.anl.gov/anlpubs/2011/05/69907.pdf.

O : Reprinted with permission from M. T. Farmer, "Thermite as a Validated Option to Melt Large Corium Masses," Plinius 2 International Seminar, Marseille, France, May 16, 2014.

(Provided by IRID)

Figure 4.3.1-2 Estimation of fuel debris properties (3/3)

Analysis results of Cs migration (evaluated when post accident migration was stabilized)



- The above values are percentages based on the total amount of Cs inventory at the time of emergency shutdown of each unit.
- Cs actually take various chemical forms but the above results show the percentages of CsOH.
- After the accident, significant amount of Cs have dissolved into the stagnant water and been collected in the water treatment systems, but such amount is not considered.

*It must be noted that there are uncertainties in the analysis results and the input data.

(Provided by TEPCO)

Figure 4.3.1-3 Estimation of Cs distribution

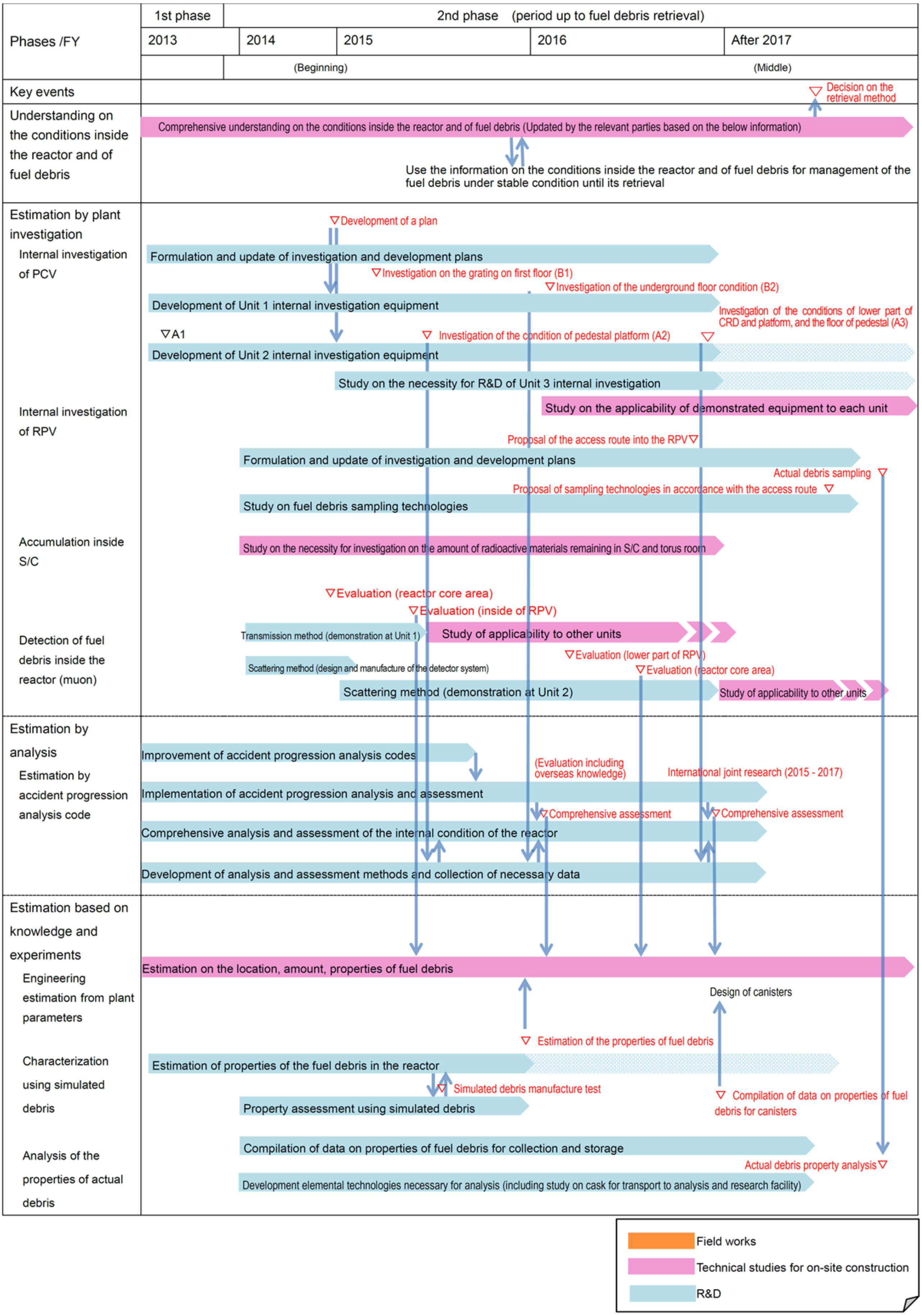
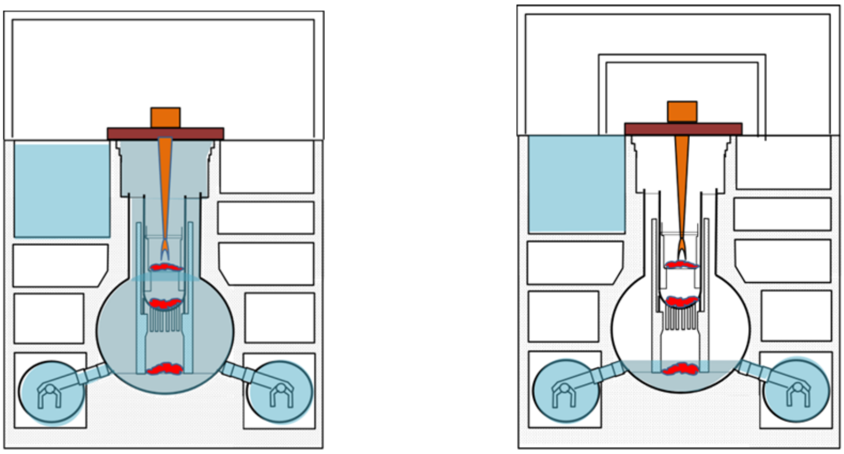


Figure 4.3.1-4 Future actions for understanding on the conditions of reactor and fuel debris

4.3.2 Study on the options of fuel debris retrieval method

For the fuel debris retrieval method of the Fukushima Daiichi NPS, studies have been conducted to aiming to employ a retrieval method used by TMI-2, which was to submerge the fuel debris underwater to allow dose reduction by use of water as a radiation shield. However, there are many challenging issues in the development of technologies required in order to repair the PCV damaged by the severe accident so that it will be able to fill with water. Assuming challenges in submerging the entire fuel debris, it is necessary to seek in parallel a method of retrieving the fuel debris while it exposed in the air and without filling the PCV with water to the top. These two methods of fuel debris retrieval are shown in Figure 4.3.2-1.



The retrieval method by filling to the top of the PCV with water to submerge the fuel debris

The method to retrieve the fuel debris exposed in the air and without filling the PCV with water

Figure 4.3.2-1 Images of fuel debris retrieval methods

In addition, unlike TMI-2 where the fuel debris remained in the RPV, it is thought that the fuel debris is extensively distributed inside the PCV as shown in Figure 4.3.1-1 in the previous section, therefore it may be difficult to reach and retrieve the fuel debris from top of the RPV as it was done in TMI-2, depending on the location of the fuel debris.

In such circumstances, options of fuel debris retrieval method based on the combination of different water levels of submersion within the PCV and the direction of accessing the fuel debris are identified, and with the assessment of applicability based on their features, multiple options are selected for more focused study so that retrieval can be successfully carried out for fuel debris under different distribution status and site conditions in each unit.

4.3.2.1 Study on the options based on PCV water level and direction of access to the fuel debris

(1) PCV water level

Since the features of the retrieval method differ depending on the water level of PCV, the classification of the retrieval method by different water levels at the time of fuel debris retrieval are defined below. The images of each water level are shown in Figure 4.3.2-2.

- Full submersion method: A method in which water fills to the top of the reactor well.
- Submersion method: A method in which the water fills to a level above the highest point of the fuel debris distribution.

Note: It is currently assumed that there is no fuel debris distributed above the reactor core area and water level is above the uppermost part of the reactor core area. This method is called the Submersion method.

- Partial submersion method: A method in which the water is filled to a level below the highest part of the fuel debris distribution.

*Note: It is currently assumed that there may be fuel debris exposed in the air if the water level is lower than the uppermost part of the reactor core area. This method is called the Partial submersion method.

- Dry method: All the areas where the fuel debris is distributed are exposed in air, and neither cooling nor filling of water is involved.

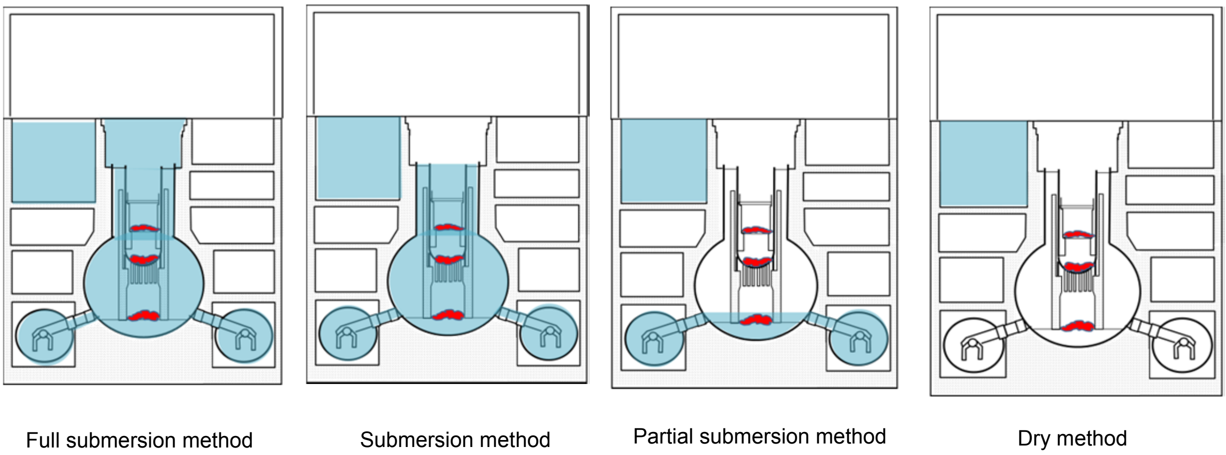


Figure 4.3.2-2 Method classification according to the PCV water level

(2) Feasibility study on the access routes for each direction of access to the fuel debris

As shown in Figure 4.3.2-3, there can be three directions to access the fuel debris, from the upper part of the PCV (Top entry), from the side of the PCV (Side entry), and from the bottom of the PCV (Bottom entry).

The feasibility of the access route for each direction is evaluated as follows.

a. Access from the top of the PCV (Top entry)

The access route from the top of the PCV into the core is structurally secured for the fuel replacement work during the outage. The access into the reactor can be secured by removing the well shield plug, PCV upper head, insulator for the RPV upper head, and RPV upper head. The upper grid plate immediately above the core may be reached by removing the steam dryer and steam separator allowing access to the fuel debris inside the RPV. However, there is a possibility that the equipment to be removed may be deformed as the results of exposure to high heat during the accident and may be difficult to remove using a normal method. In such case it is necessary to cut them before removal. Also the FPs such as Cs released from the fuels at the time of accident may have been absorbed by the equipment therefore protective measures against extremely high radiation may be necessary.

b. Access from the side of the PCV (Side entry)

On the side of the PCV, there are equipment hatch and CRD hatch which lead into PCV and even though the sizes of these openings may be restrictive, the access route into the PCV is structurally secured. At the bottom of the drywell (herein after referred to as "D/W") inside PCV, PLR pumps, valves, pipes and supports are installed outside of the RPV pedestal, and CRD handling machine and operating floor (grating) are installed inside the RPV pedestal and they may hinder access to the fuel debris, but they can be cut off and removed to enable access to the fuel debris located at the bottom of D/W.

c. Access from the bottom of the PCV (Bottom entry)

There is no access route available into the PCV from the bottom of the PCV, therefore it is necessary to establish a new access route to the bottom of D/W.

Logically it is possible to set up an underground access tunnel from outside the R/B to the bottom of D/W, but there is a concern that the establishment of such route may affect the underground water management. The tunnel must also penetrate the bedrock that supports the R/B, R/B foundations, D/W bottom shell and D/W bottom foundation, therefore there is a concern for reduced strength of R/B, D/W bottom shell and RPV pedestal foundation.

If the access route to the bottom of D/W can be built, the fuel debris at the bottom of D/W may be directly accessible and the advantage in this method is that there will be no need for removal of objects in the way. However in order to build such route, there are many important issues to be studied in order to deliver the safe and steady retrieval of fuel debris as stated above, and it will take considerably a long time of investigations and studies in order to resolve those issues.

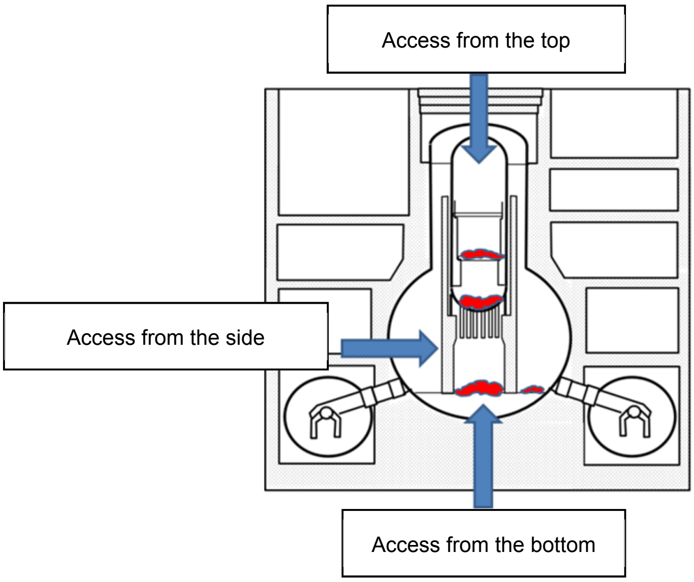


Figure 4.3.2-3 Access directions to the fuel debris

As described in a. through c. above, directions of accesses to the fuel debris are from top, side and bottom. Accesses from top and side are more feasible since the existing route may be used, but the bottom access will need establishment of a new access route and there are many critical issues to consider which makes it less feasible in a short period of time.

(3) Study and narrowing down of the options of retrieval method by combination of the PCV water level and direction of access to the fuel debris

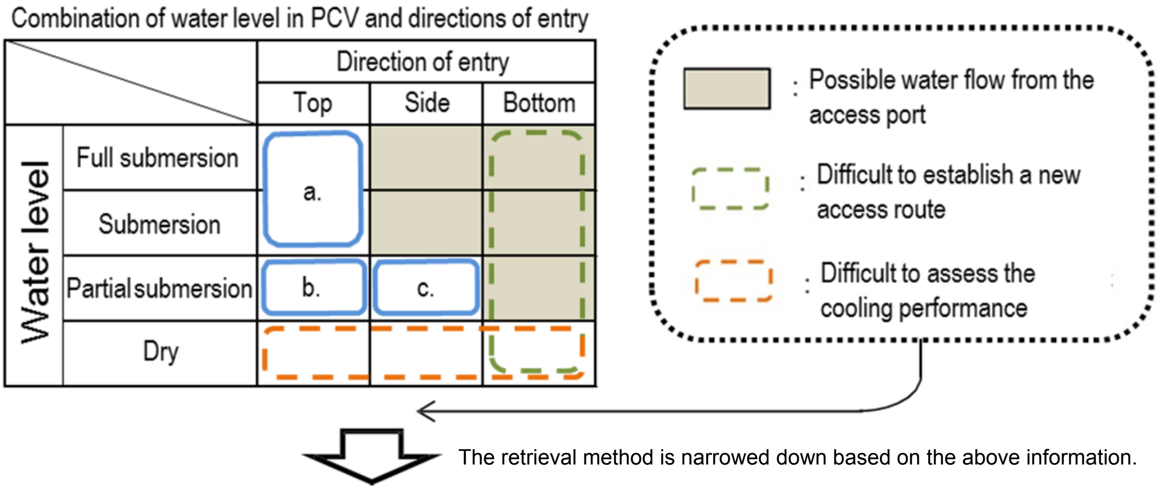
There are 12 possible patterns of fuel debris retrieval by combining different PCV water levels and the directions of access as shown in Figure 4.3.2-4. They will be studied for their applicability using actual retrieval equipment for selecting the retrieval method option.

For the Full submersion method and the Submersion method, the access port will be below the PCV water level for side and bottom entries, therefore a large water tight hatch will be required to prevent water flow from the access port when bringing equipment and materials in and out or at the time of fuel debris retrieval. Fully remote-controlled and automatic system will also be required, and there are a number of challenges for actual utilization of this method such as maintenance works through the water tight hatch or dealing with construction troubles. The same can be said for the Partial submersion method by side entry if the access port is below the PCV water level. These options will not be focused in the studies for the practical application.

The bottom entry is less feasible in terms of the establishment of the access route as explained in (2) c., therefore it will also not be focused in the study for the retrieval method option.

For the Dry method, the fuel debris properties are not confirmed at this point and it is difficult to assess the air cooling performance therefore it will not be studied in depth either.

Although the bottom entry method and the Dry method are unlikely to be chosen as feasible methods, they will continue to be studied at a fundamental level.



Retrieval methods to be focused and the names of the options

a. Full submersion or Submersion method with access from the top: Submersion-Top entry method

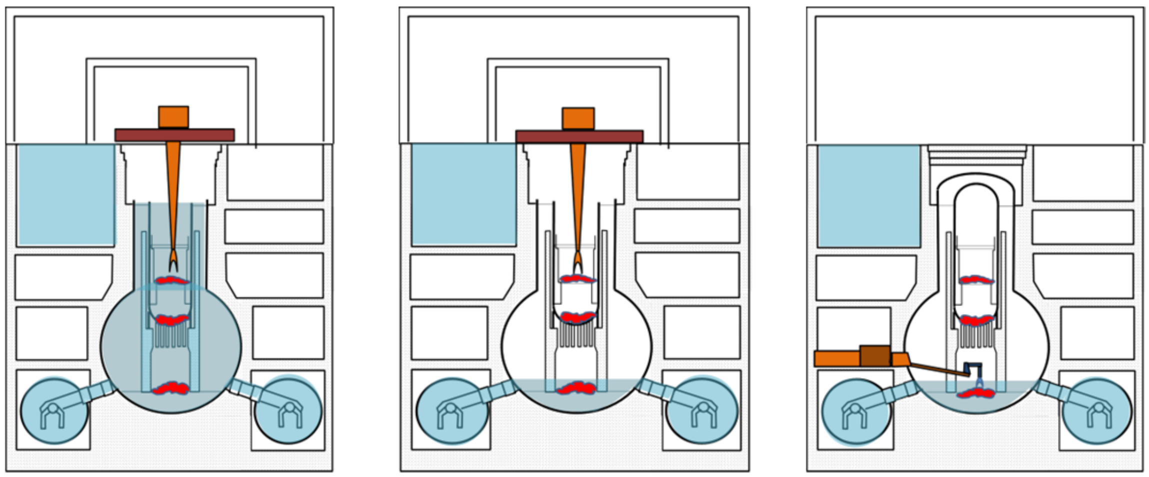
b. Partial submersion method with access from the top: Partial submersion- Top entry method

c. Partial submersion with access from the side: Partial submersion- Side entry method

Figure 4.3.2-4 Narrowing down of the methods using the combination of the PCV water level and access direction to the fuel debris

Based on the above, the options for fuel debris retrieval method are narrowed down into three methods described in the box at the bottom of Figure 4.3.2-4, namely the Submersion-Top entry method, Partial submersion-Top entry method and Partial submersion-Side entry method.

Images of these three options for fuel debris retrieval method are shown below in Figure 4.3.2-5.



Submersion-Top entry method | Partial submersion-Top entry method | Partial submersion- Side entry method

Assuming the in-core structures above the fuel debris are removed

Assuming that the in-core structures above the fuel debris are removed

Assuming that the equipment and other objects outside the RPV pedestal in PCV are removed

Figure 4.3.2-5 Images of the options for fuel debris retrieval method

4.3.2.2 Studies on the applicability of the options of retrieval method based on the location of the fuel debris

As shown in Table 4.3.1-1, the fuel debris is assumed to be located not only in the RPV (at reactor core and lower plenum), but also inside the RPV pedestal at the bottom of D/W and even at outside of the RPV pedestal for all Units 1 through 3. There also may be some fuel debris flowed into the CRD housing from the lower plenum.

The assumed distribution of the fuel debris is illustrated in Figure 4.3.2-6

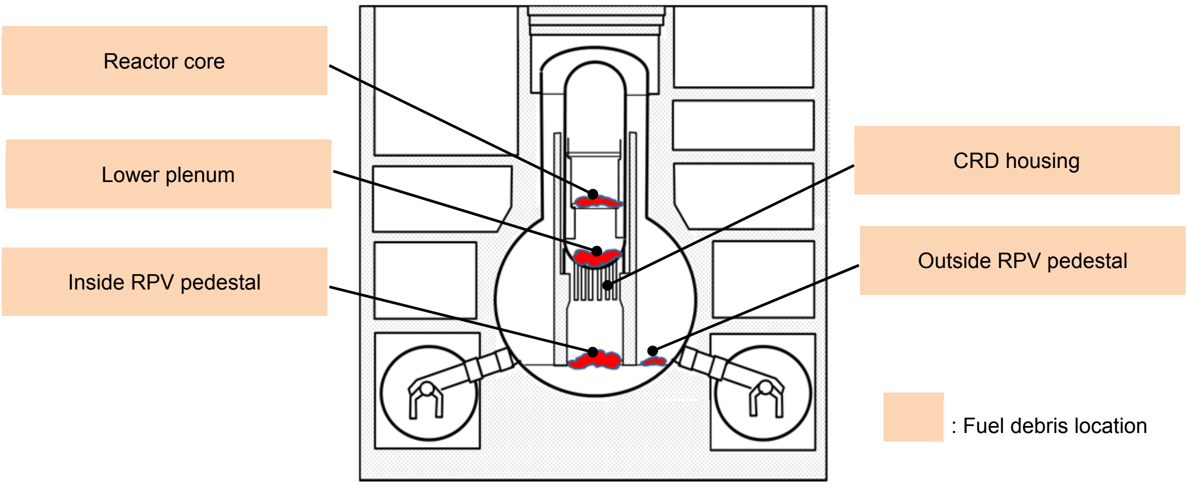


Figure 4.3.2-6 Diagram of estimated distribution of the fuel debris

Table 4.3.2-1 shows the result of study on the applicability of the options of retrieval method based on the location of the fuel debris in terms of how difficult the option is to realize, and Table 4.3.2-2 shows the summary of the result of such study.

Table 4.3.2-2 shows that regardless of the estimated locations of the fuel debris (inside RPV (at reactor core, lower plenum, CRD housing), inside RPV pedestal and outside RPV pedestal), any of the three options can be used for retrieval of fuel debris. It also shows that the combination of these options may be necessary for fuel debris retrieval depending on the distribution of the fuel debris of each unit.

Table 4.3.2-1 Study on the applicability of the options of the retrieval method based on the location of the fuel debris

△:More feasible ▲:Less feasible

Retrieval methods \ Fuel debris location	RPV: Inside RPV (Reactor core, lower plenum)	RPV: CRD housing	Inside RPV pedestal	Outside RPV pedestal
Submersion-Top entry method Partial submersion-Top entry method	△ • Removal of the upper structures[1] is assumed feasible by modification of existing technologies.	△ • Removal of the upper structures[1] is assumed feasible by modification of existing technologies. • Retrieval of fuel debris in/outside the CRD housing is assumed feasible by modification of existing technologies and short-term technical development if it is carried out together with the removal of housing.	△ • Removal of the upper structures[1] is assumed feasible by modification of existing technologies. • A large opening will be required at the bottom of RPV and is assumed feasible by modification of existing technologies and short-term technical development. • Operation position several 10m down, requiring lowering of the platform for better operability, but assumed feasible by short-term technical development.	▲ • Direct access not possible even with an opening at the bottom of RPV. It is necessary to go down a long distance to the bottom of RPV pedestal and sideways to access. The functions of retrieval equipment will be complex and assumed to require an extremely long time of technical development.
Partial submersion-Side entry method	▲ • Establishment of access route into RPV using X-6 penetration is assumed feasible by a short-term technical development. • Distance to fuel debris in RPV is app. 20m above the lower part inside RPV pedestal, and a highly rigid, large scale retrieval equipment is required for CRD housing removal, creating borehole at RPV bottom and fuel debris retrieval, but with limited size of opening and space, installation and operation of such equipment is assumed extremely difficult.	▲ • Establishment of access route into RPV using X-6 penetration is assumed feasible by a short-term technical development. • Distance to CRD housing is app. 10m above the lower part inside RPV pedestal and a highly rigid, large scale retrieval equipment is required, but with limited size of opening and space, installation and operation of such equipment is assumed extremely difficult.	△ • Establishment of access route into RPV using X-6 penetration is assumed feasible by a short-term technical development. • Removal of obstacles (grating, CRD handling machine, etc.) required for accessing the fuel debris on the floor is assumed feasible by a short-term technical development.	△ • Establishment of access route to outside of RPV pedestal using the penetration to the PCV is assumed feasible by a short-term technical development. • A lot of equipment installed outside RPV pedestal, but fuel debris is believed to be at limited locations (i.e., near the entrance of RPV pedestal), removal of obstacles within a limited area is assumed feasible by a short-term technical development.

1: Well shield plug, PCV upper head, insulator for RPV upper head, RPV upper head, steam dryer, steam separator, upper grid plate

Table 4.3.2-2 Summary of the study on applicability of the options of retrieval method based on the location of the fuel debris

○: More applicable

-: Less applicable

Options of fuel debris retrieval method	Location of the fuel debris		
	RPV (Reactor core, lower plenum, CRD housing)	Inside RPV pedestal	Outside RPV pedestal
Submersion -Top entry method	○	○	-
Partial submersion -Top entry method	○	○	-
Partial submersion -Side entry method	-	○	○

4.3.2.3 Study on the work steps for fuel debris retrieval

For three options of the retrieval method to be focused, (1) through (3) below show the current status of work steps for the fuel debris retrieval. The procedure and actual works will need to be reviewed in accordance with the site conditions and the future progress of studies, and the work for "fuel debris retrieval" itself needs to be developed into more specific work steps for each option.

(1) Submersion-Top entry method

Basically the following work steps 1 through 9 were considered for the fuel debris retrieval by Submersion-Top entry method so far, and the overview of the work steps is illustrated in Figure 4.3.2-7.

The overall procedure is, to reduce the dose of the working areas where the fuel debris retrieval and its preparation works take place and the access route to such area by decontamination (1), to establish a work environment inside the R/B and investigate the internal conditions of the PCV (3), to investigate the leak locations of the PCV and repair (water leak blockage) (2, 4, and 6) and to submerge the fuel debris (5 and 7), to open the RPV upper head (7), to access inside the reactor vessel and investigate the internal conditions (8), and then to retrieve the fuel debris (9).

1. Decontamination inside the R/B
2. Investigation of the leak locations of the PCV
3. PCV internal investigation
4. Repairs on the lower part of the PCV and R/B penetrations
5. PCV partial submersion
6. Repair of the upper part of the PCV
7. PCV and RPV submersion, RPV upper head removal

8. Internal investigation on the reactor vessel, fuel debris sampling
9. Fuel debris retrieval

The work steps need to be reviewed to ensure the safe and steady fuel debris retrieve by understanding the internal conditions at an early stage, such as carrying out the internal investigation in (8) before filling the PCV with water in (5), or filling the PCV with water all at once in (7) instead of in 2 phases in (5) and (7).

(2) Partial submersion-Top entry method

The work steps for the Partial submersion-Top entry method are assumed to be basically the same as those for the Submersion-Top entry method, but since the water level inside PCV is lower and the upper part of the PCV is exposed in the air, there may be differences in the areas of repair on the lower part of the PCV (4) and specifications for the repair of the upper part of the PCV (6). Moreover, the retrieval work is to be conducted with some part of the fuel debris exposed in the air, therefore cooling, shielding and prevention of scattering of the dust will need to be considered.

The work steps need further elaboration in order to gain understanding on the reactor condition as soon as possible, and to deliver safe and steady fuel debris retrieval from PCV that has low level of water as mentioned above.

(3) Partial submersion-Side entry method

For the work steps 1 through 6 explained in (1) above, the upper part of PCV is exposed in the air like in the case of the Partial submersion-Top entry method, so there may be differences in the areas of repair of the lower part of the PCV (4) and specifications for the repair of the upper part of the PCV (6).

PCV water level is lower than the access port located on the side of the PCV, therefore submersion up to top of the PCV (7) is unnecessary, and the partial submersion (5) may not be required either. RPV upper head removal (7) is not necessary since the access is made from the side of the PCV, but instead an additional step of installation of an access port at the side of the PCV is required. Moreover, the fuel debris to be retrieved is located at the bottom of D/W, therefore instead of the internal investigation of the reactor vessel (8), an investigation on the bottom of D/W from the established access port may need to be studied in addition. As with the Partial submersion-Top entry method, the retrieval work is to be conducted with some part of the fuel debris exposed in the air, therefore cooling, shielding and prevention of scattering of the dust will need to be considered.

Based on the above, it is necessary to further elaborate the work steps for safe and steady fuel debris retrieval.

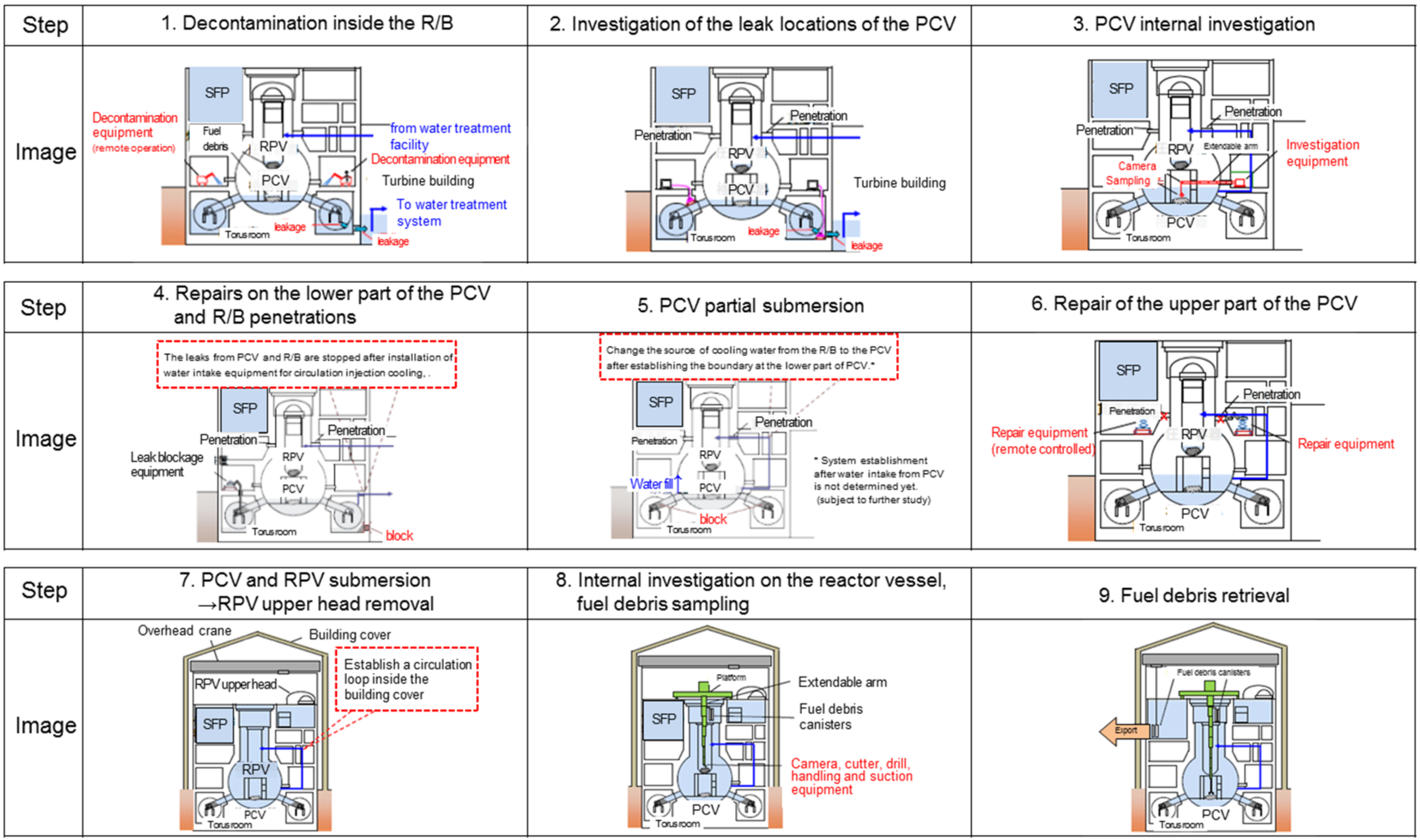


Figure 4.3.2-7 Outline of work steps of the Submersion-Top entry method

4.3.3 Assessment on the approaches and FS on the Submersion method

4.3.3.1 Overview

With regards to nine technical requirements listed below which are necessary for realization of the fuel debris retrieval by the Submersion method, actions to be taken to satisfy the requirements and necessary measures for judgment of whether such requirements are met are identified, and based on the current status of R&D projects (achievements and plans), the way forward including the subjects of further study is explained below.

In addition, based on the assessment on the feasibility of these nine requirements, study policy for the applicability of the Submersion method in each unit is summarized.

- Securing the structural integrity of the PCV and the R/B
- Criticality control
- Maintaining the cooling function
- Establishment of the containment function
- Reduction of exposure to the workers during operation
- Development of the fuel debris retrieval equipment and devices
- Establishment of access routes to the fuel debris
- Establishment of the system equipment and working areas
- Ensuring the work safety

4.3.3.2 Assessment of approaches using the technical requirements

The following sections explain the purpose, major requirements, current status and the future actions on the nine technical requirements.

4.3.3.2.1 Securing the structural integrity of the PCV and the R/B

(1) Purpose

In order to ensure safe and steady fuel debris retrieval by the Submersion method, 1) R/B must maintain its supporting function of the PCV, 2) PCV must retain its present shape to maintain the water level and prevent the massive release of radioactive materials, 3) RPV must retain its present shape to maintain the circulation of cooling water and it must be assessed that these are also available at the time of earthquake. Figure 4.3.3-1 shows the PCV and the RPV in the cross section view of the R/B.

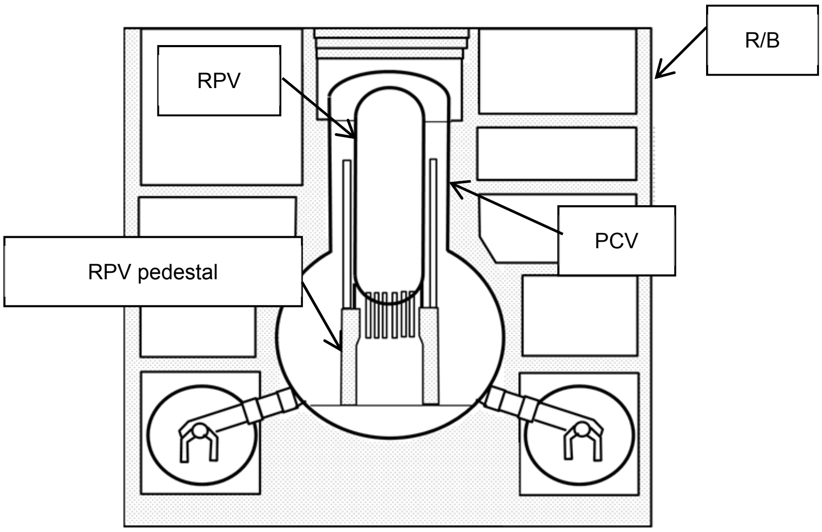


Figure 4.3.3-1 Cross section view of the R/B

(2) Major requirements

a. An appropriate seismic ground motion and evaluation criteria are to be defined based on the required functions described in 1) -3) of (1) and the impact in case of failure of these functions.

b. The damages caused by the accident, degradation of materials due to exposure to high temperature, corrosion by the seawater injection and further degradation and further corrosion that may occur by the time of the completion of fuel debris retrieval are to be studied.

c. The weights of fuel debris, cooling water inside of the PCV and other areas, and fuel debris retrieval equipment, shielding, construction materials and machinery are to be considered as criteria for load during earthquake according to the fuel debris retrieval method plan.

(3) Current status

The following actions have been taken at present.

a. Evaluation on the material degradation due to exposure to high temperature
Based on the temperature measured in each unit after the accident, the testing conditions were established and results of the strength test of metal materials of the PCV and the RPV exposed to high temperature has been acquired. The test data showed little change in the parameter of material strength and it was confirmed that parameters of both materials fall within the standard value range.

b. Evaluation of the corrosion progression by salt corrosion caused by seawater injection
Based on the measurement data taken after the accident in each unit, the temperature and water quality (e.g. salinity concentration) over the time period from immediately after the accident to the present and until the time of the fuel debris retrieval were estimated and corrosion thinning progression test for the materials used for the PCV and the RPV are conducted on the parameters

of temperature and water quality. Based on the test results, an evaluation formula for the corrosion thinning for a given time period is being developed. Also, the test for the corrosion impact caused by the increase in dissolved oxygen after opening of the PCV upper head and development of the corrosion inhibitor have been started.

c. Development of RPV/PCV seismic strength evaluation method

Assuming the future condition of each unit, the case study for seismic evaluation is implemented setting the water level inside the PCV, amount of corrosion in the equipment, weight of construction materials and machinery to be added to the building as parameters. Reference evaluation for each case is conducted based on the seismic evaluation standards for normal operating plant to determine the seismic margin. Using the results of this case study, simplified evaluation method is being developed setting seismic condition such as the water level inside the PCV, weight of fuel debris retrieval equipment/construction equipment, status of equipment repair works and corrosion of equipment as parameters so that the seismic evaluation may be conducted promptly in accordance with the progress on planning for the Submersion method.

d. Studies on the degradation of the RPV pedestal and development of the resistance evaluation method

Studies on the material degradation characteristics by concrete thermal impact assessment tests under the accident condition and corrosion test for reinforcement bars as well as development of plan resistance evaluation method by resistance test on reduced-scale RPV pedestal and comparative evaluation on the simulation analysis of this resistance test are being carried out. As for the erosion at the basement caused by fuel debris, impact assessment method is being developed on the parameters of degree of erosion.

e. Confirmation of seismic resistance of the R/B

Seismic analysis was conducted using the model reflecting the conditions of the R/B damaged by the hydrogen explosion and the seismic margin against the standard seismic ground motion Ss has been confirmed for each unit.

(4) Future actions

The following are the actions to be taken.

a. The items listed in a. through d. of (3) are to be completed in the last half of FY2015 as scheduled and the preparation work for PCV and RPV seismic evaluation is to be completed.

b. For (3) b., long term corrosion tests (10,000 hours target) regarding the corrosion impact resulting from the boric acid injection to prevent criticality is to be considered.

c. In light of safety regulations, the seismic ground motion and evaluation criteria mentioned in (2) a. are to be promptly studied.

d. Based on the seismic evaluation using the simplified evaluation method to be formulated under (3) c., the Submersion method is to be studied while determining the level of seismic margin. A detailed seismic evaluation on the final option using the seismic ground motion and evaluation criteria described in (2) a. is to be carried out.

e. For (3) d., assuming that the fuel debris is confirmed to be scattered at the RPV pedestal base by the PCV internal investigation, necessary activities for seismic evaluation based on such condition (such as additional investigations) is to be considered.

f. For the R/B referred to in (3) e., seismic evaluation assuming the further degradation is to be carried out taking into account the distribution of the fuel debris at the time of retrieval and approximate weights of the cooling water, construction equipment, shielding and other devices.

4.3.3.2.2 Criticality control

(1) Purpose

Over the course of fuel debris retrieval, water injection and retrieval works will be carried out. Even in case that the shapes of fuel debris and water level change as a result of these operations, it is necessary to prevent exposures to workers and impacts to the environment due to recriticality. Hence, in addition to the neutron absorber, sub-criticality evaluation and monitoring technologies needs to be developed in order to ensure that criticality is under control.

(2) Major requirements

In order to achieve the target, it will be important to understand how the fuel debris which does not currently show any indication of criticality goes into a state of recriticality. And with that understanding, a technology to bring the fuel debris to a sub-critical state in case of the occurrence of recriticality will be required. These technologies will be extremely difficult to develop, and it will be essential to identify the requirements for development of each method and technology and to fully assess whether these requirements can be satisfied.

a. Criticality evaluation methods

In order to appropriately control criticality in current status where the condition inside the PCV is not clear, it is necessary to broadly estimate the location, amount, shape and properties of the fuel debris, and identify events that may induce recriticality over the period from the preparation up to the fuel debris retrieval work, and assess the possibility of recriticality under these conditions. However, excessive conservatism may affect the judgment on the feasibility of criticality control, therefore it is important to set a reasonable level of conservativeness. It is also necessary to accurately evaluate the amount of FPs and exposure dose rate to consider the measures for mitigation of environmental impacts in case of recriticality.

The following are the requirements to be satisfied for the criticality evaluation methods to be put into practice.

- The criticality scenario is to be evaluated based on appropriate conditions.

- The information necessary for the judgment on the reasonable conservatism is to be identified, and a plan for acquisition of such information is to be drafted and implemented.
- The accuracy of the assessment on recriticality consequences is to be verified.

b. Sub-criticality monitoring methods

The neutron multiplication factors change if the retrieval work affects the criticality (water level/amount) of the fuel debris, therefore it is necessary to monitor such changes. In addition, if any abnormity is detected, works should immediately be suspended or neutron absorber should be used to maintain the state of sub-criticality.

The following is the requirement to be satisfied for the sub-criticality monitoring methods to be put into practice.

- The partial increase in effective multiplication factor of the widely distributed fuel debris must be detectable.

c. Recriticality detection technologies

The distribution of the fuel debris is not fully understood, making it difficult to monitor the neutron multiplication factors and the technology is currently underdeveloped. On the other hand, the amount of FPs and neutron and gamma doses will increase once the criticality occurs, making it rather easy to detect them. However, this method may result in the delay in detection and responses since detection may take time as well. Therefore, it is required to take appropriate measures to prevent the exposures to the workers and the public.

The following are the major requirements to be satisfied for the recriticality detection technologies to be put into place.

- Safety must be ensured by the combination of recriticality detection, exposure evaluation and mitigation measures.
- Recriticality of partial fuel debris scattered in a wide area must be detectable by neutron monitoring.
- The water level must be closely monitored and the fuel debris retrieval works must be carefully implemented.

d. Criticality prevention technologies

By dissolving the neutron absorber in the coolant or covering the surface of the fuel debris with neutron absorber, criticality must be prevented regardless of the condition of the fuel debris. If this can be achieved, there may be fewer restrictions posed on the fuel debris retrieval method.

The following are the major requirements to be satisfied for the criticality prevention technology to be put into practice.

- The reactivity required to maintain the recriticality in assumed conditions must be specified and secured.
- The integrity of the facility must be maintained taking into account of corrosion of materials inside the reactor and impact on the cooling water circulation system.

(3) Current status

The development of methods and technologies for criticality control began in 2012 and is still ongoing. The achievements to date are outlined below[1].

a. Criticality evaluation methods

For each location where the fuel debris is assumed to be deposited, initial condition (shapes and compositions of the fuel debris and cooling conditions) and combination of the events that may cause criticality in each step of fuel debris retrieval were assumed, and the likelihood of criticality was determined. The parameters were roughly established for severe cases and the criticality evaluation was conducted, enabling identification of a certain range of conditions that may cause recriticality. There is a certain range of conditions that leads to recriticality if the FPs and the control rods are not taken into account but the possibility of recriticality was confirmed to be low realistically considering the Gd contained in the fuels and the stainless steel of the structural materials.

Moreover, in order to assess the neutron response and amount of FPs generated after recriticality for development of an impact mitigation measure against exposures, a thermal-hydraulic model for a single-point reactor kinetics analysis code was improved, and FP generation assessment model necessary for the development of recriticality detection system was created using the exposure and gamma-ray at the time of recriticality. Furthermore, the items and challenges for the developments for handling the complex fuel debris (such as stub-shaped debris) were identified and summarized and the verification by a three-dimensional analysis code was carried out in FY2014.

b. Sub-criticality monitoring methods

The sub-criticality monitoring methods were developed for the liquid waste treatment facilities and cooling facilities that may reach criticality as a result of leakage and accumulation of the fuel debris and its development completed in FY2013.

For the sub-criticality monitoring system equipped with a neutron detector, gamma spectrum detector, and gamma dosimeter, concepts in accordance with the reverse multiplication method was established, its design and prototype created, and the feasibility was evaluated by the criticality facility. In the element test, the basic data on the detection characteristics of neutron detectors and gamma ray detector in high background gamma-ray was obtained. In the system test, the performance to recognize the changes in the sub-criticality state by processing the signals from the detectors was evaluated, and confirmed that the criticality approach can be monitored in sub-critical condition with an effective multiplication factor of approx. 0.5 to 0.7. Moreover, as a different method, usage of the reactor noise in the neutron count rate measurement was studied and possibility of its application was confirmed. (Figure 4.3.3-2)

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[1] IRID Symposium 2014 "R&D in Preparation for Fuel Debris Retrieval, etc." (July 18, 2014)
IRID. Overview of Achievements in Fiscal 2013 "Development of Fuel Debris Criticality Control Technology" (July 31, 2014)

The development of the sub-criticality monitoring methods began in FY2014 for application in the PCV and the RPV.

c. Recriticality detection technologies

Studies have been conducted on the measurement methods of neutron and gamma-ray from short-lived FPs (Figure 4.3.3-2).

Neutron dose distribution in and outside the PCV in the event f recriticality was analyzed, and a concept was developed on the neutron detection system to be installed inside the PCV. The design and prototype of the equipment was created, and the feasibility was evaluated in the irradiation test facility. As a result, data on the count rate sensitivity for neutron signals distinctive from the gamma ray under high gamma irradiation environment was obtained. The development on the measurement method based on neutron detection was completed in FY2013.

For the gamma detection system assuming installation in the gas treatment systems, an option of an improved method that has faster response speed of recriticality detection than the current PCV gas control system has been studied, and an optimized design focusing on the difference of FP yield between spontaneous fission and neutron fission was created. As a result, concurrent counting for Kr-87/88 in addition to the current counting system of Xe-135 was selected, and the element test was conducted for verification of the principles and the feasibility of the system was confirmed. Depending on the conditions, the detection limit may be improved by more than 10% (figure 4.3.3-3).

In detection of recriticality based on the gamma ray, the delay in detection time may have a significant impact on the mitigation and termination of accident progression, therefore it is as equally important as the development of the dose evaluation and impact mitigation measures. The current target is to shorten the detection time to 1/10 of the current speed, and further attempts are being made.

d. Criticality prevention technologies

The impacts of the soluble neutron absorbers (boric acid and sodium pentaborate) on the material integrity inside the reactors (corrosion resistance) were studied, and tasks were identified and a project plan was drafted. Furthermore, by testing with the presence of boric acid and chlorine in the irradiation test facility, it was confirmed that the amount of hydrogen generated by the radiation decomposition of water increases but falls within the expected range of values. With regards to the impacts on the performance of the nuclide removal system and separation and collection method of the neutron absorber, tasks were identified and a project plan was drafted. An appropriate concentration must be specified before the actual use of the soluble neutron absorbers to ensure rationalization of the facilities and the integrity of the materials, therefore the criticality scenarios and the impacts of corrosion on the integrity of the PCV are carefully studied.

Study was conducted on the insoluble neutron absorber materials and the material to bind the absorber to the fuel debris and the samples of possible candidates were manufactured or procured. The characteristics such as the density and thermal conductivity were measured on the samples and the elution characteristics in high-temperature water were evaluated to narrow down the candidates. As a result of the tests, B_4C/ metal sintered body, B/Gd containing glass material, Gd_2O_3 grains, cement/Gd_2O_3 grains and slurry/Gd_2O_3 grains were selected as the candidates (Figure 4.3.3-4).

(4) Future actions

The past achievements and the current studies were compared to the requirements, and the areas that require further studies are identified and summarized below.

a. Criticality evaluation methods

- In order to acquire necessary information accordingly over the course of the development of various criticality control methods, the required information and the timing must be more specifically identified and such information should be definitely acquired.

b. Sub-criticality monitoring methods

- The locations where recriticality may occur is to be identified and detectors are to be installed around those locations. However, because the distribution of the fuel debris is unconfirmed and there are restrictions on the installable locations, possibility of meeting the requirements should be fully determined.
- The development policy is to be amended if requirements cannot be met.

c. Recriticality detection technologies

- The practical application should be determined with the involvement of the site personnel. Therefore, for recriticality detection technologies using the neutron detection system whose development completed in FY2013, it is necessary to confirm the installable locations of the detectors and determine whether the requirements can be met.
- The targets for securing the safety are to be reconfirmed, including the target time of detection to be 1/10 of the current time in case of gamma ray detection for recriticality detection system.

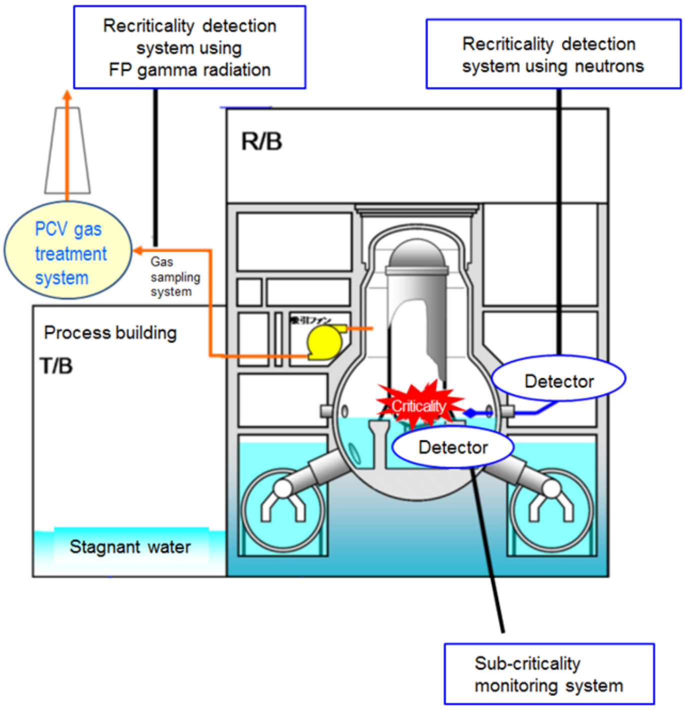
d. Criticality prevention technologies

- For the use of soluble neutron absorbers, boron concentration has been reviewed considering the impact of corrosion on the integrity of the PCV, but since the condition of the fuel debris is unknown, an excessive boron concentration may be necessary for maintaining the sub-critical state. Therefore, the effective information (presence of stub-shaped fuels) needs to be identified and acquired in order to ensure reasonable conservativeness to assess the criticality scenarios.
- A criticality control method is to be studied to reduce the boron concentration as much as possible, such as combination with the other criticality control methods.

- A method is to be formulated to confirm the amount of neutron absorber absorbed to the fuel debris due to packers a way to quantify the reactivity effect so that the insoluble neutron absorber can actually be used on site.

The above mentioned actions should be carried out as early as practicable in preparation for the fuel debris retrieval. However, processes that may affect the water level or the shapes of the fuel debris require criticality control before the retrieval work, and studies for the application will be necessary to prepare for the increase of water levels after water leak blockage of the PCV.

The possible technologies that can be applied in such case include soluble neutron absorber and recriticality detection by gamma ray or a combination of these technologies, and the development of these technologies must be completed as soon as practicable.



(Provided by IRID)

Figure 4.3.3-2 Sub-criticality monitoring and recriticality detection systems

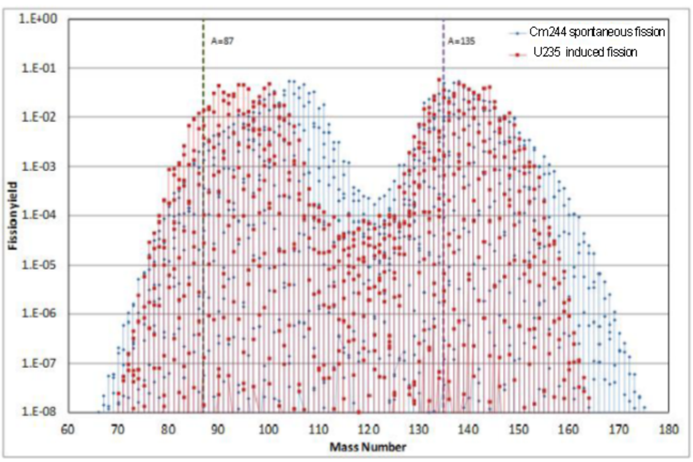


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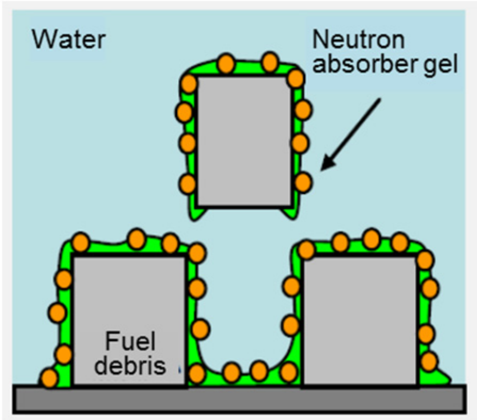
Figure 4.3.3-3 Difference in yields of spontaneous fission and neutron fission



(Provided by IRID)

Figure 4.3.3-4 Image of insoluble neutron absorber

4.3.3.2.3 Maintaining the cooling function

(1) Purpose

To maintain the cooling function since decay heat is constantly generated by the fuel debris. The temperature at the bottom of the RPV and in the gas phase of the PCV are stably maintained at approx. between 10°C and 30°C by the circulation cooling loops and the cooling function is confirmed at present. In preparation for the completion of fuel debris retrieval and completion of stagnant water treatment, it is planned to complete the establishment of small circulation loop, in sequence of first the circulation inside the building to reduce the risk of contaminated water leakage to outside, and then the PCV circulation cooling by the time of the PCV repair, and at each stage the cooling function needs to be confirmed.

(2) Major requirements

There are different requirements for each phase of preparation for the fuel debris retrieval. The following are the major requirements for each phase.

a. Phase 1: Circulation loops during stagnant water treatment

- The reactor vessel must be cooled and removal of Cs and desalting of the contaminate water must be possible (Figure 4.3.3-5)
- Sequential implementation of treatments of the stagnant water of each building with different floor height and water levels must be possible. In the building where the treatment is not completed, operation and management need to be established (monitoring and control of each water level) to maintain the underground water level higher than the building's stagnant water level at all times.
- Emergency cooling measures are to be developed (during cooling system shutdown).

b. Phase 2: Circulation loops during the PCV repair work

- Circulation, collection and drainage with required flow rate must be possible before the start of the PCV repair work.

- Emergency cooling measures are to be developed (during cooling system shutdown).

c. Phase 3: Circulation loops during fuel debris retrieval work
   - The necessary functions must be in place for long term operation during the fuel debris retrieval works.
   - Treatment of the pieces of fuel debris that flow into the circulation loops needs to be studied.
   - Emergency cooling measures are to be developed (during cooling system shutdown and in the event of massive drainage).

(3) Current status

By maintaining the cooling water injection, the RPV bottom temperatures and the PCV gas phase temperatures of Units 1 through 3 are maintained between approx. 10°C to 30°C over the recent one month in spite of the differences in units and the locations of the thermometer. There are no significant changes in the parameters such as the pressure inside PCV and the amount of radioactive materials emitted from PCV and no abnormality in the cooling condition or the indication of criticality was observed. From the above, it was confirmed that the overall cold shutdown state has been maintained and the reactors are in stable condition (reference: Presentation from 15^{th} Contaminated Water and Decommissioning Issues Team/Secretariat Meeting dated February 26, 2015). In addition, there are multiple back-up systems for injection of coolant into the reactors so that credibility of the cooling system is improved (Figure 4.2-6 Example of Unit 1).

(4) Future actions

a. Phase 1: Circulation loops during stagnant water treatment

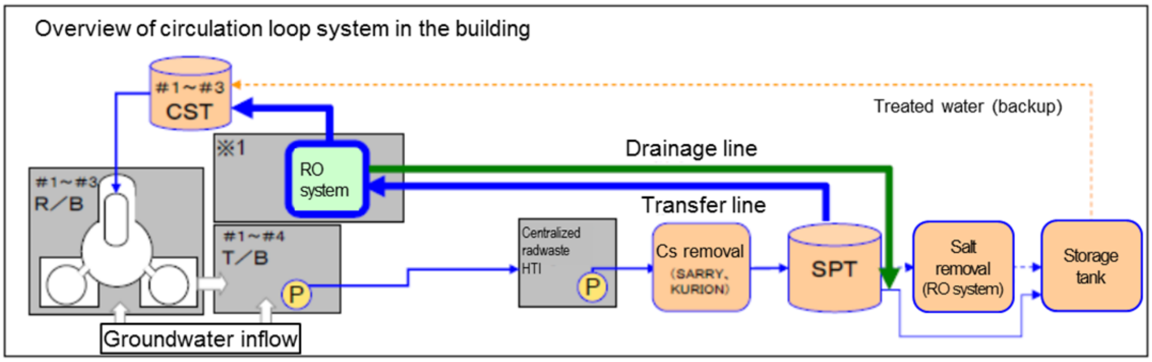
   As shown in Figure 4.3.3-5, cooling of the fuel debris and removal of Cs and salt in stagnant water must be possible, and taking into account of the stagnant water level inside the building, underground level, timing for the land-side impermeable walls to be in place, and the status of water drainage through sub-drains, leakage of contaminated water to the outside of the building must be prevented by maintaining the underground water level higher than the stagnant water level in the buildings at all times. To do so, detailed study for operation and management (monitoring and control of each water level) should be carried out for the establishment of circulation loops inside the building.

b. Phase 2: Circulation loops during the PCV repair work

   Studies on the flow rates of collection, circulation and drainage from torus rooms must be conducted based on the estimated amount and locations of leakage after PCV repair and the circulation loops must be designed. To do so, actual performance of water leak blockage (permissible amount of leakage) of PCV repair project must be confirmed and location of water intake and installation method of the water intake lines for circulation system must be studied, and prior to the start of the PCV repair work, the cooling system with functions to collect, drain and circulate the cooling water will be installed.

c. Phase 3: Circulation loops during fuel debris retrieval work

The circulation loops with necessary functions to enable fuel debris retrieval under water must be developed. In parallel with the studies for collection system of leaked water based on the estimated amount and locations of leakage after PCV repair works, cooling, criticality prevention, removal of radioactive materials, turbidity prevention, water quality management, water level control, massive drainage, monitoring, engineering of interlocks, R&D and response to regulations should be carried out in preparation for fuel debris retrieval.



(Provided by TEPCO)

Figure 4.3.3-5 Phase 1: Circulation loops during stagnant water treatment

4.3.3.2.4 Establishment of the containment function

(1) Purpose

To block the leakage from PCV as much as possible so that the water level may rise to reduce the impacts on the workers and the surrounding environment in light of the effects of radiation shielding and prevention of dust scattering. Technologies to investigate and repair the leak locations are to be developed and leakage from PCV needs to be blocked.

(2) Major requirements

The following are the major requirements to be satisfied at the time of the PCV submersion.

- The stable performance for the water leak blockage needs to be secured for a long period of time including construction period for fuel debris retrieval work from the viewpoint of ensuring the safety and responding to the regulatory requirements.
- The integrity of the PCV and PCV supporting structures must be ensured so that they could sufficiently resistant to the water pressure at time of the PCV submersion and in case of earthquake.
- Inspection method after PCV repair work, repair method in the event of leakage, and countermeasures for risks such as prevention of spread of contamination must be established.

(3) Current status

The above requirements are prerequisites in the case that it is confirmed that submersion to the top of the PCV is possible using the technologies under development at present or to be developed in the future (Figure 4.3.3-6). The investigations showed that there may be possible damages in the PCV (Unit 1) or at the welded parts of the pipes connecting to the PCV. It is also currently assumed that because it requires access to extremely high dose areas, it may be difficult to identify all locations of leakage and to repair them completely by welding. Therefore, more reliable repair method such as welding is planned for the areas more accessible for workers if dose reduction and removal of hindering objects are carried out, and a remote-controlled method is being sought for other areas where access is difficult. Studies on the feasibility of water leak blockage is under way so that the circulation cooling system can function stably using small circulation loops. (Figure 4.3.3-7 shows the areas where the water leak blockage and other repair works are necessary.)

a. Investigation of the PCV damaged areas

i) In order to identify the leakage locations of the PCV, investigation of lower part of the PCV (torus rooms) is underway using an investigation robot developed for this purpose, and the results of investigation are as follows.

- Unit 1

  The water level in D/W is estimated to be approx. 3.0m from the bottom, and leakage from sand cushion drain pipe and protective cover of an expansion joint on vacuum break line was confirmed. PCV may be damaged by shell attack (the opening caused by the damage is assumed to be small based on the hydraulic head pressure). (Figure 4.3.3-8) Repair may be difficult if shell attacks occurred.

- Unit 2

  The water level in D/W is low, approx. 0.3m from the bottom, and there may be leakage with relatively low level of flow resistance of the channel but not yet detected. (Figure 4.3.3-9)

- Unit 3

  The water level in D/W is estimated to be approx. 6.5m, and even if there may be damages at the lower part of the PCV, the opening caused by the damage is assumed to be small based on the hydraulic head pressure. A leakage from the expansion joint of the main steam pipe was confirmed. (Figure 4.3.3-10)

  Investigation on the upper part of the PCV has been implemented for limited area so far. Investigation technologies are currently being developed, and investigations around the reactor well (bulk head) and at the equipment storage pool are necessary.

b. Repair technology development for lower part of the PCV

R&D is underway in order to realize following twofold method for repair of lower part of the PCV.

- The vent tube is to be provisionally repaired by the inserting sealing material (air-bag like inflatable seal) and then completely repaired by the injection of grout.
- S/C is to be filled with grout to the top of the downcomer outlet.

In addition, for the leakage from the vacuum break line which is a facility unique to Unit 1, a repair method by inserting a packer for provisional repair followed by injection of grout for full repair is going to be studied as well as another method by injection of silicon based materials between a pair of balloons.

By the vent tube sealing experiments performed using a scaled-down model, issues such as the insufficient inflation of the sealing material in the tube leaving openings in the tube, or the expansion of the vent tube under high water pressure causing detachment of grout and the creation of water passage have been identified so far. Therefore, there will be studies to improve the water leak blockage performance (such as to first stop the downcomer leakage) by formulating a method to allow more moderate requirements of cooling water flow. The technical applicability will be confirmed by element tests using 1/2- and 1/1-scale models of the surrounding structures (such as down comer) of the areas of repair, and in addition, the developed technologies including repair feasibility using remote-controlled devices will be verified by full scale tests using realistically simulated models of S/C (including vent tubes and down comer) including floors of the 1st floor of the R/B and boundaries such as outer wall of the underground floor and S/C leg part.

c. Repair technology development for the PCV upper part

The following R&D is underway for repair of the PCV upper part.

i) Repair the penetration at the upper part of the PCV (Pipe bellows at open space)

By means of remote control, it is to be repaired temporarily using non-cement-based material (urethane foam) and then more completely using cement-based material. The current issue is that if there is grease or rust, the adhesion of the urethane foam becomes weak and it is unable to withstand the water pressure. More reliable repair method such as welding is planned for the areas accessible for workers if dose reduction and removal of hindering objects are carried out, and a remote-controlled method is being sought for other areas where access is difficult.

ii) Repair of the equipment hatch

For the assumed leakage from the gasket, a method involving drilling of a hole into the concrete shield to inject and fill with the cement materials and the seal with the urethane foam has been planned so far. However, a more assuring method of remote-controlled welding of the sealed part of the equipment hatch from the hole drilled into the shield is going to be studied.

iii) Repair of the bellows and cable penetration in the small chamber

Current plan is to build a wall in the small chamber with mortar spray and then repair the bellows and cable penetrations with highly fluid cement-based material. There was no destruction caused by water pressure or visible leakage during the pressure test of the repairing materials, but it was confirmed that there were cracks near the leakage location and water is penetrated into the repairing materials through these cracks. While addressing these issues, more reliable repair method such as welding is going to be considered for the areas of the small chamber accessible for workers, and a remote-controlled method for other areas where access is difficult.

As explained above, the repair technology development for the PCV upper part will continue based on the achievements so far and by conducting studies for improvement of the water leak blockage performance such as extensive application of more reliable repair method like welding.

d. Reinforcement of S/C support structures

The seismic evaluation results from the PCV integrity evaluations conducted so far indicate the necessity of reinforcement for the column supports and seismic supports which are both parts of S/C support structures. In order to reinforce the entire S/C support structures, the injection of mortar into the torus room is planned.

As a result of experiments conducted so far, a certain degree of the effectiveness of filling the entire S/C support structures with mortar has been confirmed and more detailed evaluations will be made in the future followed by verification by full-scale tests.

(4) Future actions

The issues to be addressed are identified based on the measures and studies carried out so far with regards to PCV investigations and repair, and the following are the areas that should be more actively addressed in order to have a better understanding of further actions which need to be implemented as soon as possible.

a. Confirmation of the validity of assumptions concerning the locations of damages on PCV

The upper part of the PCV has a number of penetration pipes, but investigation has been difficult due to limited accessibility under high dose. In the current researches, the locations that have high risk of leakage are assumed based on the stress, temperature and pressure at the time of earthquake and the accident, and the technologies to repair those places are being developed. In the future study, it will be necessary to examine the validity of these assumptions and to confirm and investigate the leakage locations as necessary, so to have a prospect on repair works.

b. Confirmation on the level of performance of the PCV repairs

For the PCV repair technology, the target is to secure efficient water leak blockage, for example by extensive application of reliable repair method (such as welding) as much as possible. However, there may be some areas where the repairs must be done by remote-controlled injection of grout due to limited accessibility under high dose, and in such case leakage may occur. It will be necessary to confirm the integrity of the PCV during submersion at normal operation and at time of earthquake, taking into account of the results of future experiments and site conditions.

Studies on a method of leakage control will also be required in parallel with confirmation on the level of performance of the water leak blockage for the repaired parts and the maximum water level possible for submersion.

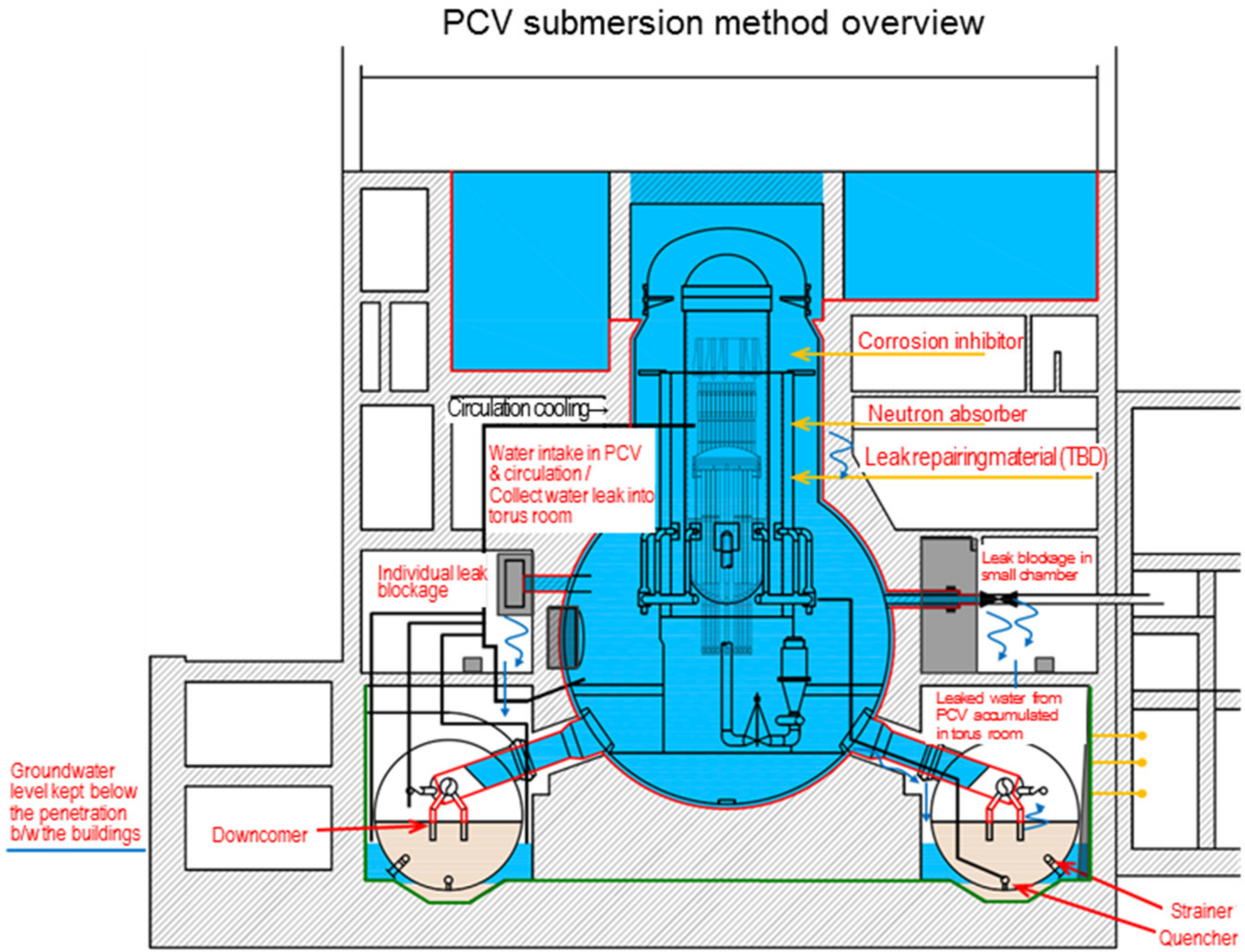
In addition, it will be necessary to have a prospect on the performance of the PCV repairs, such as the ability to replicate the same level of repair performance during actual on-site construction work or on the long-term integrity.

c. Development of testing methods for confirmation of performance of the PCV repaired parts, the monitoring methods for leakage, and countermeasures against the risk of leakage (prevention of spread of contamination and contaminated water collection system)
Studies on the testing methods for confirmation of performance of the PCV repaired parts and the monitoring methods for leakage must be accelerated. And the investigation on the contamination status of water used for submersion and study on the necessity of purification will be required as well. Furthermore, in the event of leakage from the upper part of the PCV during submersion, there are risks of spread of contamination through the pipes and leakage at the time of earthquake, therefore the measures against such risks (such as prevention of spread of contamination and contaminated water collection system) must also be considered.

The requirements for collection system also need to be clarified, such as the amount of leakage with a margin as a precautionary measure against risks.

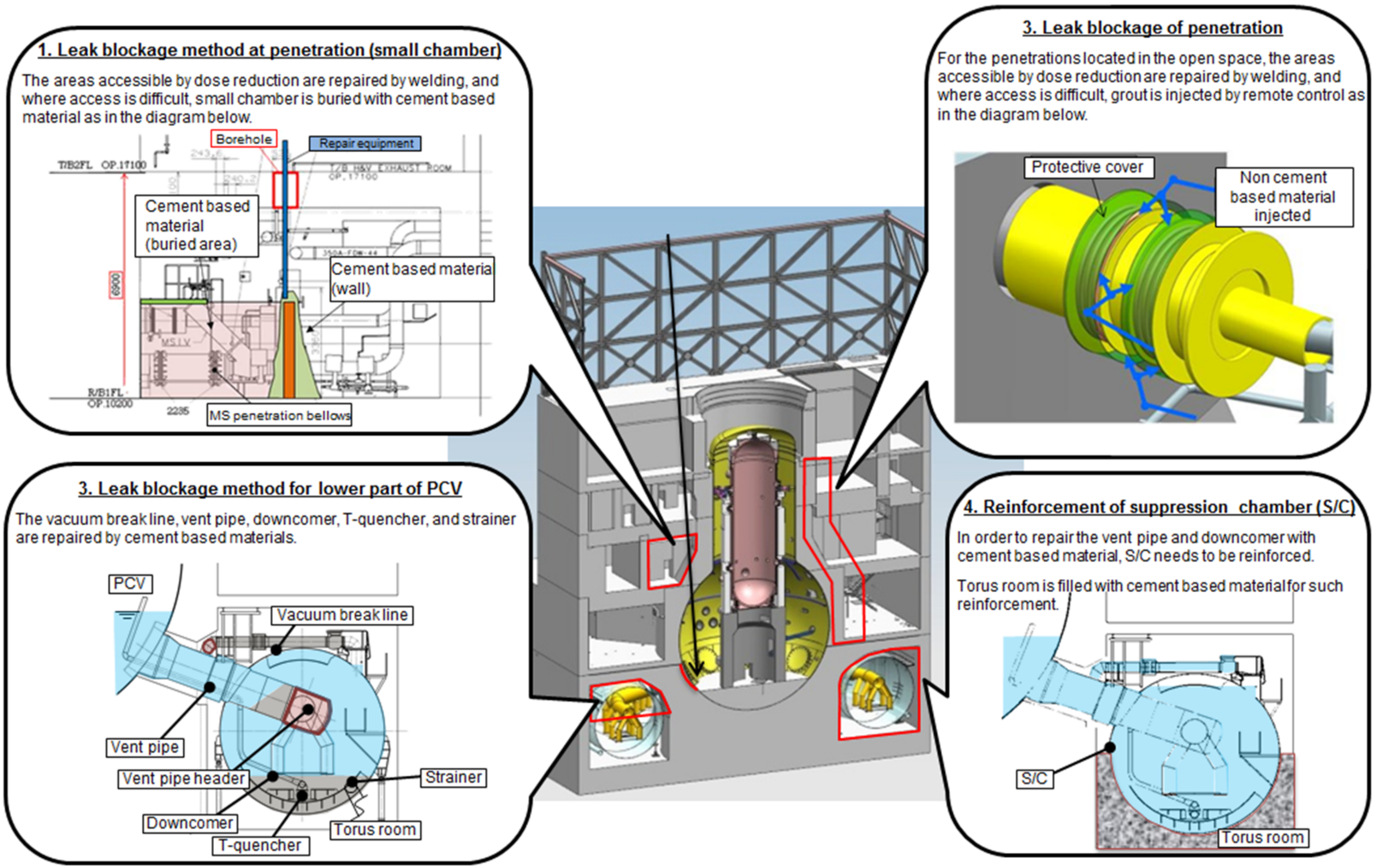
d. Risk control measures for contaminated water leakage to the outside of the building
Use of the torus room as a buffer store is being considered if there are possible risks of leakage of contaminated water from the lower part of the PCV. It will be necessary to formulate measures to control the risks of leakage to the outside of the R/B in such event. Those measures include prevention of leakage of contaminated water by controlling the difference of water levels between the underground water and torus room (underground water must be higher than the water level in the building), purification of stagnant water as much as possible, removal of contaminated water accumulated inside the building, and water leak blockage around the penetration on the underground outer wall of the R/B. The element technology of water leak blockage is currently being developed for penetrations between the buildings, but possibility and necessity for development of more effective technologies must be sought as well.

e. Assessment on the radiation degradation of the repairing materials and impacts of decay heat
It will be necessary to study the radiation degradation of the materials used for repair works and impacts of the decay heat by investigation on the status of accumulation of radioactive materials in areas such as S/C.



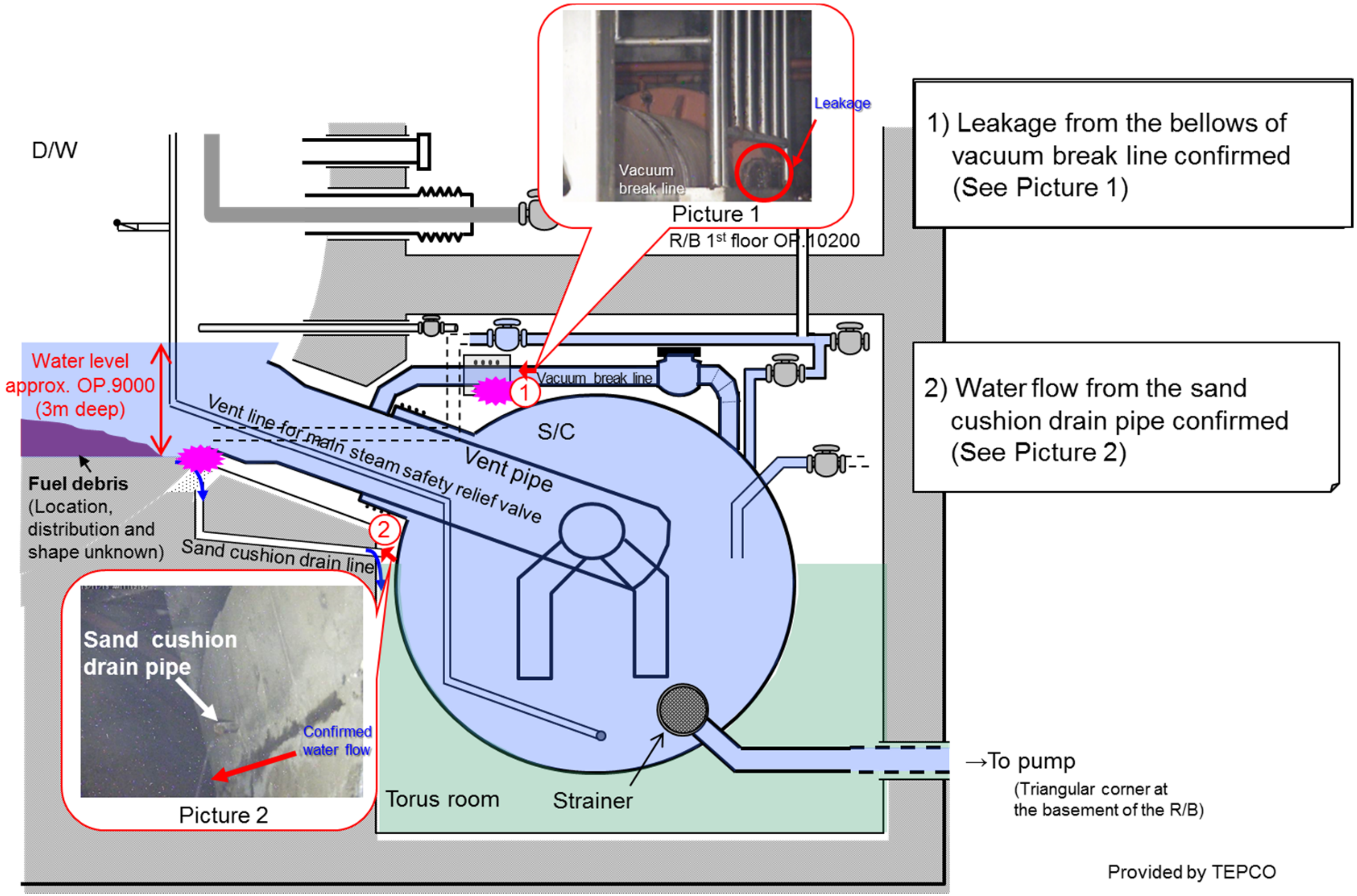
(Provided by IRID)

Figure 4.3.3-6 Conceptual diagram of the Submersion method



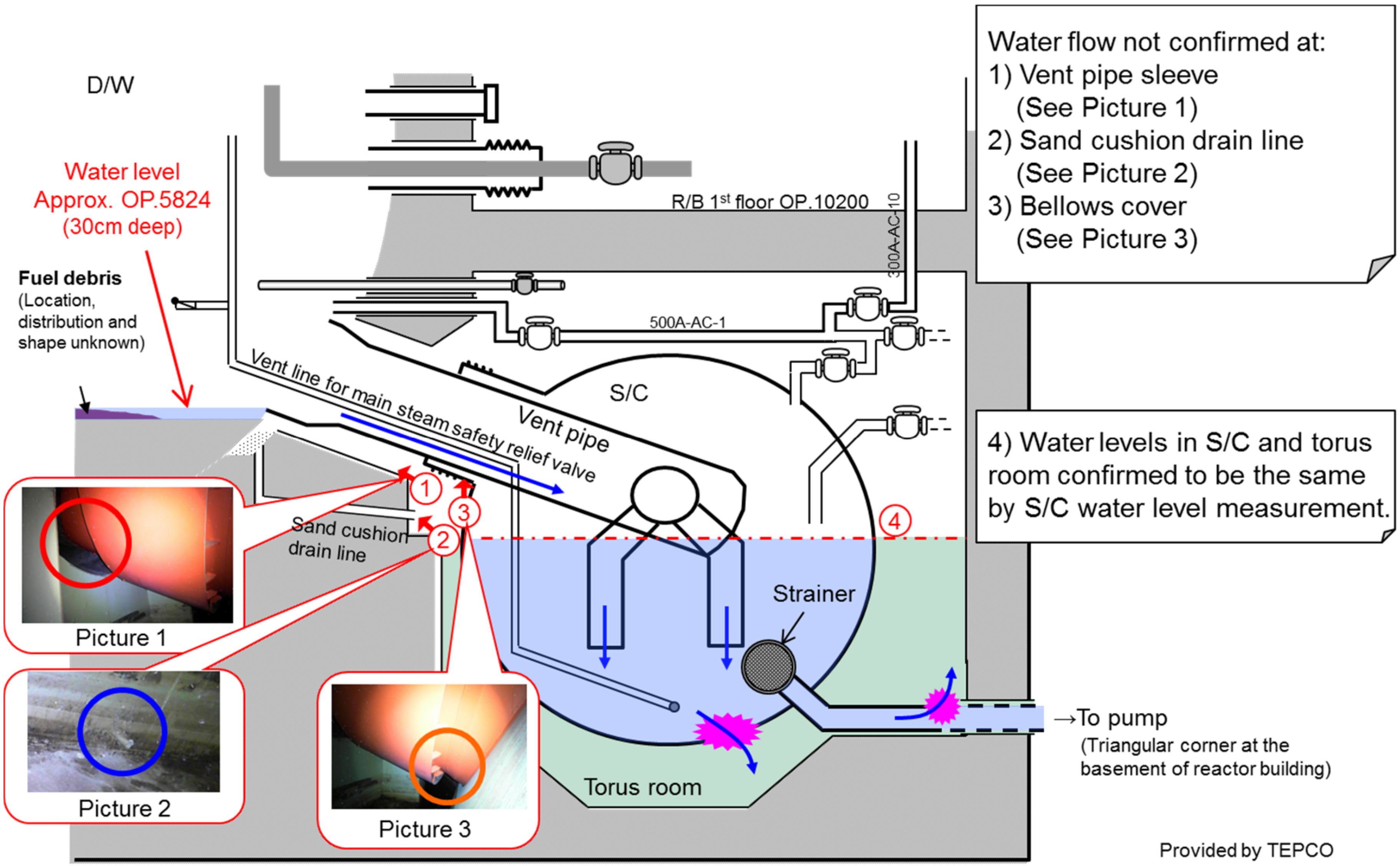
(Document provided by IRID (revised))

Figure 4.3.3-7 Outline of the water leak blockage and repair of the PCV



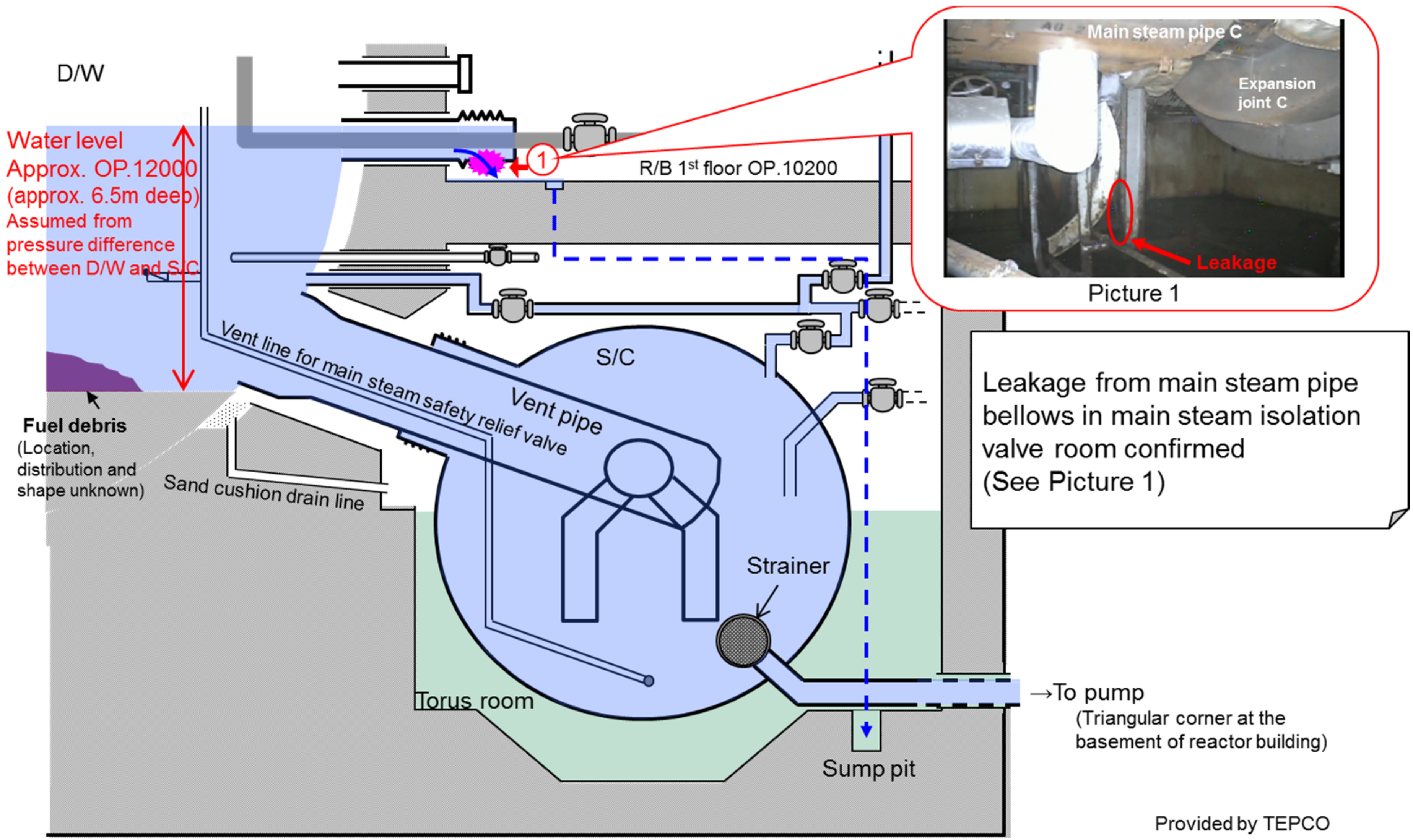
(Source: material for IRID FY2014 symposium, Jul. 18, 2014)

Figure 4.3.3-8 Current condition of Unit 1(image)



(Source: material for IRID FY2014 symposium, Jul. 18, 2014)

Figure 4.3.3-9 Current condition of Unit 2(image)



(Source: material for IRID FY2014 symposium, Jul. 18, 2014)

Figure 4.3.3-10 Current condition of Unit 3(image)

4.3.3.2.5 Reduction of exposure to the workers during operation

(1) Purpose

There are following two ways for dose reduction during operation.

a. To develop the remote technology considering the decontamination and shielding and removal of radiation sources in the working areas and access routes. Exposure to the workers involved in the investigation and repair of the PCV and preparation for fuel debris retrieval is to be reduced.

b. To minimize the exposure to the workers by the reactor internals and fuel debris during the retrieval work and to reduce the dose at the site boundary by evaluating the shielding effect of water by filling the PCV with water and the amount of generated dusts.

(2) Major requirements

Following are the major requirements for dose reduction during operation.

a. Internal conditions inside the RPV/PCV are to be investigated and necessary information in preparation for the fuel debris retrieval is obtained.

b. The site condition is to be investigated to understand the status of contamination and scattered rubbles in Units 1 through 3.

c. A comprehensive dose reduction plan is to be developed based on the above understanding. As a part of the plan, target dose of the working areas are to be set. The target dose should be determined by the work method, working days and hours, number of workers taking into account the dose rate of the working area before dose reduction, maximum dose per person per day, and 50mSv/year (100mSv/5year).

d. The dose limit in the site boundary is not to be exceeded.

e. Remote decontamination technology is to be developed for ensuring the safety.

(3) Current status

a. Internal PCV

- For the radiation dose attributable to the reactor internals and fuel debris, simple assessments are made on the effect of the water shielding on the operating floor and necessary thickness of the shields of the cell. (Figure 4.3.4-5)

b. Site condition

- Contamination investigation has been completed on the 1st to 3rd floors of Units 1 and 2 and on the 1st floor of Unit 3. However, there are some uninvestigated areas due to inaccessibility by the investigation devices. The 2nd and 3rd floors of Unit 3 are not investigated due to scattered rubbles.
- For decontamination works, dose reduction work (decontamination) is underway near the floor of the 1st floor of each unit but not yet carried out in the higher areas. For the 2nd and

3rd floors, PCV investigation and areas for repair are considered and the areas to implement dose reduction work are being selected.

- The decontamination of the operating floor started in October 2013 for Unit 3, but it was not sufficiently effective, and additional decontamination and shielding measures were developed in November 2014. As a result, the air dose rate at which the workers may operate is expected to be achieved.

c. Comprehensive dose reduction plan

- Based on the results of contamination status investigation, estimation of radiation source contribution, evaluation of the effects of dose reduction by decontamination, shielding and removal, and study on the dose reduction measures were carried out and completed at the end of 2014.
  From these studies, it was assumed that the structures such as ducts and pipes installed near the ceiling contributed to a large proportion of radiation sources, but information regarding whether contamination is present inside of these structures or the types of gases and liquids which may be present inside them is not sufficiently obtained.

d. Development of remote decontamination technology

- Underground floor (the area where contaminated water is accumulated): Decontamination scenarios and necessity for development of decontamination device are under study.
- Lower part of 1st floor of the building (2m or lower): Demonstration test completed in FY2013 but limited effectiveness. (Figure 4.3.3-11)
- Higher part of first floor of the building (2m or higher): Demonstration test to be completed in FY2014. (Figure 4.3.3-12)
- Lower part of 2nd and 3rd floors, upper floors of the building: Demonstration test to be completed in FY2015. (Figure 4.3.3-13)
- Installation of remote-controlled shields: Demonstration test completed and the actual use is expected.

(4) Future actions

a. Internal PCV

- In order to improve the accuracy of the evaluation of dose attributable to the reactor internals and fuel debris by incorporating the results of internal RPV/PCV investigations to be conducted in the future, and to minimize exposure to the workers and reduce dose within the site boundary, it is necessary to determine the required thickness of the shields of the cells taking account of shielding effect of water.
- For the dusts, the Cs adsorption mechanism and amount of adsorption is to be identified by internal investigation. Also the amount of dusts that may be generated when cutting the fuel debris must be identified and such information needs to be incorporated into building’s negative pressure control and air cooling filter designs.

b. Site conditions

- It is necessary to make reasonable judgments on whether to choose remote control or direct operations by workers depending on the conditions of the working areas or the actual tasks for dose reduction. On the other hand, the areas of decontamination may change depending on the fuel debris retrieval method to be employed, therefore dose reduction works must be carried out by determining the areas of priority and in line with the currently unknown reactor conditions and the progress on the studies on the retrieval method.
- In order to keep the cumulative dose over many years below the limit and to develop a sustainable radiation environment, it is necessary to set a target dose rate for each working area based on the target dose (dose limit) which is set lower than the legal limit of dose and taking into account the working hours/days and achieve the target dose by decontamination and shielding.
- It is necessary to update the information on the existing decontamination technologies or shielding technologies as necessary and create a database.

c. Comprehensive dose reduction plan

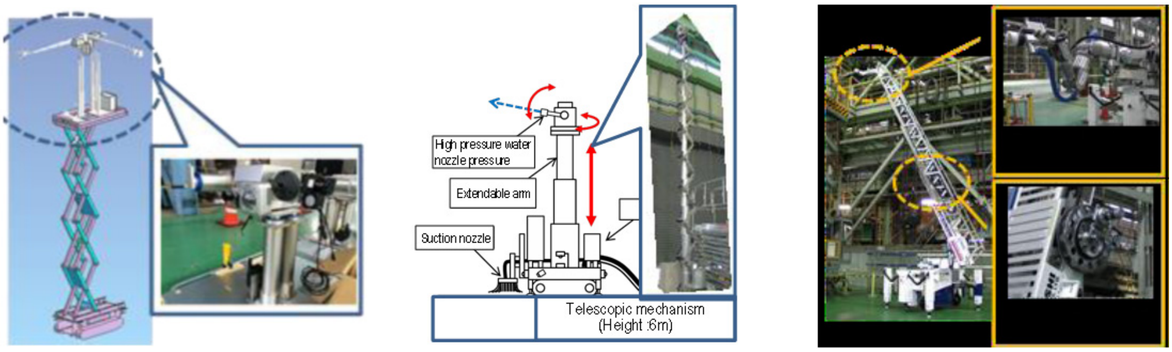
- For areas such as the small chamber, where investigations are not sufficiently carried out because of inaccessibility of the investigation devise, access method and improvement of the devices must be studied and data on contamination status must be obtained.
- In order to effectively implement the decontamination plan, the dose rates from the structures (such as cable tray, pipes, and ducts) installed near the ceiling where the radiation source contribution is relatively large and the contamination status inside the duct etc. must be identified.
- For decontamination of the operating floor, it is necessary to assess the prospect of dose reduction of the radiation from the floor and the data on the actual decontamination effectiveness for Unit 3 where decontamination is carried out in advance, and reflect the results in the decontamination plans of the other units.

d. Development of remote decontamination technology

- Among the current statuses of development of remote decontamination technology listed in (3) d. above, the development of upper floor decontamination device will be continued in accordance with the current development plan.

Dry ice blast High pressure water Suction and blast

Figure 4.3.3-11 Decontamination devices for lower areas (Provided by IRID)



Dry ice blast High pressure water Suction and blast

Figure 4.3.3-12 Decontamination devices for higher areas (Provided by IRID)

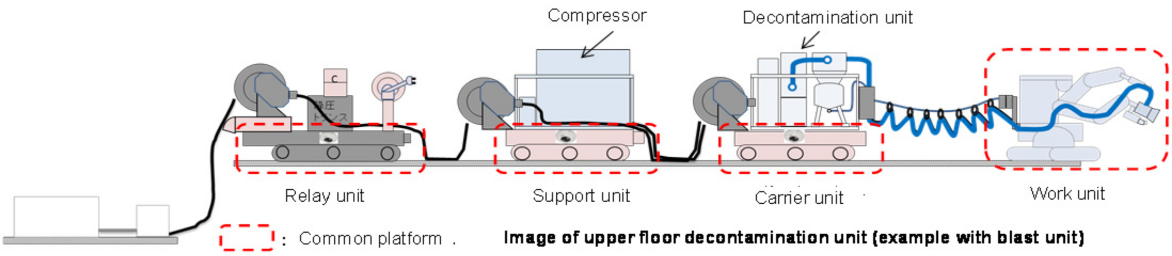
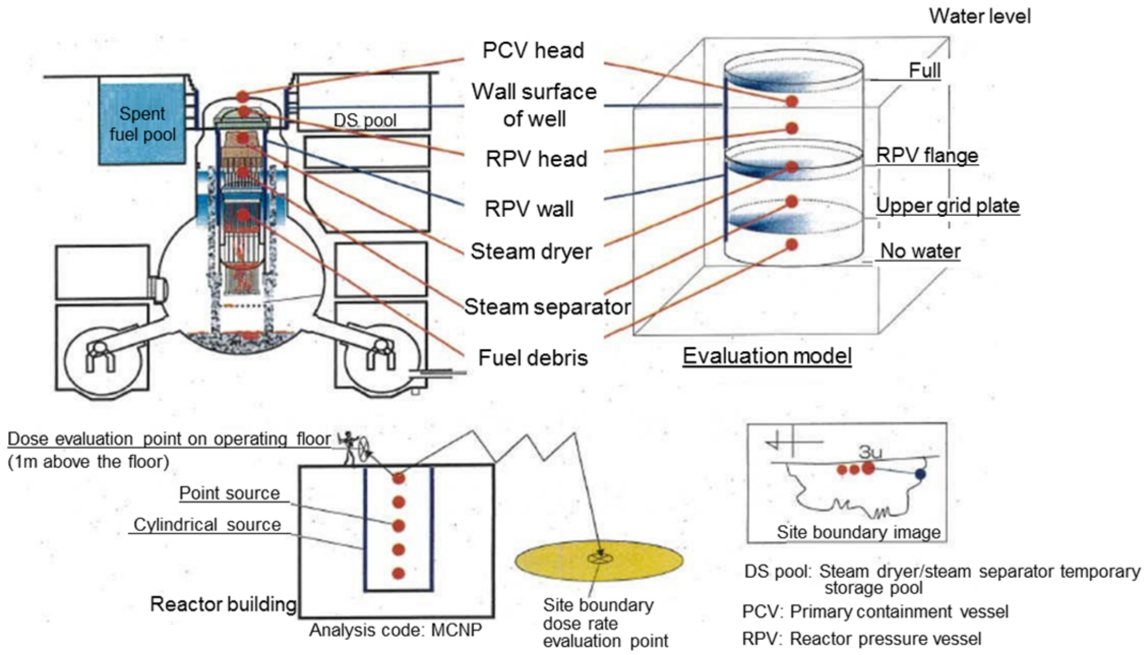


Figure 4.3.3-13 Decontamination device for upper floors (Provided by IRID)



[Dose evaluation model]

Maximum dose when equipment is removed

Operating floor dose rate (Sv/h)	Fuel debris *1	0.9
	Cs	6.6
	Co	14.3
	Total	21.9 *2

Can be reduced to less than 1mSv/h with approx. 30cm steel shielding.

*1 The dose rate for fuel debris is calculated considering the self-shielding with the average core burnup of the Units 1 to 3.
*2 Rounded off to the first decimal point
*3 Includes Co

Maximum dose when equipment is removed considering the work steps (Debris source*1 and Cs sources are considered)

	Water level	Max. dose
Operating floor dose rate (Sv/h)	Fully filled	0.28
	Partial submersion	6.6
	No water	7.6 (21.9)*3
Site boundary dose rate (Sv/h)	Fully filled	0.2
	Partial submersion	3.3
	No water	3.6

Effect of Cs adhering to the wall surface of the well
Fuel debris submerged
Fuel debris exposed
Can be reduced to less than 1mSv/h with approx. 25cm steel shielding.
Can be reduced to less than 1mSv/yr with approx. 8cm steel shielding.

Maximum dose when components are removed with due consideration of decay

		10 yrs later	20 yrs later	30 yrs later
Operating floor dose rate (Sv/h)	Fuel debris	0.9	0.5	0.3
	Cs	6.6	5.3	4.2
	Co	14.3	3.8	1.0
	Total (Thickness of shielding required to reduce to 1mSV/h)	21.9*2 (approx. 30 cm)	9.6 (approx. 27 cm)	5.5 (approx. 24 cm)

- The evaluation results contain following conservative points;
  - The radiation source intensity of fuel debris is calculated assuming that all nuclides remain except Cs and noble gases. If semi-volatile nuclides is dissolved, the intensity will be about 60%. Increased effect of shielding in the event the fuel debris flowed out of the pedestal is not considered.
  - The point source is used for the calculation and the self-shielding effect of the structure in the PCV which is the radiation source is not considered. The fuel debris shape is assumed to be cylindrical although it is unknown. The source intensity of the fuel debris is supposed to be 0.055 times considering the self-shielding effect.

[Dose evaluation results]

Figure 4.3.3-14 Example of dose rate evaluation at the time of fuel debris retrieval
(Provided by TEPCO)

4.3.3.2.6 Development of the fuel debris retrieval equipment and devices

(1) Purpose

To complete development and design for the equipment and devices that will be used to directly access and retrieve the fuel debris and reactor internals to which fuel debris is attached. The equipment and devices must meet the required specifications in order to conduct effective retrieval works. Also, installation area of the equipment and device is to be secured and the areas for replacement of the parts, maintenance and management such as inspections and troubleshooting are to be established with appropriate conditions.

(2) Major requirements

The following measures are necessary before the installation and operation of the retrieval equipment and devices.

a. Requirements for development and design of the equipment and devices

- The equipment and devices for fuel debris retrieval must have the specified resistance against radiation and acceptable life duration sufficient for the application under the radiation of the operated areas. In addition, the use under the presence of dust, which is an assumed operation environment, must be possible.
- The equipment and devices of fuel debris retrieval need to be equipped with the visual and measurement systems to allow unlimited confirmation of the surroundings.
- The equipment and devices of fuel debris retrieval need to be able to retrieve all fuel debris distributed in the plant regardless of its location. If necessary, multiple equipment and devices must be prepared or planned to enable completion of the retrieval work. Auxiliary operations by remote control and manipulators to handle the equipment and devices and retrieved objects must be in place.
- The equipment and devices of fuel debris retrieval (cutting and dust collection) must have sufficient capability to cut the fuel debris with assumed degree of hardness. The cutting speed must also be confirmed in advance on the simulated debris.
- For the consumable goods which are replaced frequently, remotely operated replacement must be possible.
- The equipment and devices must be developed in accordance with the planned design of the canisters.
- Recovery methods must be formulated in case of equipment and devices failures during retrieval work so that the subsequent works are not affected.
- Fail-safe concept must be incorporated as much as possible in the design of the equipment and devices.

If any of the above requirements cannot be met, alternative measures must be formulated.

b. Requirements for the site areas where the equipment and devices are installed
  - Appropriate areas must be secured for the installation of the equipment and devices for retrieval and access to the location of retrieval needs to be possible.
  - Areas for normal maintenance such as inspection and parts replacement needs to be prepared.
  - Maintenance areas where people can access are to be prepared to respond to the troubles.

(3) Current status

The R&D project called "Development of technology for retrieval of fuel debris and reactor internals" is underway since FY2014. The requirements to determine the fuel debris retrieval method has been formulated while study of retrieval method to be prioritized and the element test of technologies to be developed have begun.

(4) Future actions

The following should be implemented to develop the fuel debris retrieval equipment and devices.

Information regarding other development projects and field works has to be obtained to be incorporated into the basis for determining the retrieval method. The retrieval method will be determined based on the information necessary to evaluate the prospects of PCV repair, fuel debris distribution identified by the PCV internal investigation, the weight of load to be applied according to the method, and results of integrity of the PCV and the R/B. A good coordination between development and investigation projects should be ensured to acquire necessary information at the right timing.

The followings need to be confirmed to judge the feasibility of fuel debris retrieval scenario.

- Confirm the possibility of meeting the specifications for the equipment and devices. The prospect for the certain specifications is to be evaluated by element technology tests.
- Confirm that the possibility of meeting the specification of the site conditions by the time of fuel debris retrieval.
- Confirm the water level of the PCV which can be filled with water.
- Check the conformity with the plan for collection, transport and storage of the retrieved fuel debris.

Also, the actions should be taken to satisfy the requirements in (2) a., b. toward the practical application of the fuel debris retrieval method after the determination of the policy.

4.3.3.2.7 Establishment of access routes to the fuel debris

(1) Purpose

To establish the route inside the building and the route accessing from the operating floor to the fuel debris for fuel debris retrieval work by the Submersion-Top entry method.

(2) Major requirements

a. The dose of the working areas inside the building needs to be reduced, the obstacles removed, and the access route inside the building must be established to carry-in/out and install the equipment for the fuel debris retrieval as well as transferring the retrieval equipment and fuel debris.

b. For the retrieval method accessing from the operating floor to the fuel debris, existing equipment located on the access route between the upper part of the PCV and the fuel debris are to be removed to secure the route.

c. If there is fuel debris outside of the core shroud, it will be necessary to remove the core shroud and access the fuel debris, therefore a plan needs to be established according to the conditions. It also has to be established assuming the possibility of fuel debris located in and outside the pedestal at the bottom of the PCV.

d. A plan needs to be established according to the conditions since a large opening needs to be created on the RPV bottom to access the fuel debris located on the bottom of the PCV. It also has to be established assuming the possibility of fuel debris located in and outside the pedestal at the bottom of the PCV.

(3) Current status

Necessary access route inside the building includes the one which runs from the entrance of the R/B to the operating floor, and another one from the operating floor to the periphery of the RPV to carry out the fuel debris retrieval work on the operating floor. Under present circumstances, dose inside the building is high and its environment is not suitable for the work.

The access route from the top of the PCV into the core is structurally secured for the fuel replacement work during the outage. The access to the inside of the reactor can be secured by removing the well shield plug, PCV upper head, insulator for the RPV upper head, and RPV upper head. The upper grid plate immediately above the core may be reached by removing the steam dryer and steam separator allowing access to the fuel debris inside the RPV. In the fuel debris retrieval work, the access is to be made by the access route for the periodical inspection mentioned above. However, there is a possibility that the equipment to be removed may be deformed as the results of exposure to high heat during the accident and may be difficult to remove using a normal method, but the damage condition of the equipment has not yet been confirmed under the present circumstances.

(4) Future actions

The following are the actions to be taken.

a. It is necessary to elaborate and implement plans for dose reduction of the access route into the building and removal of the obstacles for carry-in/out and installation of equipment and devices for fuel debris retrieval as well as transfer of the retrieval equipment and fuel debris.

b. An investigation plan for the damage condition and dose for handling the equipment and devices to be removed which is located in the access route from the operating floor to the fuel debris needs to be established and implemented. If the equipment and devices are difficult to be removed in a normal way due to its damage (e.g. cut and removal of the equipment), countermeasures and an action plan will be necessary. Also the plan must be established assuming the case where the conditions cannot be determined sufficiently in advance.

c. If there is fuel debris outside of the core shroud, it will be necessary to remove the core shroud and access the fuel debris, therefore a plan needs to be established according to the conditions.

d. It is necessary to formulate an action plan for construction of a large borehole at the bottom pf RPV in order to access the fuel debris located at the bottom of the PCV.

4.3.3.2.8 Establishment of system equipment[1] and working areas

(1) Purpose

To conduct conceptual studies for the additional container to be installed in the building, cell with prevention function for dust dispersion during the fuel debris retrieval work, and various systems to be used for the fuel debris retrieval. Also preparation for the installation and operation of facilities and systems and securing and operating of the necessary working area are necessary.

In addition to the device control system directly related to the fuel debris retrieval work, the systems to be prepared may include the cooling water injection system, contaminated water collection system, negative pressure control/gas control system, radioactive gas treatment system, criticality control system, and a system for treatment and transport of the retrieved fuel debris.

(2) Major requirements

The following should be confirmed to evaluate the achievement of targets, prior to the installation and operation of the facilities, equipment and devices.

a. The design for the additional containers and cells to be installed in the building is to be completed, and the function, performance and integrity of these facilities are to be evaluated and must be feasible. Sufficient installation space needs to be secured for the equipment, devices and apparatuses that constitute the systems. Requirements for the environment in accordance with the design requirements of equipment, devices and systems must be met.

b. Sufficient space for the operation and maintenance of equipment, devices, apparatuses that constitutes the systems needs to be secured. Requirements for the environment of the maintenance area in accordance with the design requirements of equipment, devices and systems must be met.

[1] System equipment includes the building, container and cell as well as the system related facilities such as cooling water injection system (e.g. contaminated water collection system) and radioactive gas treatment system.

c. If existing equipment is used for the fuel debris retrieval work, it must be confirmed that there is no damage or deterioration in the equipment and its function needs to be maintained.

d. Processing and disposal methods are to be established for the fuel debris, severely contaminated structures, cut objects to be exported over the course of the fuel debris retrieval work. The areas for temporary placement of equipment, working areas and the destination of the transport need to be determined and the sufficient areas need to be secured.

e. Fuels must be removed from the SFP, and other stored objects including the control rod, fuel racks and rubbles are also to be removed.

(3) Current status

Conceptual studies on the devices and equipment that constitute the systems, establishment of the layout, and formulation of a plot plan of the Fukushima Daiichi NPS considering the temporary placement area for retrieval equipment and fuel debris storage area need to be conducted. These activities will be carried out from FY2015 starting with those required for feasibility confirmation of the retrieval method.

(4) Future actions

The following are the actions to be taken.

This technical requirements are established based on the results of the related R&D project (e.g. “Development of technology for remotely operated decontamination inside the R/B,” “Establishment of the total dose rate reduction plan,” “Development of technology for retrieval of fuel debris and reactor internals,” “Development of technology for evaluating integrity of the RPV/PCV,” “Development of technology for collecting, transporting and storing fuel debris inside the reactor.”) and technical study results related to the on-site construction. To determine the approaches to the fuel debris retrieval method, the followings are to be carried out to evaluate the feasibility of fuel debris retrieval scenario for each unit in parallel with the development of the fuel debris retrieval equipment design.

a. Since the evaluation of the integrity of the buildings is required to confirm the feasibility of the method, the overview of the major weights and dimensions of equipment such as containers and cells which may have impact on the evaluation needs to be confirmed, and based on this confirmation the integrity should be evaluated.

b. Confirm that the installation space is secured for the major equipment used for the method.

c. Confirm if the storage area can be secured for the equipment including the retrieved equipment which are severely contaminated, cut objects and fuel debris.

After the selection of the method to be used for fuel debris retrieval work, the details of layout plans for the installation and operation of the equipment that constitutes the systems and detailed plot plan for the areas for temporary placement and handling of the retrieved equipment, and storing the retrieved fuel debris need to be established. Evaluation criteria for decontamination and shielding, and dust dispersion prevention need to be established to satisfy the environmental conditions required for the working areas and approaches should be taken to meet those criteria.

4.3.3.2.9 Ensuring the work safety

(1) Purpose

Most of the operations prior to the fuel debris retrieval will be carried out inside the R/B. The environment of the R/B is in extremely severe condition with narrow space, insufficient lighting, rubbles scattered, high radiation, dusts, etc. Since the operations such as retrieval work for fuel debris which has reached the PCV will be carried out for the first time under such a severe condition, it is important to develop the careful measures and preparation to prevent workplace accidents.

(2) Major requirements

The work safety measures will need to be fully prepared to a level incomparable to the past in order to prevent, reduce, and mitigate workplace accidents.

(3) Current status

a. Operations in the R/B and its peripheral area are carried out under the condition that requires radiation protection, such as full face mask which imposes burden to the workers.

b. In light of the fact that fatal accidents have been taking place repeatedly, such as falling from the top board of the rainwater collection tank which occurred on January 19, 2015, various types of safety improvements have been made to prevent, reduce, and mitigate workplace accidents by safety check, awareness improvement, case study meetings, and meetings to remind of the fatal accidents occurred in the past.

(4) Future actions

The following measures should more strongly be imposed to prevent, reduce, and mitigate workplace accidents.

a. Conduct the current safety improvement measures more thoroughly.

b. Establish better work environment as much as possible by the restoration of the lighting (restoration of the power), improvement of communication environment, and removal of rubbles.

c. Review the dose reduction work inside the R/B and the PCV internal investigation work which have been carried out to utilize the experience in the preliminary measures including preparation, planning, and training for other operations.

d. In addition to the reactor dose reduction work inside the R/B described in b., the PCV internal investigation, R/B repair, removal of contaminated water accumulated inside the building, dismantling of the upper part of the R/B (Unit 2), and operation to remove fuels from the SFP are currently planned for fuel debris retrieval. Trainings on the mock-up have to be conducted sufficiently for the operations to be carried out for the first time.

e. Identify possible accidents and troubles that may occur during each operation in advance, conduct risk assessments and take measures in order to prevent the accidents and troubles. Consider contingency measures to respond to any unexpected situations.

4.3.3.3 Flow for the judgment of feasibility of the Submersion method

With regards to nine technical requirements which are necessary for realization of the fuel debris retrieval by the Submersion method, actions to be taken to satisfy each of the requirements and necessary measures for judgment of whether such requirements are met are identified, and based on the current status of R&D projects (achievements and plans), the way forward including the subjects of further study is explained below.

Since the Submersion method is to retrieve fuel debris by filling PCV with water and submersing all fuel debris, cooling of the fuel debris, radiation shielding, and prevention of the radioactive dust dispersion during the fuel debris retrieval can be expected. However, in order to fill the PCV with water, the leak locations of the PCV must be repaired so that the water level can be stably maintained. To realize the Submersion method, nine technical requirements need to be satisfied, and there are three issues which are especially important.

(1) PCV repair and establishment of the water level control system
Development and studies for the repair method for the leak locations of the PCV, PCV circulation cooling loops, and leaking water collection/water level control system are to be carried out and the system to safely control the water level inside the PCV is to be established. Also safety, quality and long-term reliability for the PCV repair work and prevention of contaminated water leakage to the outside at the time of accident need to be studied.

(2) Securing the structural integrity of the PCV and the R/B considering its load and aged deterioration when submerged
Evaluation method for the structural integrity at the time of earthquake is to be developed considering the deterioration caused by the load applied to the PCV when submerged and corrosion of the structures. The areas to be reinforced are to be identified and the method of repair those areas should be formulated.

(3) Maintaining sub-criticality when the water level rises
Subcritical state needs to be maintained when the water level and form of the fuel debris are changed during the fuel debris retrieval work. For this reason, sub-criticality evaluation and monitoring technologies are being developed in addition to the development of neutron absorber. In specific, if fuels with high reactivity remain in the reactor vessel, criticality may occur when the reactor vessel is filled with water. If boric-acid solution (a neutron absorber) is used to prevent criticality, there is a possibility of causing an impact to the corrosion of the PCV materials, therefore maintaining sub-criticality and the PCV integrity needs to be verified as a countermeasure.

Development and studies are to be carried out with periodic review considering the progress status of nine technical requirements and especially of the three important issues mentioned above and the feasibility of the Submersion method is to be evaluated.

Figure 4.3.3-15 shows the future actions for the nine technical requirements.

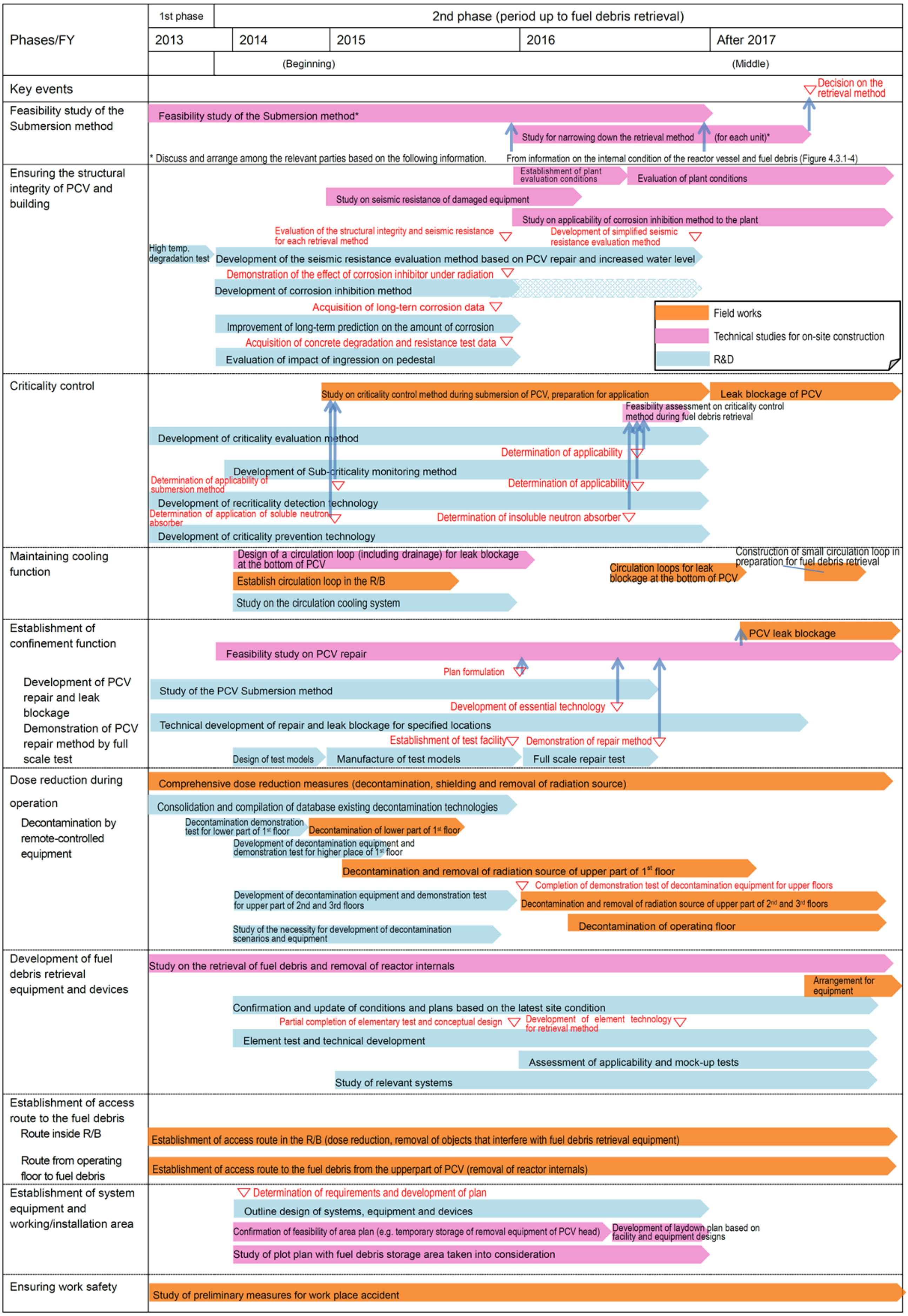


Figure 4.3.3-15 Future actions on the FS on the Submersion method

4.3.4 Assessment of approaches and FS based on the Partial submersion (Partial submersion-Top entry method and Partial submersion-Side entry method)

4.3.4.1 Overview

Considering the severe impact caused by the accident, it is expected that it might be difficult to submerge to the upper part of the PCV or to the level where fuel debris is deposited. Therefore, as an alternative method to the Submersion method, a method to retrieve fuel debris without filling water up to the level covering fuel debris, namely the "Partial submersion method" has started to be studied.

The Partial submersion method for fuel debris retrieval has never been employed before and it is believed that there are more difficult issues than in the Submersion method, especially in shielding and dust dispersion. Some issues are expected to be common with the Submersion method and there may be fewer issues depending on the technical requirements for the method.

The study and evaluation for the feasibility of the method may be conducted focusing on the following categories of technical requirements as with the Submersion method.

The aspects of each technical requirement to be noted in comparison with the Submersion method are described in the next section.

Following nine requirements for the Partial submersion method for fuel debris retrieval are to be studied.

- Securing the structural integrity of the PCV and the R/B
- Criticality control
- Maintaining the cooling function
- Establishment of the containment function
- Reduction of exposure to the workers during operation
- Development of the fuel debris retrieval equipment and devices
- Establishment of access routes to the fuel debris
- Establishment of the system equipment and working areas
- Ensuring the work safety

The purposes of these technical requirements are the same as those of the Submersion method. Also, some specifications and current status of the Submersion method are applicable for the Partial submersion method. In this strategic plan, technical requirements are studied for two types of the Partial submersion methods, which are the Partial submersion-Top entry method and the Partial submersion-Side entry method.

4.3.4.2 Approaches to the technical requirements

The purpose, major requirements, current status, and future actions for nine technical requirements for the Partial submersion-Top entry method and the Partial submersion-Side entry method are described below.

Out of the nine technical requirements described in previous section, the requirements of "Securing the structural integrity of the PCV and the R/B" includes the common issues with the Submersion method, and the Partial submersion-Side entry method needs to be evaluated considering the building conditions and possibility of enlargement of the openings on the PCV which are specific to the side access.

Although there are some differences in the verification conditions for the "Criticality control" with the Submersion method, no additional verification to a large extent is expected. "Maintaining the cooling function" requires the cooling system considering the fuel debris retrieval while exposed in the air. As for the "Establishment of the containment function," PCV needs to be repaired while maintaining negative pressure inside the PCV so as to prevent dust dispersion. Also, the lower part of the PCV requires water leak blockage capability. For "Reduction of exposure to the workers during operation," it is believed that the measures need to be reinforced for the Partial submersion method because higher dose is anticipated for the working areas. Also, for "Reduction of exposure to the workers during operation," since the Partial submersion-Side entry method needs the access route which is different from those used for the Submersion method and Partial submersion-Top entry method, the access route exclusive for the Side entry method has to be studied. For "Development of the fuel debris retrieval equipment and devices" and "Establishment of access routes to the fuel debris," studies and evaluations are necessary according to the details for each of the Submersion method, the Partial submersion-Top entry method and Partial submersion-Side entry method. "Ensuring the work safety" requires the same consideration as the Submersion method.

4.3.4.2.1 Securing the structural integrity of the PCV and the R/B

(1) Purpose

As with the Submersion method, the safe and reliable retrieval of fuel debris by the Partial submersion method requires that 1) the R/B sustains supporting function of the PCV, 2) PCV remains in current form, keeps water level inside the PCV and prevents a large amount of radiation leakage and 3) RPV remains in current form and maintains cooling water supply path, from the viewpoint of the structural integrity. The above requirements should also be evaluated if those are feasible in the seismic condition.

Figure 4.3.4-1 shows the sectional view of the R/B of the PCV and the RPV subject to the evaluation.

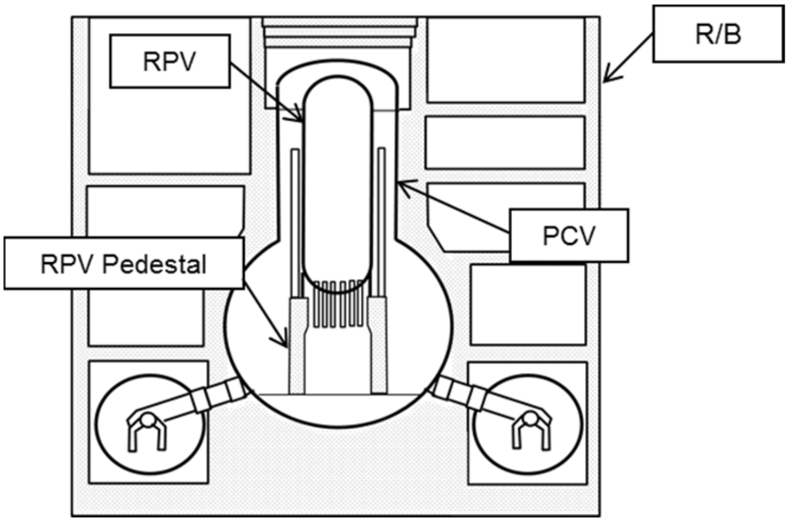


Figure 4.3.4-1 Sectional view of the R/B

(2) Major requirements

As in the case of the Submersion method, the requirements to be satisfied are as follows.

a. An appropriate seismic ground motion and evaluation criteria are to be defined based on the required functions described in 1) -3) of (1) and the impact in case of failure of these functions.

b. The damages caused by the accident, degradation of materials due to exposure to high temperature, corrosion by the seawater injection and further degradation and further corrosion that may occur by the time of the completion of fuel debris retrieval are to be studied.

c. The weights of fuel debris, cooling water inside of the PCV and other areas, and fuel debris retrieval equipment, shielding, construction materials and machinery are to be considered as criteria for the load during earthquake according to the fuel debris retrieval method plan.

(3) Current status

The following actions have been taken for the Submersion method. They can be applied for the seismic evaluation for the Partial submersion method except for the item c.

a. Evaluation on the material degradation due to exposure to high temperature

Based on the temperature measured in each unit after the accident, the testing conditions were established and results of the strength test of metal materials of the PCV and the RPV exposed to high temperature has been acquired. The test data showed little change in the parameter of material strength and it was confirmed that parameters of both materials fall within the standard value range.

b. Evaluation of the corrosion progression by salt corrosion caused by seawater injection

Based on the measurement data taken after the accident in each unit, the temperature and water quality (e.g. salinity concentration) over the time period from immediately after the accident to the present and until the time of the fuel debris retrieval were estimated and corrosion thinning progression test for the materials used for the PCV and the RPV are conducted on the parameters of temperature and water quality. Based on the test results, an evaluation formula for the corrosion thinning for a given time period is being developed. Also, tests for the corrosion impact caused by the increase in dissolved oxygen after the opening of the PCV upper head and development of the corrosion inhibitor have been started.

c. Development of the RPV/PCV seismic strength evaluation method
Following actions have been taken for the Submersion method.

Assuming the future condition of each unit, the case study for seismic evaluation is implemented setting the water level inside the PCV, amount of corrosion in the equipment, weight of construction materials and machinery to be added to the building as parameters. Reference evaluation for each case is conducted based on the seismic evaluation standards for normal operating plant to determine the seismic margin. Using the results of this case study, simplified evaluation method is being developed setting seismic condition such as the water level inside the PCV, weight of fuel debris retrieval equipment/construction equipment, status of equipment repair works and corrosion of equipment as parameters so that the seismic evaluation may be conducted promptly in accordance with the progress on planning for the Submersion method.

d. Studies on the degradation of the RPV pedestal and development of the resistance evaluation method
Studies on the material degradation characteristics by concrete thermal impact assessment tests under the accident condition and corrosion test for reinforcement bars as well as development of plan resistance evaluation method by resistance test on reduced-scale RPV pedestal and comparative evaluation on the simulation analysis of this resistance test are being carried out. As for the erosion at the basement caused by fuel debris, impact assessment method is being developed on the parameters of degree of erosion.

e. Confirmation of seismic resistance of the R/B
Seismic analysis was conducted using the model reflecting the conditions of the R/B damaged by the hydrogen explosion and the seismic margin against the standard seismic ground motion Ss has been confirmed for each unit.

(4) Future actions
The following are the actions to be taken. Those are the same as in the Submersion method except for the item d.

a. The items listed in (3) a. b. and d., are to be completed in the last half of FY2015 as scheduled and the preparation work for PCV and RPV seismic evaluation is to be completed.

b. For (3) b., long term corrosion tests (10,000 hours target) regarding the corrosion impact resulting from the boric acid injection to prevent criticality is to be considered.

c. In light of safety regulations, the seismic ground motion and evaluation criteria mentioned in (2) a. are to be promptly studied.

d. Based on the seismic evaluation using the simplified evaluation method to be formulated under (3) c., the Partial submersion-Top entry method is to be studied while determining the level of seismic margin. Also, the simplified evaluation is to be revised for the Partial submersion-Side entry method. A detailed seismic evaluation on the final option using the seismic ground motion and evaluation criteria described in (2) a. is to be carried out.

e. For (3) d., assuming that the fuel debris is confirmed to be scattered at the RPV pedestal base by the PCV internal investigation, necessary activities for seismic evaluation based on such condition (such as additional investigations) is to be considered.

f. For the R/B referred to in (3) e., seismic evaluation assuming the further degradation is to be carried out taking into account the distribution of the fuel debris at the time of retrieval and approximate weights of the cooling water, construction equipment, shielding and other devices.

4.3.4.2.2 Criticality control

(1) Purpose

In the application of the Dry method, recriticality is unlikely to occur since there is no water which acts as an essential moderator for criticality. However, if there is any water present, there is a possibility that the shape of the fuel debris and amount of water may change during the retrieval work, therefore the technology to prevent exposure to the workers and impact on the environment by recriticality is required to be developed in order to ensure criticality control.

(2) Major requirements

The methods and requirements of criticality control for the Partial submersion method are as follows, and they are basically the same as the Submersion method.

a. Criticality evaluation methods
  - The criticality scenario is to be evaluated based on appropriate conditions.
  - The information necessary for the judgment on the reasonable conservatism is to be identified, and a plan for acquisition of such information is to be drafted and implemented.
  - The accuracy of the evaluation on recriticality consequences is to be verified.

b. Sub-criticality monitoring methods
  - The partial increase in effective multiplication factor of the widely distributed fuel debris must be detectable.

c. Recriticality detection technologies
  - Safety must be ensured by the combination of recriticality detection, exposure evaluation and mitigation measures.
  - Recriticality of partial fuel debris scattered in a wide area must be detectable by neutron monitoring.

- The water level must be closely monitored and the fuel debris retrieval works must be carefully implemented.

d. Criticality prevention technologies
  - The reactivity required to maintain the recriticality in assumed conditions must be specified and secured.
  - The integrity of the facility must be maintained taking into account of corrosion of materials inside the reactor and impact on the cooling water circulation system.

(3) Current status

Development has been conducted by FY2014 assuming the Submersion method.

(4) Future actions

Although many of the technologies developed by FY2014 will be applied for the Partial submersion method, the appropriateness of the evaluation requirements and applicability of developed technology to the Partial submersion method have to be confirmed. Following are the items to be verified assuming the Partial submersion method with water which exists partially.

a. Criticality evaluation methods
  - Evaluate the impact on the possibility of recriticality caused by the change in the ratio of water to the fuels by the fuel debris retrieval work as a criticality scenario. In specific, the condition, such as the fall of the chips of the retrieved fuel debris and increase in the ratio of accumulated fuel debris to water is assumed. If water level is changed from the current status, assessment for the impact caused by the water level is required.
  - Check if the method of impact evaluation in the event of recriticality developed and verified for the Submersion method is applicable for the Partial submersion method.

b. Sub-criticality monitoring methods
  - Check if the sub-criticality monitoring methods developed and verified for the Submersion method is applicable for the Partial submersion method.

c. Recriticality detection technologies
  - Check if the Recriticality detection technologies using neutron detection and gamma-ray detection developed and verified for the Submersion method is applicable for the Partial submersion method.
  - Check if the mitigation measures for the impact after the recriticality, such as insertion of neutron absorbers and decrease in the water level are feasible for the Partial submersion method and effective for management of the assumed ratio of fuel debris to water level. If it is not, impact mitigation measures need to be developed for the Partial submersion method.

d. Criticality prevention technologies

- Check if the neutron absorber developed and verified for the Submersion method is applicable for the Partial submersion method.
- Evaluate the reactivity effects of the dissolved neutron absorber under the condition where fuel debris are not completely covered.
- For undissolved neutron absorber, confirm the absorption of the binder to the fuel debris exposed in the air, and evaluate the reactivity effect.

4.3.4.2.3 Maintaining the cooling function

(1) Purpose

To establish the circulation loop with functions of poring cooling water, cooling of fuel debris, and purification during the fuel debris retrieval by the Partial submersion method.

(2) Major requirements

Treatment of the pieces of fuel debris that flow into the circulation loop during the retrieval work is to be studied as well as stable cooling for fuel debris during the period of fuel debris retrieval.

(3) Future actions

Study fuel debris cooling by pouring cooling water, purification of cooling water and the treatment of the pieces of fuel debris that flow into the circulation loop toward the fuel debris retrieval work by the Partial submersion method.

Since a part of fuel debris may not be submerged depending on the method of constructions, the evaluation may be required for air cooling of fuel debris.

4.3.4.2.4 Establishment of the containment function

(1) Purpose

To prevent the leakage of radioactive materials from the PCV in order to minimize impacts to the surrounding environment and workers.

(2) Major requirements

Scope of the Partial submersion method is applied for the cases where current PCV water level and the level where some debris locations are higher than PCV water level.

Also, the fuel debris retrieval from higher and lower part of the PCV basically requires water leak blockage performance and leakage management by pouring water over the debris to be retrieved corresponding to the working environment. Therefore, the technologies for investigation and repair of the PCV for the Partial submersion method are almost the same as those required for the Submersion method. Major requirements to be satisfied are described below.

a. The leakages of radioactive materials from the gas phase of the PCV are controlled and prevented.
The requirements for negative pressure control for the PCV is met by repairing the gas phase part where leakage is assumed. Specific requirements are to be defined through the studies for the Partial submersion method.

b. Contaminated water leakage from the liquid phase of the PCV is prevented.
Since PCV water level is low compared with the level of submersion up to the top of the PCV, required pressure resistance performance corresponds to the water level. The requirements for the investigation and repair of the PCV are basically the same as the Submersion method described in 4.3.3.2.4.

(3) Current status
The current status related to the investigation and repair of the PCV is the same as 4.3.3.2.4 in the Submersion method.

(4) Future actions
Determine if the requirements for negative pressure control for the PCV obtained from the studies on the Partial submersion method may be satisfied by the repair method described in the Submersion method in 4.3.3.2.4 as soon as possible.

4.3.4.2.5 Reduction of exposure to the workers during operation

(1) Purpose
There are two purposes of the reduction of exposure to the workers as follows.

a. To develop the remote technology considering the decontamination and shielding and removal of radiation sources in the working areas and access routes. Exposure to the workers involved in the investigation and repair of the PCV and preparation for fuel debris retrieval is to be reduced.

b. To reduce the exposure to the workers attributable to the reactor internals and fuel debris during the retrieval work and the dose at the site boundary by evaluating the shielding effect of the cells and the amount of generated dusts assuming that the water shielding effect by filling PCV with water cannot be expected.

(2) Major requirements
Following are the major requirements for dose reduction during operation, and those are the same as the Submersion method.

a. Internal conditions inside the RPV/PCV are to be investigated and necessary information in preparation for the fuel debris retrieval is obtained.

b. The site condition is to be investigated to understand the status of contamination and scattered rubbles in Units 1 through 3.

c. A comprehensive dose reduction plan is to be developed based on the above understanding. As a part of the plan, target dose of the working areas are to be set. The target dose should be determined by the work method, working days and hours, number of workers taking into account the dose rate of the working area before dose reduction, maximum dose per person per day, and 50mSv/year (100mSv/5year).

d. The dose limit in the site boundary is not to be exceeded.

e. Remote decontamination technology is to be developed for ensuring the safety.

(3) Current status

a. Condition inside the PCV

- Assuming that the water shielding effect by filling PCV with water cannot be expected, simplified evaluation is implemented on the necessary thickness of the shielding by the cells, etc. (Table 4.3.4-5)

b. Site condition

- Contamination investigation has been completed on the 1st to 3rd floors of Units 1 and 2 and on the 1st floor of Unit 3. However, there are some uninvestigated areas due to inaccessibility by the investigation devices. The 2nd and 3rd floors of Unit 3 are not investigated due to scattered rubbles.
- For decontamination works, dose reduction work (decontamination) is underway near the floor of the 1st floor of each unit but not yet carried out in the higher areas. For the 2nd and 3rd floors, PCV investigation and areas for repair are considered and the areas to implement dose reduction work are being selected.
- The decontamination of the operating floor started in October 2013 for Unit 3, but it was not sufficiently effective, and additional decontamination and shielding measures were developed in November 2014. As a result, the air dose rate at which the workers may operate is expected to be achieved.

c. Comprehensive dose reduction plan:

- Based on the results of contamination status investigation, estimation of radiation source contribution, evaluation of the effects of dose reduction by decontamination, shielding and removal, and study on the dose reduction measures were carried out and completed at the end of 2014. From these studies, it was hypothesized that the structures such as ducts and pipes installed near the ceiling contributed to a large proportion of radiation sources, but information regarding whether contamination is present in these structures or the types of gases and liquids which may be present inside them is not sufficiently obtained.

d. Development of remote decontamination technology

- Underground floor (the area where contaminated water is accumulated): Necessities of decontamination scenario and development of decontamination device are under study.

- Lower part of 1st floor of the building (2m or lower): Demonstration test completed in FY2013 but its effect is limited. (Table 4.3.4-2)
- Higher part of 1st floor of the building (2m or higher): Demonstration test to be completed in FY2014. (Table 4.3.4-3)
- Lower part of 2nd and 3rd floors, upper floors of the building: Demonstration test to be completed in FY2015. (Table 4.3.4-4)
- Installation of remote-controlled shields: Demonstration test completed and the actual use is expected.

(4) Future actions

They are the same as the Submersion method but the studies need to be conducted assuming that the feasibility conditions of the structures of the cells and negative pressure control system will be stricter since the water shielding effect or dust dispersion prevention by filling PCV with water and cannot be expected.

a. Internal PCV

- In order to improve the accuracy of the evaluation of dose attributable to the reactor internals and fuel debris by incorporating the results of internal RPV/PCV investigations to be conducted in the future, and to minimize exposure to the workers and reduce dose within the site boundary, it is necessary to determine the required thickness of the shields of the cells taking account of shielding effect of water.
- For the dusts, the Cs adsorption mechanism and amount of adsorption is to be identified by internal investigation. Also the amount of dusts that may be generated when cutting the fuel debris must be identified and such information needs to be incorporated into building's negative pressure control and air cooling filter designs.

b. Site conditions

- It is necessary to make reasonable judgments on whether to choose remote control or direct operations by workers depending on the conditions of the working areas or the actual tasks for dose reduction. On the other hand, the areas of decontamination may change depending on the fuel debris retrieval method to be employed, therefore dose reduction works must be carried out by determining the areas of priority and in line with the currently unknown reactor conditions and the progress on the studies on the retrieval method.
- In order to keep the cumulative dose over many years below the limit and to develop a sustainable radiation environment, it is necessary to set a target dose rate for each working area based on the target dose (dose limit) which is set lower than the legal limit of dose and taking into account the working hours/days and achieve the target dose by decontamination and shielding.
- It is necessary to update the information on the existing decontamination technologies or shielding technologies as necessary and create a database.

c. Comprehensive dose reduction plan

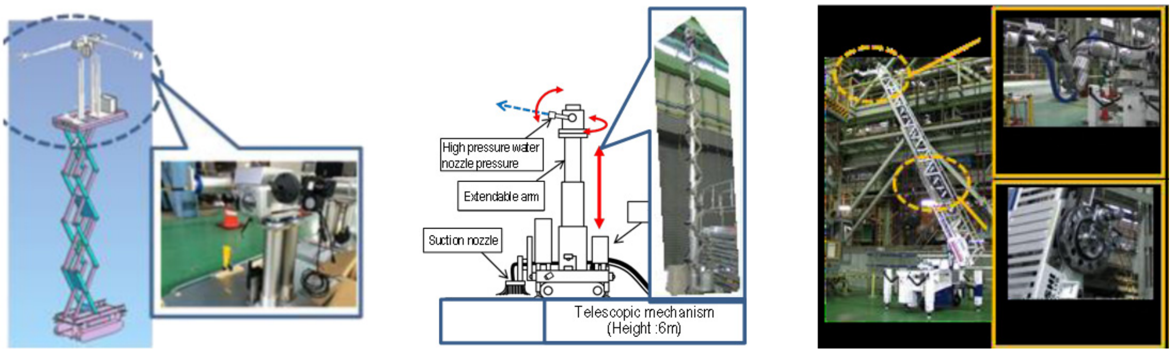
- For areas such as the small chamber, where investigations are not sufficiently carried out because of inaccessibility of the investigation devise, access method and improvement of the devices must be studied and data on contamination status must be obtained.
- In order to effectively implement the decontamination plan, the dose rates from the structures (such as cable tray, pipes, and ducts) installed near the ceiling where the radiation source contribution is relatively large and the contamination status inside the duct etc. must be identified.
- For decontamination of the operating floor, it is necessary to assess the prospect of dose reduction of the radiation from the floor and the data on the actual decontamination effectiveness for Unit 3 where decontamination is carried out in advance, and reflect the results in the decontamination plans of the other units.

d. Development of remote decontamination technology

- Among the current statuses of development of remote decontamination technology listed in (3) d. above, the development of upper floor decontamination device will be continued in accordance with the current development plan.

Dry ice blast High pressure water Suction and blast

Figure 4.3.4-2 Decontamination equipment for lower places (provided by IRID)



Dry ice blast High pressure water Suction and blast

Figure 4.3.4-3 Decontamination equipment for higher places (provided by IRID)

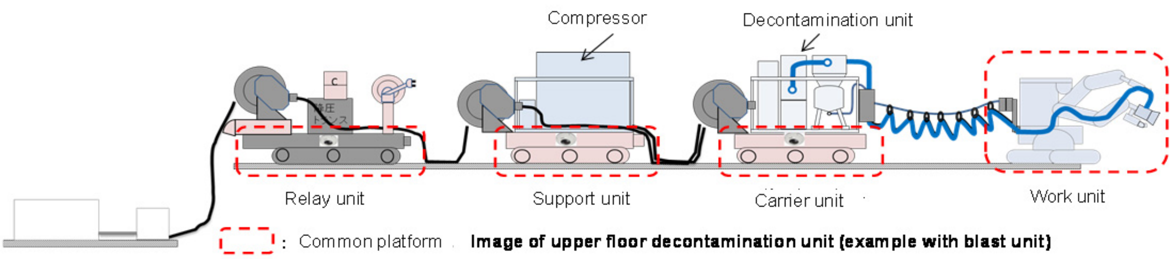
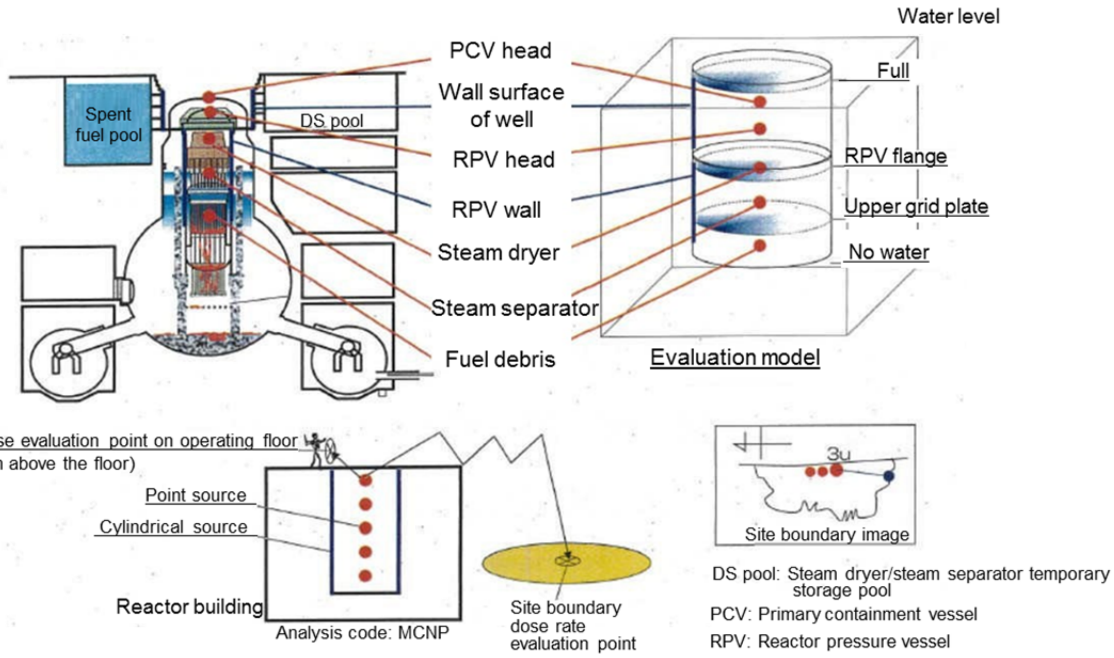


Figure 4.3.4-4 Decontamination equipment for upper floors (provided by IRID)



[Dose evaluation model]

Maximum dose when equipment is removed

Operating floor dose rate (Sv/h)	Fuel debris *1	0.9
	Cs	6.6
	Co	14.3
	Total	21.9 *2

Can be reduced to less than 1mSv/h with approx. 30cm steel shielding.

*1 The dose rate for fuel debris is calculated considering the self-shielding with the average core burnup of the Units 1 to 3.
*2 Rounded off to the first decimal point
*3 Includes Co

Maximum dose when equipment is removed considering the work steps (Debris source*1 and Cs sources are considered)

	Water level	Max. dose	
Operating floor dose rate (Sv/h)	Fully filled	0.28	Effect of Cs adhering to the wall surface of the well
	Partial submersion	6.6	Fuel debris submerged
	No water	7.6 (21.9)*3	Fuel debris exposed; Can be reduced to less than 1mSv/h with approx. 25cm steel shielding.
Site boundary dose rate (Sv/h)	Fully filled	0.2	
	Partial submersion	3.3	
	No water	3.6	Can be reduced to less than 1mSv/yr with approx. 8cm steel shielding.

Maximum dose when components are removed with due consideration of decay

		10 yrs later	20 yrs later	30 yrs later
Operating floor dose rate (Sv/h)	Fuel debris	0.9	0.5	0.3
	Cs	6.6	5.3	4.2
	Co	14.3	3.8	1.0
	Total (Thickness of shielding required to reduce to 1mSV/h)	21.9*2 (approx. 30 cm)	9.6 (approx. 27 cm)	5.5 (approx. 24 cm)

- The evaluation results contain following conservative points;
  - The radiation source intensity of fuel debris is calculated assuming that all nuclides remain except Cs and noble gases. If semi-volatile nuclides is dissolved, the intensity will be about 60%. Increased effect of shielding in the event the fuel debris flowed out of the pedestal is not considered.
  - The point source is used for the calculation and the self-shielding effect of the structure in the PCV which is the radiation source is not considered. The fuel debris shape is assumed to be cylindrical although it is unknown. The source intensity of the fuel debris is supposed to be 0.055 times considering the self-shielding effect.

[Dose evaluation results]

Figure 4.3.4-5 Referential data on dose evaluation at the time of fuel debris retrieval (provided by TEPCO)

4.3.4.2.6 Development of the fuel debris retrieval equipment and devices

(1) Purpose

The purpose is the same as that of the Submersion method as follows.

To complete development and design for the equipment and devices that will be used to directly access and retrieve the fuel debris and reactor internals to which fuel debris is attached. The equipment and devices must meet the required specifications in order to conduct effective retrieval works. Also, installation area of the equipment and device is to be secured and the areas for replacement of the parts, maintenance and management such as inspections and troubleshooting are to be established with appropriate conditions.

(2) Major requirements

Major requirements for development and design of equipment and device and the installation area are the same as those of the Submersion method, but since dose of the Partial submersion method is especially severe, the degree of importance of the manipulators for remote handling or the imaging/measurement technologies under the condition where direct visual confirmation is difficult is higher than that of the Submersion method. Also, response capacity to the radioactive materials released when cutting fuel debris in the air, and equipment and device’s resistance to the dust generated and decontaminability for maintenance are to be evaluated and its feasibility needs to be confirmed.

a. Requirements for development and design of the equipment and devices

- The equipment and devices for fuel debris retrieval must have the specified resistance against radiation and acceptable life duration sufficient for the application under the radiation of the operated areas. In addition, the use under the presence of dust, which is an assumed operation environment, must be possible (the condition may be even severer for the Partial submersion method).
- Collectability of the radioactive materials that will be released when the debris are cut into pieces is to be evaluated, and the designs of the equipment and devices must be able to respond to such condition (the condition may be even severer for the Partial submersion method).
- The equipment and devices of fuel debris retrieval need to be equipped with the visual and measurement systems to allow unlimited confirmation of the surroundings (the condition may be even severer for the Partial submersion method).
- The equipment and devices of fuel debris retrieval need to be able to retrieve all fuel debris distributed in the plant regardless of its location. If necessary, multiple equipment and devices must be prepared or planned to enable completion of the retrieval work. Auxiliary operations by remote control and manipulators to handle the equipment and devices and retrieved objects must be in place. (the condition may be even severer for the Partial submersion method).

- The equipment and devices of fuel debris retrieval (cutting and dust collection) must have sufficient capability to cut the fuel debris with assumed degree of hardness. The cutting speed must also be confirmed in advance on the simulated debris.
- For the consumable goods which are replaced frequently, remotely operated replacement must be possible.
- The equipment and devices must be developed in accordance with the planned design of the canisters.
- Recovery methods must be formulated in case of equipment and devices failures during retrieval work so that the subsequent works are not affected.
- Fail-safe concept must be incorporated as much as possible in the design of the equipment and devices.

If any of the above requirements cannot be met, alternative measures must be formulated.

b. Requirements for the site areas where the equipment and devices are installed

The specifications are the same as in the Submersion method and following are necessary.

- Appropriate areas must be secured for the installation of the equipment and devices for retrieval and access to the location of retrieval needs to be possible.
- Areas for normal maintenance such as inspection and parts replacement needs to be prepared.
- Maintenance areas where people can access are to be prepared to respond to the troubles.

(3) Current status

The R&D project called "Development of technology for retrieval of fuel debris and reactor internals" is underway since FY2014. The requirements to determine the fuel debris retrieval method has been formulated while study of retrieval method to be prioritized and the element test of technologies to be developed have begun.

(4) Future actions

The following should be implemented to develop the fuel debris retrieval equipment and devices.

In order to determine the policies concerning the fuel debris retrieval method for each unit, feasibility of the development of the fuel debris retrieval equipment and devices to be used in the selected method needs to be confirmed, and information from other projects and field work should be referred to. The policy concerning the fuel debris retrieval method should be determined based on the evaluation of the various information including a prospect on PCV repair, the distribution of the fuel debris revealed by investigations inside PCV, the load to structure and water level that are dependent on the choice of the fuel debris retrieval method. A good coordination between development and investigation projects should be ensured to acquire necessary information at the right timing.

The followings need to be confirmed to judge the feasibility of fuel debris retrieval scenario.

- Confirm the collectability of the radioactive materials released when the debris are cut into pieces is feasible during the operation.
- Confirm the possibility of meeting the specifications for the equipment and devices. The prospect for the certain specifications is to be evaluated by element technology tests.
- Confirm that the possibility of meeting the specification of the site conditions by the time of fuel debris retrieval.
- Check the conformity with the plan for collection, transport and storage of the retrieved fuel debris.

Also, the actions should be taken to satisfy the requirements in (2) a., b. toward the practical application of the fuel debris retrieval method after the determination of the policy.

4.3.4.2.7 Establishment of access routes to the fuel debris

(1) Purpose

To establish the access route for fuel debris retrieval work by the Partial submersion-Top entry method and the Partial submersion-Side entry method. The route inside the building to access the operating floor, a route from operating floor to the fuel debris for the Partial Submersion-Top entry method and a routes from 1st floor of the building to the fuel debris at the bottom of the D/W for the Partial submersion-Side entry method are to be developed.

(2) Major requirements

a. The dose of the working areas inside the building needs to be reduced, the obstacles removed, and the access route inside the building must be established to carry-in/out and install the equipment for the fuel debris retrieval as well as transferring the retrieval equipment and fuel debris. (Access route inside the building used in the Partial submersion-Top entry method is the same as that of the Submersion method, and access route inside the building used in the Partial submersion-Side entry method is different from the Submersion method.)

The Partial submersion-Top entry method requires b. through d. which are the same as the Submersion method in addition to a.

b. Existing equipment located on the access route between the upper part of the PCV and the fuel debris are to be removed to secure the route.

c. If there is fuel debris outside of the core shroud, it will be necessary to remove the core shroud and access the fuel debris, therefore a plan needs to be established according to the conditions. It also has to be established assuming the possibility of fuel debris located in and outside the pedestal at the bottom of the D/W.

d. A plan needs to be established according to the conditions since a large opening needs to be created on the RPV bottom or removing the RPV itself to access the fuel debris located on the bottom of the D/W. It has to be established assuming the possibility of fuel debris located in and outside the pedestal at the bottom of the D/W.

The Partial submersion-Side entry method requires item e. in addition to a.

e. A plan is to be established including the installation of the opening on the wall and enlargement of opening on the PCV required depending on the retrieval method to access the fuel debris on the bottom of the D/W from the first floor of the building.

(3) Current status

Establishment of the access route to the fuel debris in the Partial submersion-Top entry method is the same as the Submersion method. The access route from the top of the PCV into the core is structurally secured for the fuel replacement work during the outage. The access into the reactor can be secured by removing the well shield plug, PCV upper head, insulator for the RPV upper head, and RPV upper head. The upper grid plate immediately above the core may be reached by removing the steam dryer and steam separator allowing accesses the fuel debris inside the RPV. However, there is a possibility that the equipment to be removed may be deformed as a result of exposure to high heat during the accident and may be difficult to remove using a normal method. In such case it is necessary to cut them before removal.

The reactor internals of which removal should be considered in the Top entry method are show in Table 4.3.4-7.

As for the Partial submersion-Side entry method, there are equipment hatch and CRD hatch on the side of the PCV which lead into the PCV. Although the sizes of these openings may be restrictive, the access route into the PCV is structurally secured. At the bottom of the D/W inside the PCV, PLR pumps, valves, pipes and supports are installed outside of the RPV pedestal, and CRD handling machine and operating floor (grating) are installed inside the RPV pedestal and they may hinder access to the fuel debris, but they can be cut off and removed to enable access to the fuel debris located at the bottom of D/W. However, the export route for equipment to be removed is necessary.

Table 4.3.4-6 shows the condition of the interference objectives in the Partial submersion-Side entry method.

(4) Future actions

The following are the actions to be taken.

a. The access route from the side into the highly contaminated building needs to be developed for the Partial submersion-Side entry method. The measures for decontamination and shielding including the removal of obstacles, preparation work, etc. need to be fully developed since it may be necessary to access the high dose areas which is different from the Submersion method and the Partial submersion-Top entry method.

b. The access route for the Partial submersion-Top entry method is the same as that of the Submersion method. Check if the dimension of the opening is large enough when equipment and devices to be carried in/out of each area in the Partial submersion method are larger than those of the Submersion method.

If the fuel debris is located outside the core shroud, the core shroud may need to be removed to secure the access.

In order to access the fuel debris at the bottom of the D/W, a large opening on the bottom of the RPV needs to be created or the RPV itself needs to be removed beforehand. Since the distance from the operating floor to the construction location will be as long as several dozens of meters, workability is needs to be improved by, for example, lowering the construction stage for work.

(Note 1) For the Partial submersion-Side entry method, removal of equipment and obstacles around the RPV pedestal and construction of the access route in the high dose area are highly difficult issues.

Example of Unit 1 (Provided by GE Hitachi)

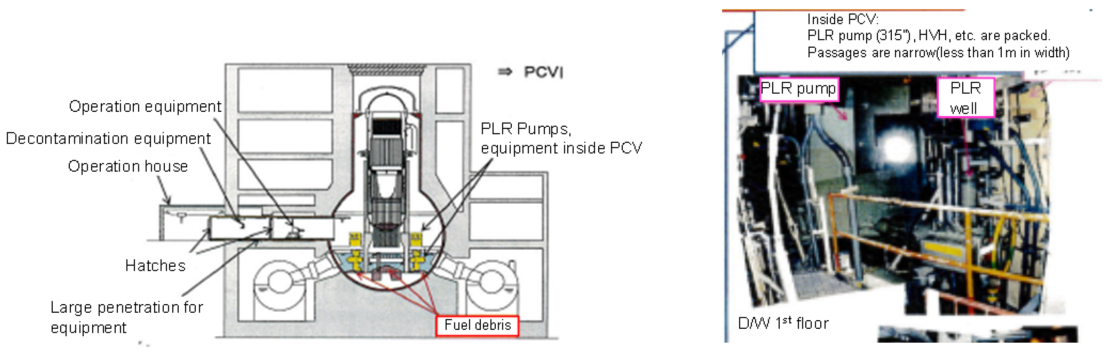


Figure 4.3.4-6 Obstacles Partial submersion-Side entry method

(Note 2) For the Partial submersion- Top entry method, it is necessary to remove reactor internals located at the upper part of the fuel region before starting fuel debris retrieval. This work is considered highly difficult and takes a long time.

Schematic diagram of the reactor internals (presented by IRID)

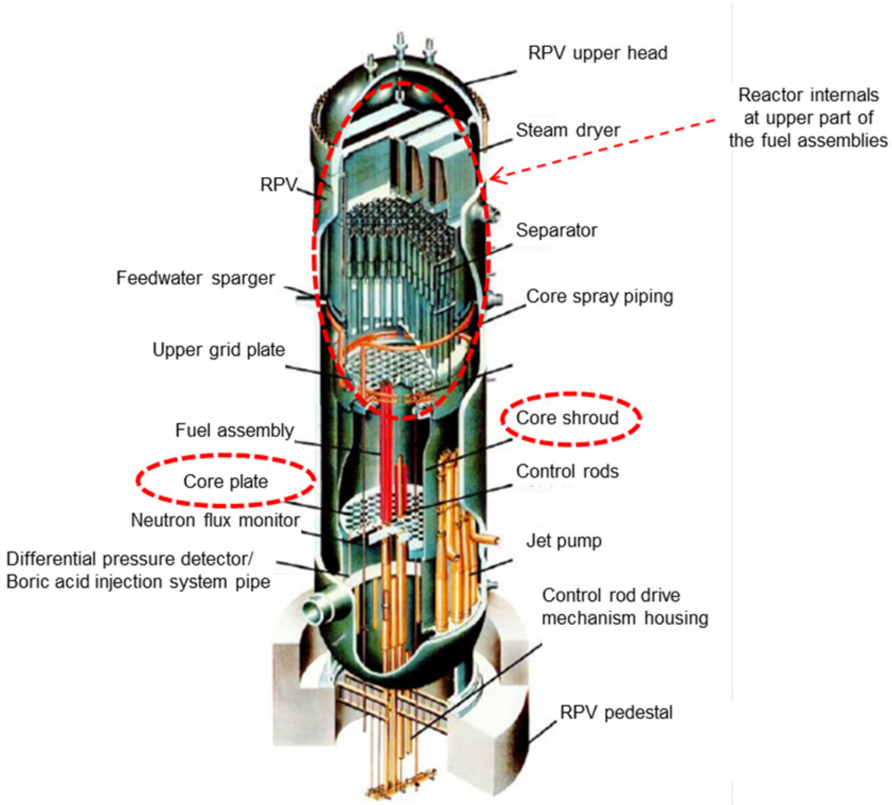


Figure 4.3.4-7 Major reactor internals that may be removed in Top entry method

4.3.4.2.8 Establishment of system equipment[1] and working areas

(1) Purpose

The purpose are the same as that of the Submersion method as follows.

To conduct conceptual studies for the additional container to be installed in the building, cell with prevention function for dust dispersion during the fuel debris retrieval work, and various systems to be used for the fuel debris retrieval. Also preparation for the installation and operation of facilities and systems and securing and operating of the necessary working area are necessary.

In addition to the device control system directly related to the fuel debris retrieval work, the systems to be prepared may include the cooling water injection system, contaminated water collection system, negative pressure control/gas control system, radioactive gas treatment system, criticality control system, and a system for treatment and transport of the retrieved fuel debris.

However, since the level of dose and dust dispersion is severer compared to the Submersion method, specifications required for container, cell, and system will be different and the Partial submersion-Top entry method and the Partial submersion-Side entry method are to be studied when the technical requirements are considered.

(2) Major requirements

Major requirements for the Partial submersion-Top entry method are the same as that of the Submersion method described in a.-e.

Major requirements for the Partial submersion-Side entry method are as described in a.-d.

a. The design for the additional containers and cells to be installed in the building is to be completed, and the function, performance and integrity of these facilities are to be evaluated and must be feasible. Sufficient installation space needs to be secured for the equipment, devices and apparatuses that constitute the systems. Requirements for the environment in accordance with the design requirements of equipment, devices and systems must be met.

b. Sufficient space for the operation and maintenance of equipment, devices, apparatuses that constitutes the systems needs to be secured. Requirements for the environment of the maintenance area in accordance with the design requirements of equipment, devices and systems must be met.

c. If existing equipment is used for the fuel debris retrieval work, it must be confirmed that there is no damage or deterioration in the equipment and its function needs to be maintained.

d. Processing and disposal methods are to be established for the fuel debris, severely contaminated structures, cut objects to be exported over the course of the fuel debris retrieval work. The areas

[1] System equipment includes the building, container and cell as well as the system related facilities such as cooling water injection system (e.g. contaminated water collection system) and radioactive gas treatment system

for temporary placement of equipment, working areas and the destination of the transport need to be determined and the sufficient areas need to be secured.

e. Fuels must be removed from the SFP, and other stored objects including the control rod, fuel racks and rubbles are also to be removed.

Since the operation for Partial submersion-Side entry is considered to be possible to carry out separately from the operations related to the SFP, so item e. above will not be necessary but it must be noted that the safety measures will be required when the fuels remain in the SFP.

(3) Current status

Current status is the same as the submersion method. The activities will be carried out from FY2015 starting with those required for feasibility confirmation of the retrieval method, such as with the studies on the overview of the systems including the containers and cells.

(4) Future actions

It is the same as the Submersion method. Following items are to be implemented by the time to judge the feasibility of the methods.

a. Since the evaluation of the integrity of the buildings is required to confirm the feasibility of the method, the overview of the major weights and dimensions of equipment such as containers and cells which may have impact on the evaluation needs to be confirmed, and based on this confirmation the integrity should be evaluated.

b. Confirm that the installation space is secured for the major equipment used for the method.

c. Confirm if the storage area can be secured for the equipment including the retrieved equipment which are severely contaminated, cut object and fuel debris.

Also, in the same way as the Submersion method, after the selection of the method to be used for fuel debris retrieval work, the details of layout plans for the installation and operation of the equipment that constitutes the systems and detailed plot plan for the areas for temporary placement and handling of the retrieved equipment, and storing the retrieved fuel debris need to be established. Evaluation criteria for decontamination and shielding, dust dispersion prevention need to be established to satisfy the environment conditions required for working area and approaches should be taken to realize those criteria.

Compared to the Submersion method, a plan which considers the dust dispersion prevention and the reduction of exposure by fuel debris etc. which are especially important in the Partial submersion method will be required.

4.3.4.2.9 Ensuring the work safety

The purpose, major requirements, current status and future actions for ensuring the work safety are described below and those are the same as 4.3.3.2.9. Since there is no shielding by water compared to the Submersion method and high radiation environment is anticipated, thorough measures against the dust dispersed in the air will be required in advance.

(1) Purpose

Most of the operations prior to the fuel debris retrieval will be carried out inside the R/B. The environment of the R/B is in extremely severe condition with narrow space, insufficient lighting, rubbles scattered, high radiation, dusts, etc. Since the operations such as retrieval work for fuel debris which has reached the PCV will be carried out for the first time under such a severe condition, it is important to develop the careful measures and preparation to prevent workplace accidents.

(2) Major requirements

The work safety measures will need to be fully prepared to a level incomparable to the past in order to prevent, reduce, and mitigate workplace accidents.

(3) Current status

a. Operations in the R/B and its peripheral area are carried out under the condition that requires radiation protection, such as full face mask which imposes burden to the workers.

b. In light of the fact that fatal accidents have been taking place repeatedly, such as falling from the top board of the rainwater collection tank on January 19, 2015, various types of safety improvements have been made to prevent, reduce, and mitigate workplace accidents by safety check, awareness improvement, case study meeting, and meeting to remind of the fatal accidents occurred in the past.

(4) Future actions

The following should more strongly be imposed to prevent, reduce, and mitigate workplace accidents.

a. Conduct the current safety improvement measures more thoroughly.

b. Establish better work environment as much as possible by the restoration of the lighting (restoration of the power), improvement of communication environment, and removal of rubbles.

c. Review the dose reduction work inside the R/B and the PCV internal investigation work which have been carried out to utilize the experience in the preliminary measures including preparation, planning, and training for other operations.

d. In addition to the reactor dose reduction work inside the R/B described in b., the PCV internal investigation, R/B repair, removal of contaminated water accumulated inside the building, dismantling of the upper part of the R/B (Unit 2), and operation to remove fuels from the SFP are currently planned for fuel debris retrieval. Trainings on the mock-up have to be conducted sufficiently for the operations to be carried out for the first time.

e. Identify possible accidents and troubles that may occur during each operation in advance, conduct risk assessments and take measures in order to prevent the accidents and troubles. Consider contingency measures to respond to any unexpected situations.

4.3.4.3 Utilization of new method proposal through the international tendering

To study the Partial submersion method for fuel debris retrieval in addition to the Submersion method, technologies have to be developed to resolve the issues with high degree of difficulty and newly identified issues. Technologies need to be improved by gathering the knowledge and experiences from all over the world through the international tendering system.

Followed by the Request for Information (RFI) conducted in 2013, as a part of the subsidized project of decommissioning and contaminated water management implemented by the Agency for Natural Resources and Energy, international request for proposal for the following three projects on the alternative fuel debris retrieval method (the Partial submersion method) was conducted in June 2014. As a result, a total of 11 proposals were adopted, and the studies on these proposals began and ended at the end of March 2015.

Based on the results the studies on the three projects, applicability, etc. to the Partial submersion method will be evaluated. Development and research are to be implemented for the technologies which are evaluated to be highly effective for application to the actual unit. The technical development in the "Development of fuel debris retrieval equipment and devices," the technical requirements explained in 4.3.4.1 and 4.3.4.2 and application in the field works should also be considered.

Concerning the themes which more detailed R&D programs are expected to be continued from FY2015 on, it is necessary to consider about the framework for the application to the actual facilities.

- "Conceptual Study of Innovative Approach to Retrieve Fuel Debris in the Air Safely and Reliably" (Four proposals selected)
  Out of four projects, three methods which are combining the access from the top and side of the PCV are being studied. The remaining one is the method with access from the top of the PCV.
- "Feasibility Study of Visual and Measurement Technology for Innovative Approach" (Four proposals selected)
- "Feasibility Study of Fuel Debris Cutting and Dust Collection for Innovative Approaches" (Three proposals selected)

Reference:

Contaminated Water and Decommissioning Issues Team meeting (The 14th), Document 4-2 "Interim report on the conceptual study for the alternative method for fuel debris retrieval"

4.3.4.4 Steps to judge the feasibility of the Partial submersion method

The Partial submersion method is a method to retrieve fuel debris while maintaining the current water level of the PCV. It is comparatively easy to control PCV water level and criticality. On the other hand, since sufficient radiation shielding and radioactive dust dispersion prevention are not always secured, following three important issues have to be addressed to realize this method.

(1) Shielding for high radiation from fuel debris
The shielding needs to be developed considering the impact to the workers and public caused by radiation from the fuel debris, FP, and activated materials. Also, impact on the R/B by the weight of shielding materials has to be considered.

(2) Prevention of the impact on the workers and environment caused by the dust dispersion to the outside of the building
The fuel debris retrieval methods and the measures have to be developed so as to prevent radioactive dust from being dispersed to the outside of the building.

(3) Confirmation of radiation resistance of fuel debris retrieval equipment, etc.
The retrieval equipment will be exposed to the fuel debris with high radiation, and it requires radiation resistance that will not gravely impact the retrieval work.

Since a part of fuel debris may not be submerged depending on the retrieval method, evaluation is necessary for cooling effect on the fuel debris which is not submerged.

Developments and discussions should be carried out with reviews as necessary, based on the progress of the actions taken for the nine technical requirements described in 4.3.4.1 and the three especially important issues explained above. The feasibility of the Partial submersion method needs to be judged so as to satisfy the technical requirements and select the scenario for fuel debris retrieval method in order to determine the retrieval method in first half of FY2018, which is the hold point in the Roadmap.

The future actions to be taken for nine technical requirements are shown in Table 4.3.4-8.

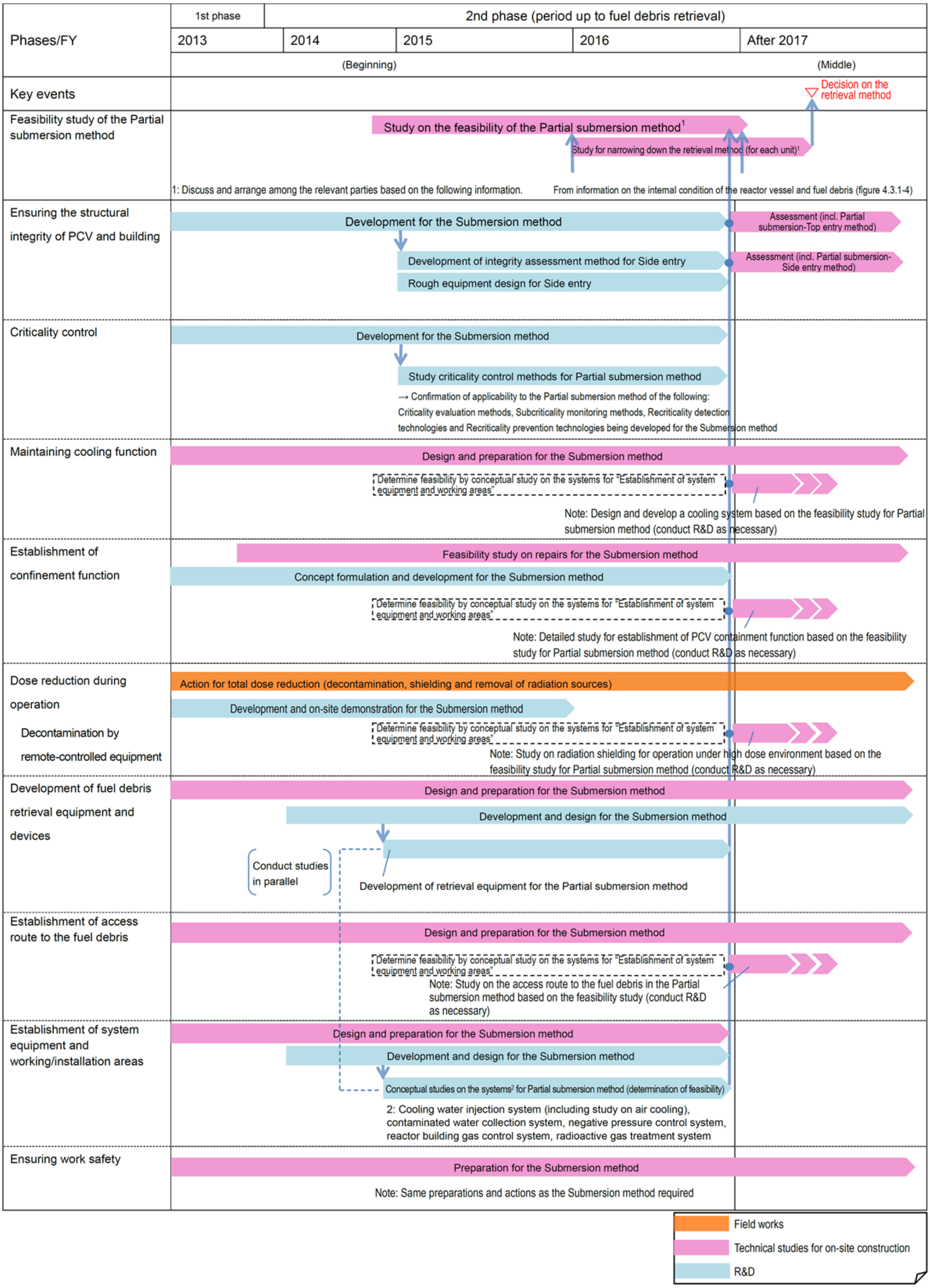
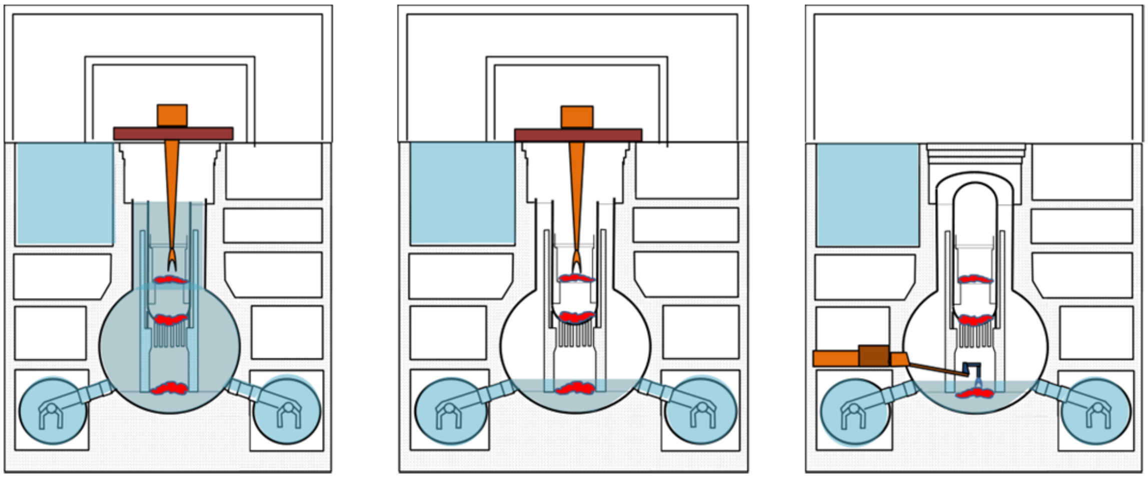


Figure 4.3.4-8 Future action for the technical requirements for the Partial submersion method

4.3.5 Studies on the multiple scenarios based on the condition of each unit

The applicability of the Partial submersion method is described in the Section 4.3.4. This section describes the scenario for the application of fuel debris retrieval method based on the information for the current status for each unit.

There are three options of retrieval methods to be studied, which are the Submersion method with access from the top, the Partial method with access from the top and the Partial method with access from the side as described in the Section 4.3.2. The image of each method is shown in Figure 4.3.5-1.



Submersion-Top entry method	Partial submersion-Top entry method	Partial submersion- Side entry method
Assuming the reactor internals structures above the fuel debris are	Assuming that the reactor internals above the fuel debris are removed	Assuming that the equipment and other objects outside the RPV pedestal in PCV are removed

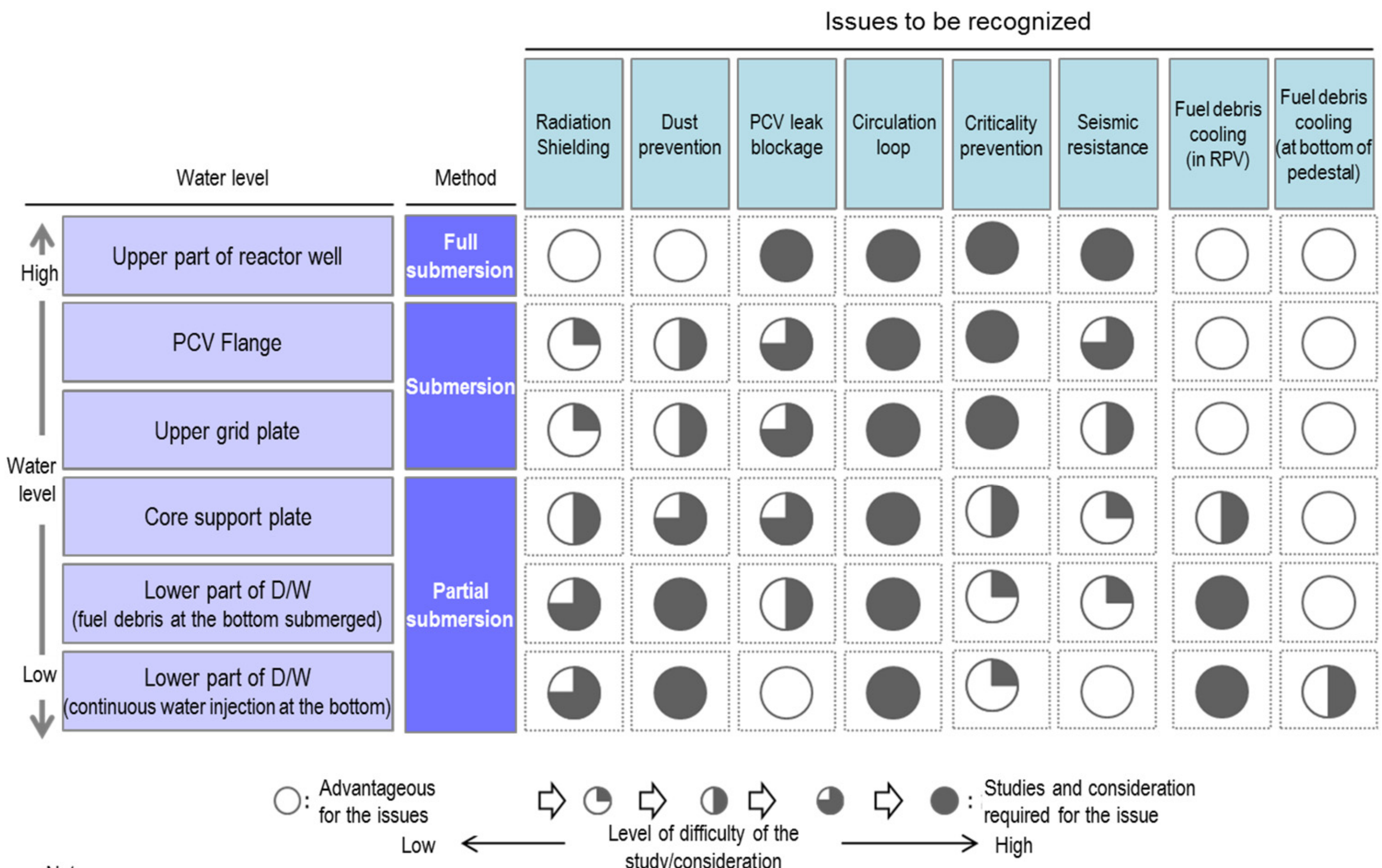
Figure 4.3.5-1 Three methods to be focused on (image)

The scenario covers the process from the start to the completion of the fuel debris retrieval work.
If single option is used through the entire process, multiple options need to be combined in series to complete the retrieval work.

The Submersion method and the Partial submersion method as the options of fuel debris retrieval method have advantages and issues. Figure 4.3.5-2 qualitatively describes the issues of the methods to be addressed according to the water filling level, and the necessity and degrees of difficulties of considerations and studies are clarified.

The Section 4.3.5 shows the concepts of the scenarios studied based on the estimation of the current status of each unit and information to be obtained.

If the estimation of the plant conditions is changed according to the information to be obtained, the revision of the contents may be necessary.



Notes:

1. The difficulty of the feasibility of the retrieval methods depending on the water level is not considered.
2. To select the method, it will be necessary to assess the necessity of the study/consideration on the issues as well as the details of development required to realize each retrieval method and rationality of the retrieval work in accordance with the site preparation and plant conditions.

Figure 4.3.5-2 The issues to be studied for each water level of retrieval method

4.3.5.1 Studies on the scenario for the application to the plant

This section describes the possible processes conceivable from the start to the completion of the fuel debris retrieval work applying the “Submersion method,” “Partial submersion-Top entry method,” and “Partial submersion-Side entry method” in the Section 4.3.2. There are a total of seven scenarios for fuel debris retrieval method, including three scenarios assuming application of one of the methods above through the entire process from the start to the completion of the retrieval work, and four scenarios applying two methods depending on the distribution of fuel debris and its order of the construction process.

Table 4.3.5-1 shows the procedures and features expected for the above scenarios and Table 4.3.5-3 shows the scenarios for each method of retrieval and the retrievable locations of fuel debris.

The procedures for each scenario (supplement for expected procedures in Table 4.3.5-1)

Scenario (1) Access by the Submersion (or Full submersion)-Top entry method
→Retrieve reactor internals and fuel debris inside the RPV
→Retrieve fuel debris inside the PCV pedestal →Complete fuel debris retrieval

Scenario (2) Access by the Partial submersion-Top entry method
→Retrieve reactor internals and fuel debris inside the RPV
→Retrieve fuel debris inside the PCV pedestal →Complete fuel debris retrieval

Scenario (3) Access by the Partial submersion-Side entry method
→Retrieve fuel debris in and outside the PCV pedestal →Complete fuel debris retrieval

Scenario (4) Access by the Submersion (or Full submersion)-Top entry method
→Retrieve reactor internals and fuel debris inside the RPV

Access by the Partial submersion-Side entry method

→ Retrieve fuel debris in and outside the PCV pedestal →Complete fuel debris retrieval

Scenario (5) Access by the Partial submersion-Side entry method
→ Retrieve fuel debris in and outside the PCV pedestal

Access by the Submersion method

→Retrieve reactor internals and fuel debris inside the RPV→Complete fuel debris retrieval

Scenario (6) Access by the Partial submersion-Top entry method
→Retrieve reactor internals and fuel debris inside the RPV

Access by the Partial submersion-Side entry method

→Retrieve fuel debris in and outside the PCV pedestal →Complete fuel debris retrieval

Scenario (7) Access by the Partial submersion-Side entry method
→ Retrieve fuel debris in and outside the PCV pedestal

Access by the Partial submersion-Top entry method

→Retrieve reactor internals and fuel debris inside the RPV →Complete fuel debris retrieval

Before the determination of the method, fuel debris retrieval method is expected to be selected based on the plant condition of each unit. Potential candidate scenarios are now being studied based on the information on the current condition of each unit.

Table 4.3.5-1 Procedures and features of each scenario

Scenario	Retrieval method			Assumed procedures	Remarks
	Full submersion /Submersion – Top entry	Partial submersion – Top entry	Partial submersion – Side entry		
(1)	○	–	–	Remove reactor internals/fuels in RPV ↓ Retrieve fuel debris inside the pedestal	Feasible when retrieval of fuel debris outside pedestal is unnecessary
(2)	–	○	–	Remove reactor internals/fuels in RPV ↓ Retrieve fuel debris inside the pedestal	Feasible when retrieval of fuel debris outside pedestal is unnecessary
(3)	–	–	○	Retrieve fuel debris in/outside the pedestal	Feasible when retrieval of fuel debris in RPV is unnecessary (fully compatible with retrieval from in/outside the pedestal)
(4)	1)	–	2)	1) Remove reactor internals/fuels in RPV ↓ 2) Retrieve fuel debris in/outside the pedestal	Hybrid method with access from top into RPV and from side to the inside/outside of the pedestal
(5)	2)	–	1)	1) Retrieve fuel debris in/outside the pedestal ↓ 2) Remove reactor internals/fuels in RPV	Hybrid method with reversed pattern of scenario (4), seismic resistance is an issue when submerged
(6)	–	1)	2)	1) Remove reactor internals/fuels in RPV ↓ 2) Retrieve fuel debris in/outside the pedestal	Hybrid method with access from top into RPV and from side to the in/outside of the pedestal
(7)	–	2)	1)	1) Retrieve fuel debris in/outside the pedestal ↓ 2) Remove reactor internals/fuels in RPV	Hybrid method with reversed pattern of scenario (6)

The above numbers 1) and 2) indicate the order of procedure.

	Method			Location of fuel debris where the retrieval scenario is feasible		
Scenario	Submersion-Top entry	Partial submersion-Top entry	Partial submersion-Side entry	Inside RPV	Inside RPV pedestal	Outside RPV pedestal
(1)	○	—	—	OK	OK	NG[1]
(2)	—	○	—	OK	OK	NG[1]
(3)	—	—	○	NG[2]	OK	OK
(4)	1)	—	2)	OK	OK	OK
(5)	2)	—	1)	OK	OK	OK
(6)	—	1)	2)	OK	OK	OK
(7)	—	2)	1)	OK	OK	OK

The above numbers 1) and 2) indicate the order of procedure.

1: Retrieval of fuel debris outside the RPV pedestal will be difficult if only the Top entry method is used.

2: Retrieval of fuel debris inside the RPV will be difficult if only the Side entry method is used.

See Tables 4.3.2-1 and 4.3.2-2

Figure 4.3.5-3 Fuel debris retrieval method scenarios and retrievable locations of fuel debris

4.3.5.2 Multiple scenarios based on the condition of each unit and future study method

Desired scenario is to be established in light of the evaluation based on the Five Guiding Principles in consideration of the plant information for each unit (results of investigation and evaluation) with the idea of the seven types of retrieval scenarios listed in 4.3.5.1.

The features of seven scenarios which may be applicable for the plant are as shown in Table 4.3.5-1.

In the scenarios (5) and (7), fuel debris is to be retrieved by using the Submersion-Top entry method or the Partial submersion-Top entry method after the construction work for the Partial submersion-Side entry method. If the fuel removal from SFP is conducted on the operating floor, it is difficult to carry out the construction work for the Submersion-Top entry method or the Partial submersion-Top entry method simultaneously since it requires works to be carried out on the operating floor. However, in the scenarios (5) and (7), the fuel debris retrieval may be started by accessing from the side of the building without being affected by the process of fuels removal from the SFP. In this regard, note that the safety is to be ensured when fuels are remaining in the SFP.

Figure 4.3.5-4 shows the investigation items to determine the scenario for fuel debris retrieval based on the various kinds of information to be the basis of judgment and Figure 4.3.5-5 shows the operation flow up to the fuel debris retrieval.

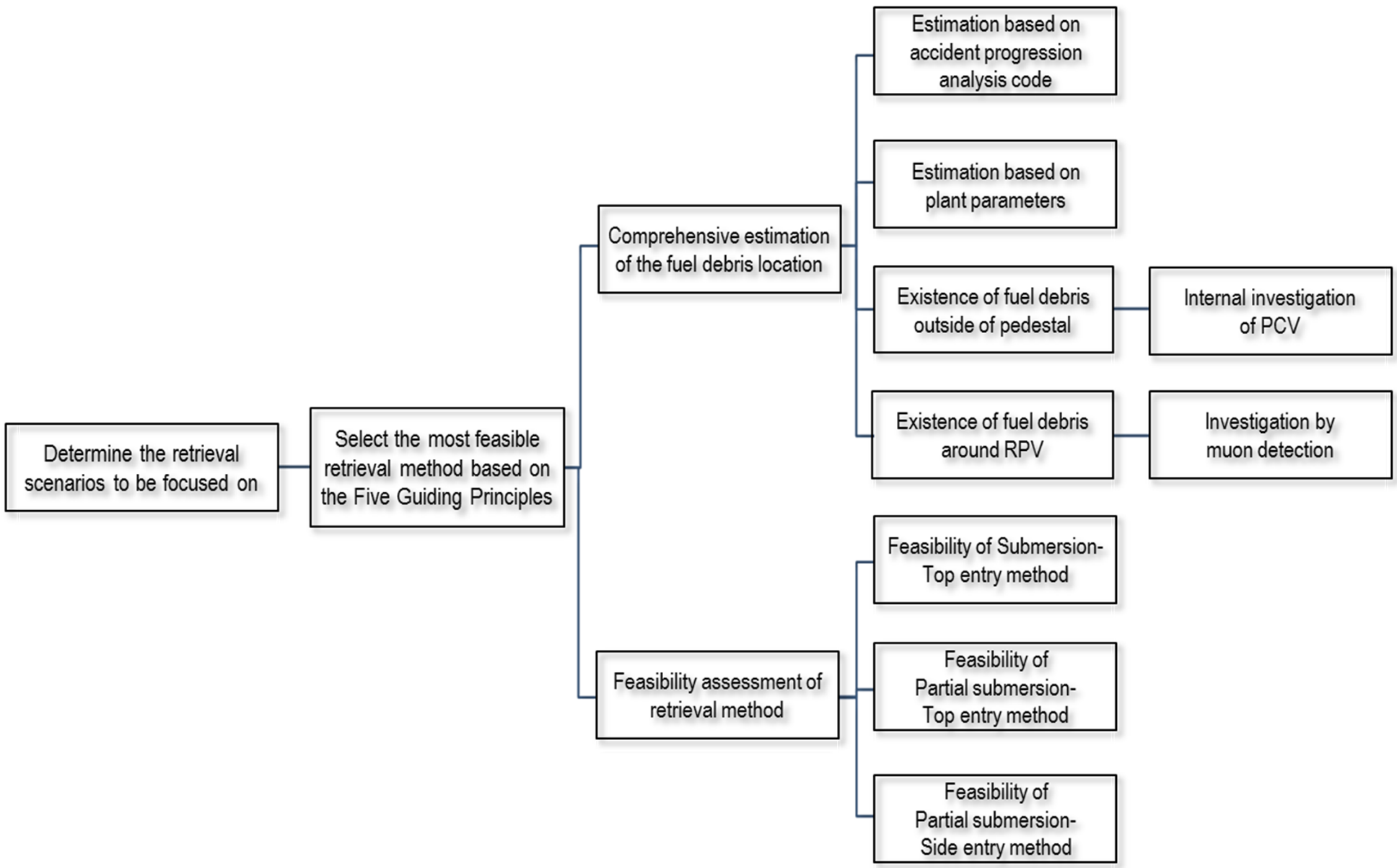
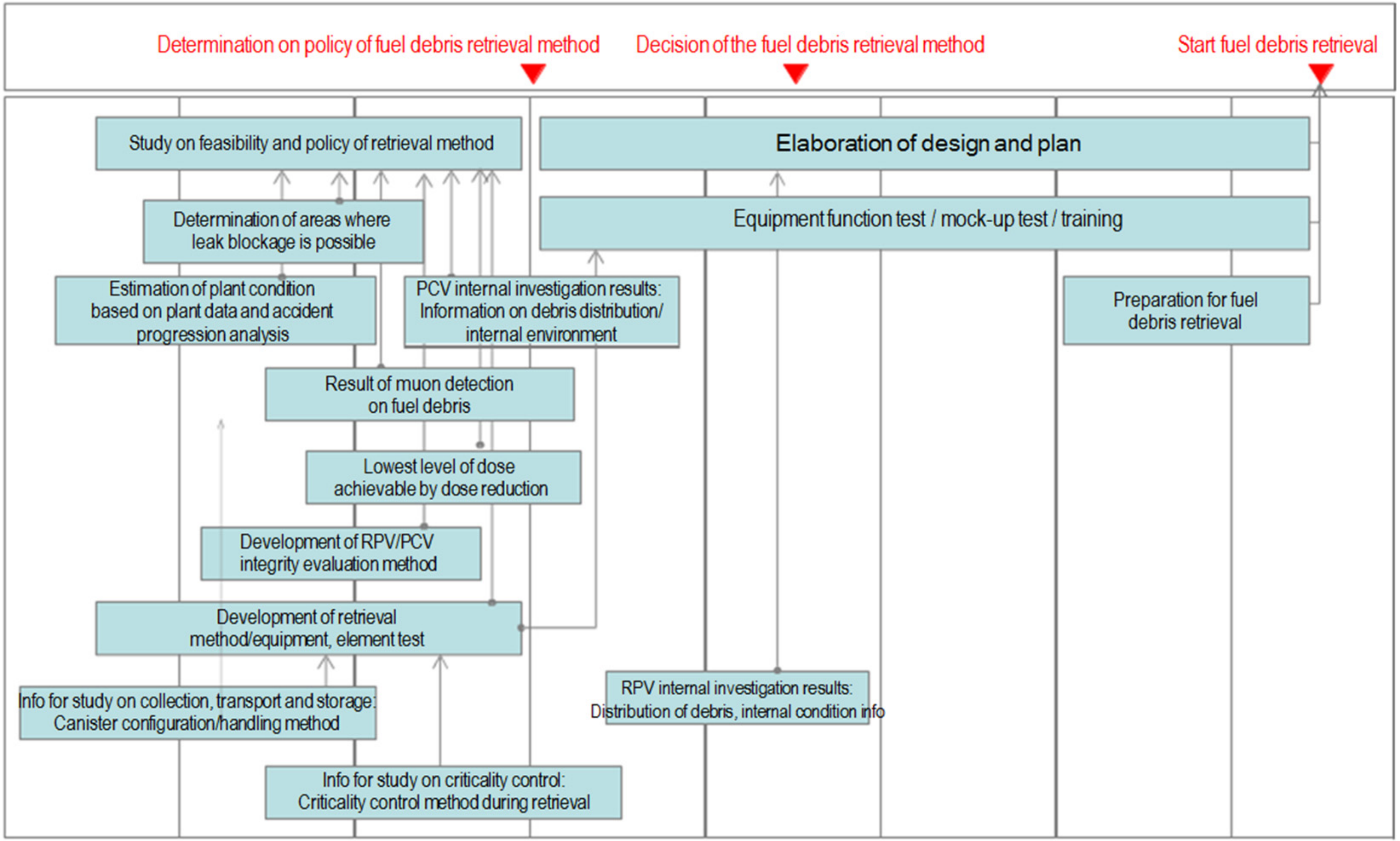


Figure 4.3.5-4 Investigation items to select scenario for fuel debris retrieval



Note: The above figure shows the image of study process by obtaining necessary information to determine the policy of fuel debris retrieval method. The areas where leak blockage is possible and the fuel debris distribution in the PCV and RPV are especially important information for determining the policy for the retrieval method. If multiple methods or scenarios are feasible, select a scenario to focus considering the results of assessment based on the Five Guiding Principles.

Figure 4.3.5-5 Operations to be conducted before starting fuel debris retrieval

The scenario is to be determined based on the current information for each unit.

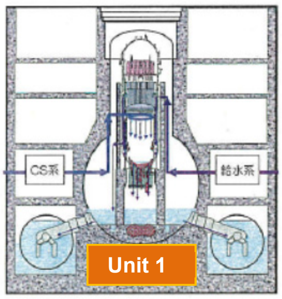
(1) Studies on Unit 1

a. Estimation for the current locations of fuel debris

- Almost all the molten fuel is assumed to have fallen to the lower plenum of the RPV, and there is almost no fuel remaining in the core region.
- Most of fuel debris that fell to the lower plenum fell to the bottom of D/W

b. Status of the water level and damage of the PCV

- Water level inside the D/W: Approx. 3m from the floor of D/W
- S/C is almost filled with the water.
- There are the leakages from the sand cushion drain pipe.
- There are the leakages from the expansion joint cover of the vacuum break line.



c. Concept for selection of the candidate scenarios assuming the potential scenarios and the plant information available in the future

In Unit 1, most of fuel debris is supposed have fallen onto the bottom of D/W.

If the fuel debris are located outside the RPV pedestal in the PCV, it needs to be retrieved by the Side entry method, and the scenarios (3), (4), (5), (6) and (7) shown in Table 4.3.5-1 will be the candidates. The fuel debris retrieval procedures of candidate scenarios are shown in Tables 4.3.5-6 and 4.3.5-7.

If the fuel debris is confirmed to be distributed in the RPV by the muon analysis and the RPV internal investigation, scenario (3) is considered to be difficult to retrieve the fuel debris inside the RPV and the scenarios (4), (5), (6) and (7) will be the candidates.

Also, in case water cannot be stopped to ensure the water level in the PCV to the upper edge above the core region, the candidate scenarios will be (6) and (7).

Concerning (5) and (7), confirmation of the integrity and the reinforcement to ensure the integrity will be necessary if the Submersion method or the Partial submersion-Top entry method is to be implemented after creating the openings on the building walls and PCV surface for side access.

In the case that fuel debris is confirmed to be distributed outside of the RPV pedestal, possibility to start fuel debris retrieval by accessing from the side (either scenario (5) or (7)) may be subject to the verification regardless of its work schedule for the removal of fuel from the pool. In this regard, it must be noted that the safety measures needs to be established for the fuels remained in the SFP.

In case more than one candidate scenario is judged to be technically feasible, it is necessary to select the one of them by the evaluation based on Five Guiding Principles.

Scenarios (4) and (5)

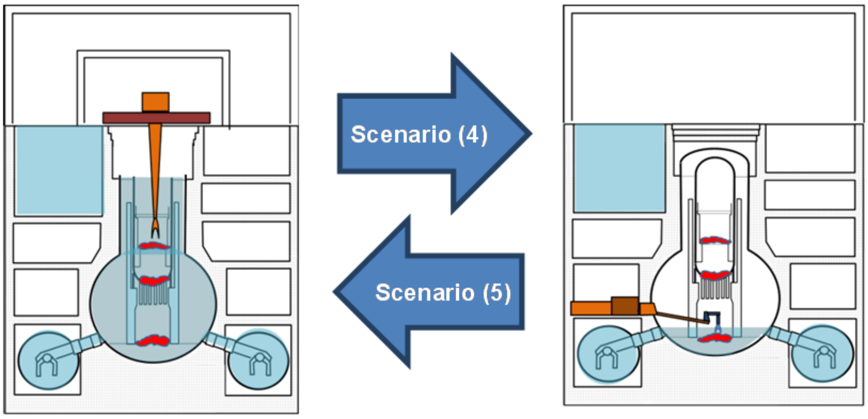


Figure 4.3.5-6 Fuel debris retrieval procedures by scenarios (4) and (5)

Scenarios (6) and (7)

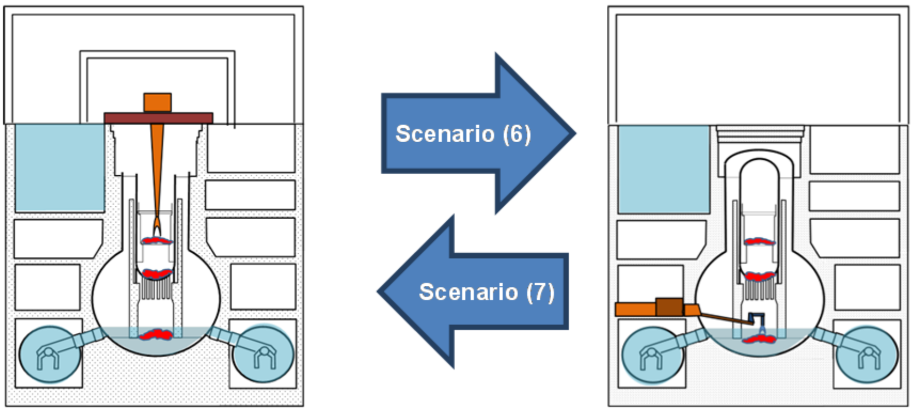


Figure 4.3.5-7 Fuel debris retrieval procedures by scenarios (6) and (7)

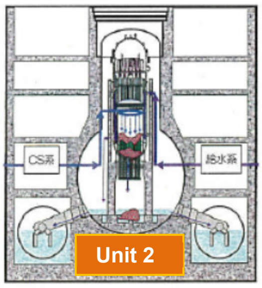
d. Notes on the studies on the fuel debris retrieval scenarios

- If fuel debris is to be retrieved by the Partial submersion-Side entry method, it is necessary have an outlook on the feasibility by carrying out the specific studies on the matters such as the removal of the existing equipment, facilities and pipes for the construction of an access route and planning for the area for temporary placement of equipment and device.
- Feasibility of water leak blockage must be judged based on the results of the leak investigation of the PCV and the development status of the technology of water leak blockage.

(2) Studies on Unit 2

a. Estimation for the current locations of fuel debris

- A part of the molten core has fallen to the lower plenum of the RPV, some to the bottom of D/W, and some remains in the core region.



b. Status of the water level and damage of the PCV

- Water level inside the D/W: Approx. 30cm from the floor of D/W
- Water level inside the S/C: Around the center of the torus
- There is no trace of leakage in the upper part of the torus room.

c. Concept for selection of the candidate scenarios assuming the potential scenarios and the plant information available in the future

The fuel debris remains inside the RPV in Unit 2 and retrieval of fuel debris including those will be necessary. Also it is considered unlikely that fuel debris is remaining at the bottom of the D/W outside the RPV pedestal.

Taking the above estimation into consideration, scenarios (1) and (2) can be leading candidate.

Table 4.3.5-8 shows the image of the fuel debris retrieval by these candidate scenarios. If water can be filled up to the upper part after repairing the PCV, scenario (1) will be achievable, and if not, scenario (2) will be applied.

Either scenario may be selected according to the degree of possibility of water leak blockage for the PCV.

If fuel debris is not distributed outside the RPV pedestal, scenarios (4), (5), (6) and (7) with access from the side are not necessarily be required and it may be more practical to conduct retrieve the fuel debris by one method. Also, if the fuel debris is located inside the RPV, it is expected to be difficult to retrieve fuel debris only by scenario (3) (Side entry method only).

Scenario (1) Scenario (2)

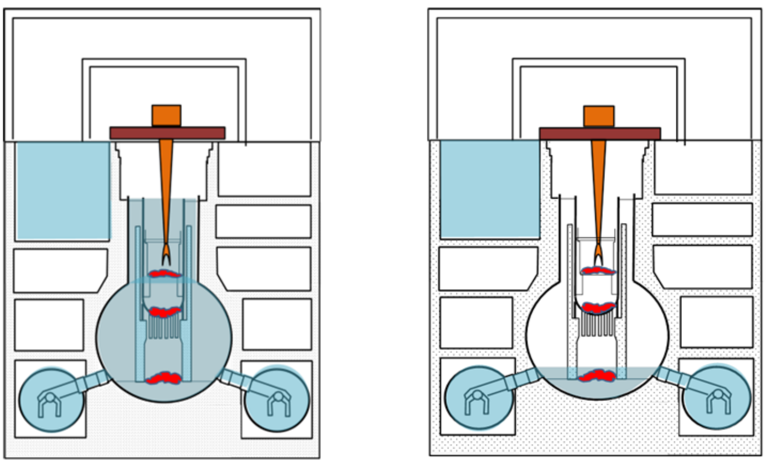


Figure 4.3.5-8 Fuel debris retrieval by scenarios (1) and (2)

In case more than one candidate scenario is judged to be technically feasible, it is necessary to select the one of them by the evaluation based on Five Guiding Principles.

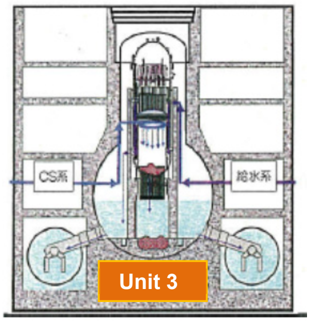
d. Notes on the studies on the fuel debris retrieval scenarios

- It is necessary to judge the water level that can be achieved by the results of the PCV leak investigation. The investigation of the upper part should be accelerated because it will be the ground for selection of the fuel debris retrieval method scenario.

(3) Studies on Unit 3

a. Estimation for the current locations of fuel debris

- A part of the molten core has fallen to the lower plenum of the RPV, some to the bottom of D/W, and some remains in the core region.



b. Status of the water level and damage of the PCV

- Water level inside the D/W: Approx. 6.5m from the floor of D/W
- There are the leakages from the expansion joint of the main steam pipe D.

c. Concept for selection of the candidate scenarios assuming the potential scenarios and the plant information available in the future

In Unit 3, damage of the PCV may be less severe than other units, and thus the Submersion method is expected to be feasible. If the fuel debris is located outside the RPV pedestal in the PCV, it needs to be retrieved by the Side entry method. Therefore, necessity of fuel debris retrieval with access from the side must be determined by PCV internal investigation at an early stage. At present, the scenarios from (1) to (2) and (4) to (7) can be candidates. If the fuel debris is located inside the RPV, it is expected to be difficult to retrieve fuel debris only by scenario (3) (Side entry method only). If it is confirmed that there is no distribution of the fuel debris outside the RPV pedestal, the scenario (1) and (2) will considered to be the leading candidate (based on the concept described in the Studies on Unit 2).

Either scenario may be selected according to the degree of possibility of water leak blockage for the PCV.

In case more than one candidate scenario is judged to be technically feasible, it is necessary to select the one of them by the evaluation in consideration of the risk reduction and evaluation results to be prioritized.

The investigation plan for the fuel debris inside the PCV of Unit 3 is under discussion and the plan for the detection of fuel debris inside the reactor vessel by muon has not been elaborated.

d. Notes on the studies on the fuel debris retrieval scenarios

- Planning and execution of the PCV internal investigation should be accelerated to understand the fuel debris condition to study the scenarios.

- If the fuel debris is located outside the RPV pedestal, an option would be to first carry out the Partial submersion-Side entry method.

The candidate scenarios of fuel debris retrieval method for each unit described above are shown in Table 4.3.5-2.

Table 4.3.5-2 Candidate scenarios of fuel debris retrieval method for each unit

Scenario No.	Full submersion/ Submersion-Top entry method	Partial submersion-Top entry method	Partial submersion-Side entry method	Retrieval method for Unit 1	Retrieval method for Unit 2	Retrieval method for Unit 3
1	○	—	—		✓	✓
2	—	○	—		✓	✓
3	—	—	○	✓*1		
4	1)	—	2)	✓	(✓)*2	✓*3
5	2)	—	1)	✓*4	(✓)*2*4	✓*3*4
6	—	1)	2)	✓	(✓)*2	✓*3
7	—	2)	1)	✓	(✓)*2	✓*3

The above numbers 1) and 2) indicate the order of procedure.

*1: For Unit 1, scenario 3 may be necessary if all the fuel debris fell from the RPV to the inside and outside of RPV pedestal.
*2: For Unit 2, fuel debris is believed unlikely to be present outside the RPV pedestal. The side entry access may not necessarily be required.
*3: For Unit 3, if fuel debris is confirmed to be not present outside the RPV pedestal, the side entry access will not be necessary, therefore it is expected to carry out the PCV internal investigation as soon as possible.
*4: For combinations of Full submersion/Submersion-Top entry and Partial submersion-Side entry, if Full submersion/Submersion-Top entry method is to be implemented after the boreholes are created in R/B and PCV for Partial submersion-Side entry method, it will be necessary to confirm the seismic resistance.

4.3.5.3 Method for future study and study objective on multiple scenarios

The scenario of application to the actual unit is to be selected in stages in accordance with the technical development which will be a key to the success in the fuel debris retrieval method that constitutes the multiple scenarios described in the 4.3.5, improvement of estimation accuracy of the prospects of feasibility based on the progress of the studies, and the locations and distributions of the fuel debris in each unit obtained from the PCV internal investigation. The investigation, and R&D plans required to determine the application scenario based on the condition of each unit need to be reviewed.

The scenario of fuel debris retrieval needs to be selected so as to determine the fuel debris retrieval method in the first half of FY2018, which is set as a hold point in the Roadmap. The target is to select the scenario which may be determined as feasible as well as suitable for application in each unit based on the latest status of R&D for the retrieval method and information on the location and distribution of fuel debris. In this regard, comparative evaluation is to be conducted for the scenarios based on the Five Guiding Principles if multiple scenarios are feasible, and desirable scenario is to be selected for each unit. Its selection flow is shown in Table 4.3.5-9. Also, all items in the “Feasibility study for the method” in Table 4.3.5-9 need to be studied for each method, but the items with high degrees of difficulties in particular for each of the submersion method and the Partial submersion method are shown in bold lines.

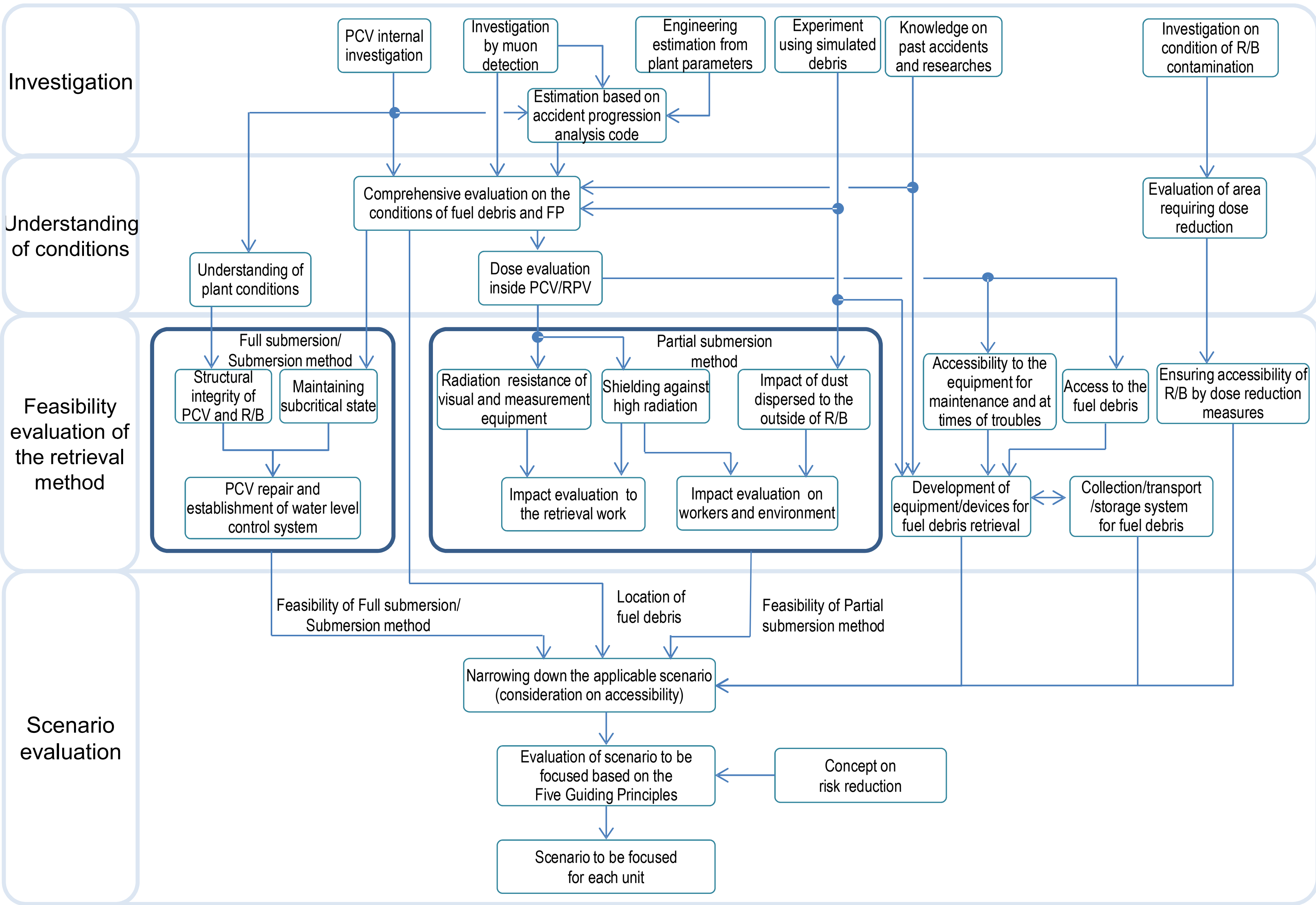


Figure 4.3.5-9 Fuel debris retrieval scenario selection flow

4.4 Study on collection, transport and storage of retrieved fuel debris

In order to start fuel debris retrieval, it is important to develop the following technologies commonly required regardless of the retrieval method:

- A system for collection, transport and storage of fuel debris after retrieval
- Material accountancy and control measures for fuel debris

4.4.1 Development of a system for collection, transport and storage of debris after retrieving

(1) Purpose

To design and manufacture the storage canisters for retrieved fuel debris and develop a system for transport and on-site storage.

(2) Major requirements

a. A system by which fuel debris can be safely collected, transported and stored is to be developed. Although the studies on the system is carried out by referring to the collection, transport and storage of the fuel debris in TMI-2, the storage canisters and handling technology should be developed based on the requirements set up in accordance with the actual conditions of the Fukushima Daiichi NPS, because when compared with TMI-2, the requirements for storage canisters of the Fukushima Daiichi NPS are stricter than those of TMI-2.

In addition, several highly feasible alternative scenarios of storage canisters are to be developed based on the comprehensive understanding and considerations for the constraints on a fuel debris retrieval method and an actual working place.

b. The specifications for storage canisters must be mutually feasible and consistent with the other related activities.
The requirements are to be tentatively formulated in relation to other related projects, and reflected the storage container design (input conditions). In addition, the requirements for the equipment for loading the canisters are to be clarified (output conditions).

Furthermore, the requirements for the methods are to be established on the basis of “Submersion and Partial submersion” for collection, “Top retrieval and Side retrieval” for transport and “Dry storage and Interim storage in a pool” for storage.

c. A prototype of storage canister and handling equipment are to be manufactured and checked by a mock-up test.

(3) Current status

a. Development of overall plan and collection of related information

- Reference information for system development and interrelations among the related projects were organized, input from and output for other projects were clarified, and overall technical development plan was formulated and the concerning issues was extracted.

b. Design of the storage canister, and study of the transport and storage system were carried out as R&D (FY2014).

i) Study of collection, transfer and storage system of fuel debris
The study on the collection, transport, and storage system is carried out based on requirements assuming various types of fuel debris in light of the conditions of the Fukushima Daiichi NPS.

ii) Development of design concept and safety evaluation technology for storage canisters
The design conditions for storage canisters have been specified, and the basic function and general shape have been determined.

The safety assessment method contributing to the designing of the canister to be developed from next fiscal year is extracted and development plan is now established (criticality evaluation, structural evaluation and external corrosion evaluation method for the storage canisters).

iii) The investigation of transport and storage of damaged fuel is carried out.

c. Studies measures on the utilization of the limited space within the Fukushima Daiichi NPS are required since much of the land is now being used for the contaminated water tanks or temporary waste storage.

(4) Future actions

As mentioned above, studies on the scenarios and other activities are being carried out, and because the technical issues are considered to be extracted with the further elaboration of the scenarios, it is necessary to appropriately respond to the future development in the situation.

In addition, the issues to be carried out from now on are as follows:

a. Refinement of the plan for transport and storage in accordance with the elaboration of scenario
Preparation must be made for transport and storage until the fuel debris retrieval is started. Detailed designs for facilities are to be carried out in accordance with the realization of the means of transport and storage.

b. Refinement of the plan for transport and storage in accordance with the conditions of the Fukushima Daiichi NPS.
Although the space within the site is used for the contaminated water tanks and temporary storage

for the spent fuels and waste, the space required for transport and storage of fuel debris needs to be secured in coordination with the related operations.

c. Clarification of safety requirements for storage canisters, and transport and storage facilities (including casks) considering the regulatory requirements.
The functional requirements such as the prevention of criticality, shielding and heat removal and the requirements for the structural strength evaluation are to be clarified in preparation for obtaining approvals.

4.4.2 Establishment of material accountancy and control policy for fuel debris

(1) Purpose
It is necessary to declare the amount of nuclear fuel materials contained in fuel debris and submit a verification report on the physical inventory of nuclear fuel materials to the Japanese government and IAEA, in accordance with Japan-IAEA safeguards agreement and other agreements. Although the accountancy and control method which deals with a fuel assembly as a unit was usually applied at the other nuclear power stations, because the nuclear fuel materials of the Fukushima Daiichi NPS melted due to the accident and are in the state of fuel debris, the normal accountancy and control method cannot be applied. Therefore, it is required to establish a new material accountancy and control policy in which transparency is secured.

(2) Major requirements

a. Literature survey and investigation of site management
To understand the material accountancy and control of nuclear fuel materials at the time of TMI-2 and Chernobyl accidents.

b. Evaluation of distribution of nuclear fuel materials
To understand the distribution of the nuclear fuel material amount after the accident.

c. Establishment of material accountancy and control policy for fuel debris
To develop a rational accountancy and control method where transparency is secured and measurement technology, for accountancy and control associated with movement of nuclear fuel materials.

(3) Current status[1]

a. Literature survey and investigation of site management
These activities are completed by the following investigations and narrowing down of the measurement technologies.
Investigations including literature investigation were carried out on the field management, the

[1] TEPCO and JAEA: Establishment of material accountancy policy for fuel debris (April 2013)
JAEA: Efforts by JAEA on decommissioning technologies (2013 edition)

measurement technologies used, etc., at the time of TMI-2 and Chernobyl accidents and of the measurements of nuclear fuel materials conducted in TMI-2 and Chernobyl were studied.

A range of application and accuracy of measurement technology were evaluated, and seven types of measurement technologies were narrowed down as the candidate of an applicable measurement technology.

b. Evaluation of distribution of nuclear fuel materials

Although the distribution of the fuel debris was estimated by the reactor condition evaluation project using a severe accident analysis code, the estimation accuracy is low at present.

The evaluation of the distribution of the fuel debris has not been started because internal investigation of the reactor vessels, fuel debris retrieval, and fuel debris sampling have not been carried out yet.

c. Establishment of material accountancy and control policy for fuel debris

Although the study has been conducted for the measures including an accountancy and control method, because they are the closed agenda of the Japanese government and IAEA, it is not explained here.

(4) Future actions

a. Evaluation of distribution of nuclear fuel materials

- To understand and evaluate the distribution of nuclear fuel materials by acquiring the result of analysis using a severe accident analysis code from the reactor condition evaluation project and the information from the related projects such as the project for developing technologies to detect core fuel debris (muon).

b. Establishment of the accountancy and control method for the fuel debris

- The material accountancy and control policy shall be established until the start of fuel debris retrieval is determined.
- The distribution of the fuel debris should be understood and reflected in development of a rational material accountancy and control policy based on the information from the projects such as for the reactor condition evaluation project through application of severe accident analysis code, characterization of fuel debris and development of fuel debris handling technology, and development of detection technology of fuel debris inside the reactor vessels (muon).
- The study results of a material accountancy and control policy need to be notified to the related projects as required and reflected in the study because the material accountancy and control policy affects the selection of fuel debris retrieval technology, development of collection, transport and storage technologies.
- A rational material accountancy and control policy should be developed based on the study results of the safeguards system carried out an operator.

- It is assumed that the movement of nuclear fuel materials and the handling method largely differ according to the conditions such as the distribution condition of fuel debris, the fuel debris retrieval method, and the storage of fuel debris after retrieval. A rational material accountancy and control policy needs to be studied for each assumption.
- An material accountancy and control policy is a subject of discussion between the Japanese government and IAEA. Proactive involvement in the discussion will be required, and the information collection and necessary studies need to be carried out.
- The technical issues clarified by the discussion between the Japanese government and IAEA should be positively addressed, for example by conducting studies in projects (a method of accountancy and control, development of measurement technology, etc.).

4.5 Conclusion

The fuel debris retrieval is one of the most important issues in technical judgments required for decommissioning of the Fukushima Daiichi NPS. This chapter described the issues to be addressed and the approaches to the technical requirements listed in the logic tree shown in Figure 4.5-1 as well as multiple scenarios based on the options of the fuel debris retrieval method.

Figure 4.5-2 shows the major items of study and actions for the fuel debris retrieval and its schedule.

This strategic plan is subject to review based on PDCA, the site conditions and R&D status.

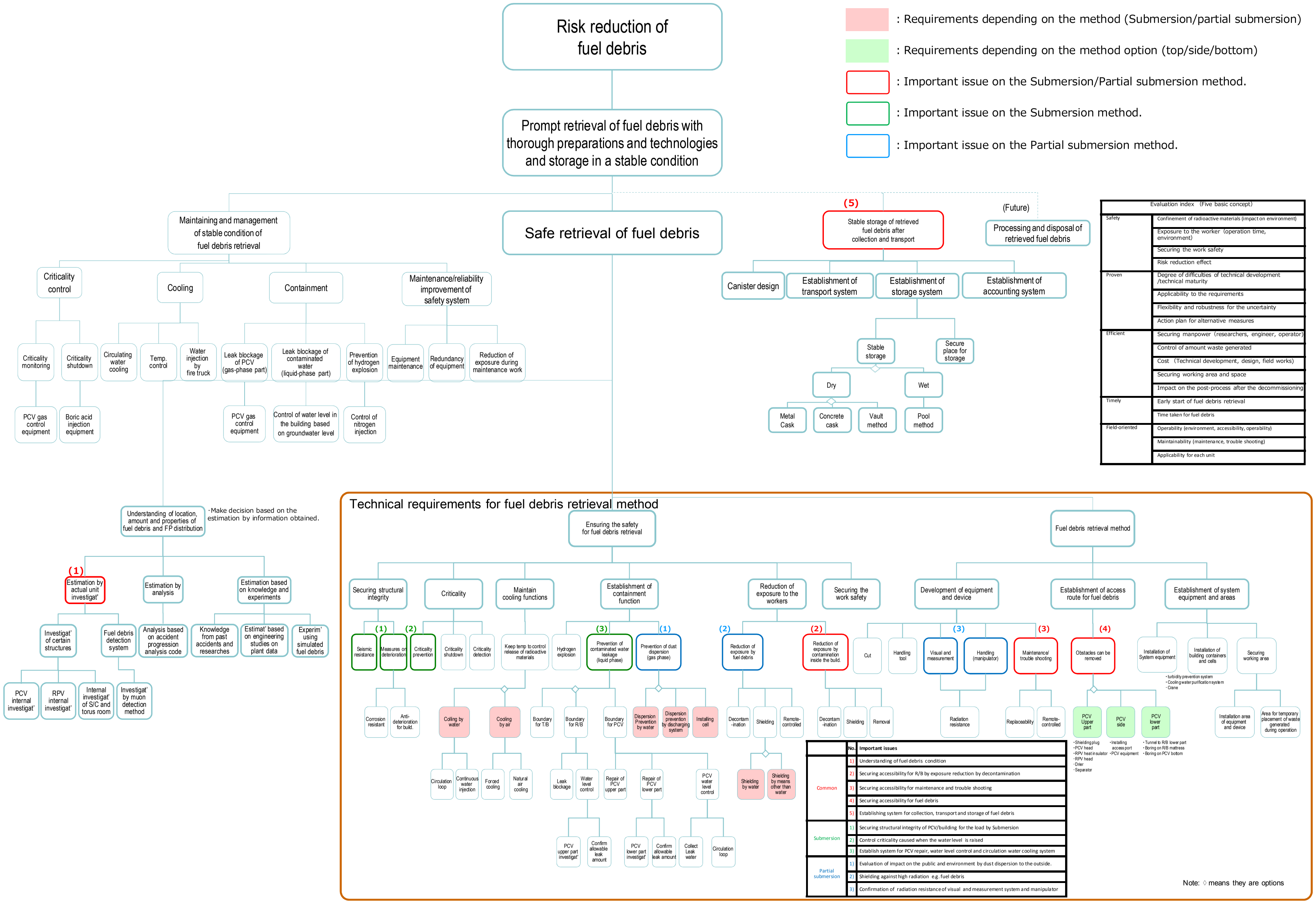


Figure 4.5-1 Logic tree for the risk reduction of fuel debris

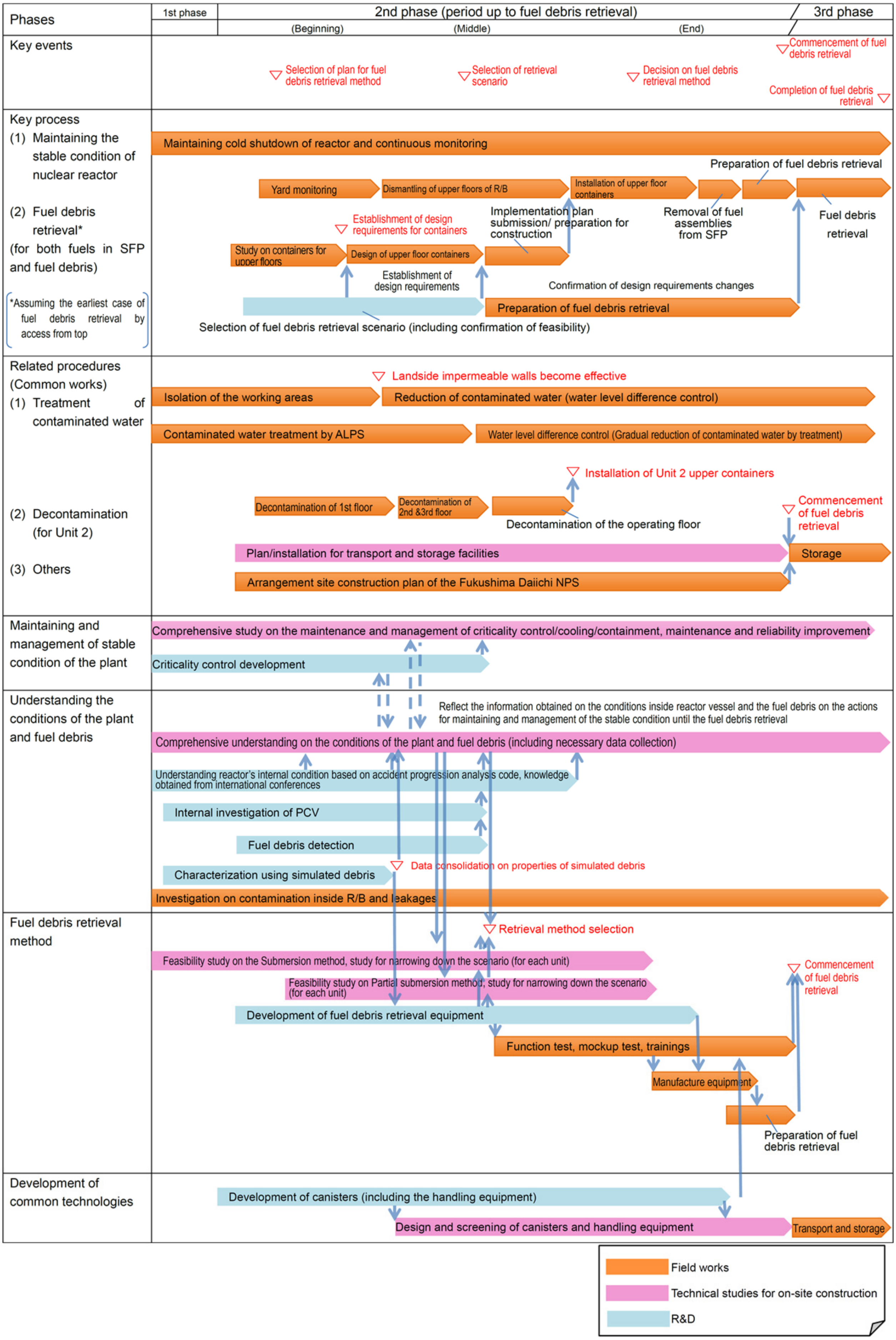


Figure 4.5-2 Entire process of fuel debris retrieval

5. Strategic plan for waste management

5.1 Study policy on the strategic plan for waste management

The knowledge and experiences on the nuclear facilities that caused accidents are summarized in a number of documents released internationally. The document, NW-T-2.7 “Experiences and Lessons Learned Worldwide in the Cleanup and Decommissioning of Nuclear Facilities in the Aftermath of Accidents” released by IAEA describes the chronological responses after the accident where emergency response, stabilization of the response, the post-accident cleanup, safety containment, and finally decommissioning and site restoration are discussed. The post-accident cleanup is currently conducted at the Fukushima Daiichi NPS. The strategic plans had to be established in the initial phase after the accident, and the Roadmap was one of them. It is important to carry out the solid radioactive waste management described in the Roadmap[1] in accordance with the Five Guiding Principles (Safe, Proven, Efficient, Timely and Field-oriented) described in Chapter 3.

In the solid radioactive waste management, it is foremost important to reduce the amount generated, and to minimize the carry-in materials, reuse, and recycle in accordance with the site conditions.

The solid radioactive waste generated nevertheless is to be segregated and stored safely depending on the properties to reduce risks for the time being.

In parallel with the storage, characterization of various types of solid radioactive waste is to be conducted and they are to be categorized by their properties, so that safe and optimal processing and disposal concept and management can be studied based on the proven technologies.

The safety regulations on storage, processing and disposal management will be reviewed as necessary, and decommissioning and other operations will be carried out while ensuring the safety.

The basic policies and specific plan for the management of solid radioactive waste are described in “Plan for management and processing and disposal of solid radioactive waste” in the current Roadmap, and measures have been carried out toward decommissioning of the Fukushima Daiichi NPS Units 1-4. The waste management is characterized by its long lead time since the prospect on safety in processing and disposal of the solid radioactive waste may be obtained by the target time of FY2021 followed by the necessary studies on regulations and confirmation of the prospect for implementation of disposal.

The solid radioactive waste generated due to the accident at the Fukushima Daiichi NPS is different from that generated from the other existing nuclear power plants in terms of the deposition of radioactive materials from the damaged fuel and presence of salt. Therefore, the future plan for processing and disposal is now under study while the waste characterization is continued. The waste storage is also being carried out placing

[1] The “solid radioactive wastes” in the Roadmap refers to “some rubble, etc. generated after the accident may not be wastes or radioactive wastes due to on-site reuse or other measures. However, these wastes and the solid radioactive wastes that were generated before the accident and have been stored at the Fukushima Daiichi Nuclear Power Station are included in the ‘solid radioactive wastes.’”

safety as the first priority.

Although sufficient information on the characteristics of wastes has not been gathered in the present circumstances, it is important to clarify the basic concept for ensuring the safety in radioactive waste management in general and to formulate an action policy that may greatly affect the solid radioactive waste management. Hence, the strategic plan for the waste management is described on the basis of the following points.

(1) Summarize the internationally established safety principles on radioactive waste disposal in general as well as the approaches to processing which is to be considered in relation to the disposal method in preparation for formulation of more specific disposal management of solid radioactive waste.

(2) Assess the action status of the solid radioactive waste management described in the current Roadmap, and extract issues that may affect the future actions and the schedule of the waste management.

(3) Describe the matters to be addressed or recognized as the mid- to long- term solid radioactive waste management for characterization, storage, processing and disposal based on the basic concept in (1) and the issues extracted in (2) above.

(4) Explain future actions on the solid radioactive waste management based on the (2) and (3) above including the R&D.

This strategic plan is to be reviewed and elaborated in accordance with the future development.

5.2 International safety principles on radioactive waste management

General safety principles on disposal of radioactive waste and approaches to processing which are established by the international organizations such as IAEA and International Commission on Radiological Protection (hereinafter referred to as "ICRP") are summarized below.

5.2.1 Safety principles on radioactive waste disposal

ICRP describes the system of radiological protection in relation to the radioactive waste disposal in Publ.46 (1986), Publ.77 (1998) and Publ.81 (1998). Publ.81 supplemented and revised the recommendation provided in Publ.46 in light of the international progress and was released to clarify the concept further. Although ICRP released Publ.103 (The 2007 Recommendations) and then Publ.122 (2013) in which Publ.103 is applied for geological disposal, Publ.81 above is still valid in each document.

The introduction of ICRP Publ.81 states that waste disposal strategies can be divided into two conceptual approaches; dilute and disperse or concentrate and retain, and both strategies are in common use and are not mutually exclusive. The main part of Publ.81 deals with the radiological protection of members of the public following the disposal of long-lived solid radioactive waste using the 'concentrate and retain' strategy.

On the other hand, IAEA's "Disposal of Radioactive Waste" (Specific Safety Requirements No. SSR-5, paragraph 1.10) states the aims of disposal of solid radioactive waste, and Safety Guide WS-G-2.3 describes

“Regulatory control of radioactive discharges to the environment” on radioactive gaseous and liquid materials as waste management instead of waste disposal, which corresponds to dilution and dispersion of ICRP.

Based on a comprehensive understanding on the above, the safety principles of waste disposal are as follows. Waste management is to be addressed based on one or combinations of these safety principles in order to prevent significant health effects.

i) To contain the waste;

ii) To isolate the waste from the accessible biosphere and to reduce substantially the likelihood of, and all possible consequences of, inadvertent human intrusion into the waste;

iii) To inhibit, reduce and delay the migration of radionuclides from the waste to the accessible biosphere at any time;

iv) To ensure that the amounts of radionuclides reaching the accessible biosphere due to any migration from the disposal facility are such that possible radiological consequences are acceptably low at all times;

v) To control the release of radioactive materials to ensure that their concentrations are at the level that will not cause significant health effects.

In Japan, the safety regulations require safety of the facility by means of the above i) to v), and specifies the dose and concentration that will not cause significant health effects. Although the institutional systems for processing and disposal of radioactive waste have been formulated, the systems have not yet been established for some of the radioactive waste generated by the operation of normal nuclear facilities. The current status of safety regulations in Japan regarding processing and disposal of radioactive waste is shown in Table 5.2-1.

5.2.2 Examples of application of safety principles for radioactive waste disposal

For the specific radioactive waste disposal, measures are taken based on one or combinations of these safety principles in order to prevent significant health effects.

(1) For the near surface disposal of low-level solid radioactive waste safety is ensured by, for example, isolating the waste from biosphere, enclosing or solidifying them in a container which meets the requirements of transport, safe handling and dispersion prevention effect, as well as establishing a disposal facility with conditioning and engineered barrier combined with surrounding natural barrier. In this case, leakage of radioactive materials is prevented or reduced by the containers and the engineered barrier, and as a result, the migration of radioactive material to the natural barrier is reduced, and furthermore, the function of the natural barrier delays the migration of radioactive materials to the biosphere.

The radioactivity is attenuated by the above method, and with the dilution and diffusion effects of the groundwater, the concentration of radioactive material is reduced, so that there will be no effect on health even if the radioactive materials reach the biosphere. In addition, when the concentration of radioactive materials is extremely low, it is possible to dispose the waste in a disposal facility without an engineered barrier (i.e. trench disposal) so as to prevent any health effects.

(2) For the near surface disposal, safety regulation is in place to impose institutional control, such as restriction of specified action until the concentration of radioactive materials is reduced to below safe and acceptable level so that people would not inadvertently access or excavate in such area.

(3) For solid radioactive material with high concentration of radioactive materials, disposal deep in the ground will secure a longer migration pathway of radioactive material so that the migration of radioactive material to the biosphere is delayed allowing the radioactivity to attenuate. The concentration of radioactive material is also reduced by the dilution and diffusion effects of groundwater. In addition, the safety is ensured by a greater disposal depth so that it is not necessary to depend on the institutional control, such as restriction of specified acts.

(4) For gaseous radioactive waste, concentration and amount of radioactive materials are reduced as much as reasonably achievable by means of filtering, storage, attenuation, etc., using a treatment system, and then, the gaseous waste is released to the environment from a stack with a diffusion function. For example, a gaseous waste disposal facility in a nuclear power station is equipped with activated carbon type rare gas hold-up system. When off-gas goes through the activated carbon filled adsorption column (charcoal bed), the noble gas repeats adsorption and desorption in the activated carbon while it moves through the system, and the radioactivity is attenuated over the course of time before reaching the stack. The exposure is controlled by reducing the concentration of radioactive materials to below the standard value defined in the regulations.

(5) For liquid radioactive material, concentration and amount of radioactive materials are reduced to the lowest level reasonably achievable by means of storage, filtering, evaporation treatment, ion exchange, attenuation, etc., using a treatment system so as to be released to the environment where dilution effect can be expected. For example, as for the liquid waste at nuclear power station, the concentration and amount of radioactive materials released are reduced as much as reasonably achievable by means of accumulation, filtering, evaporation treatment, ion exchange, etc. Treated liquid waste is released from the outlet of the condenser cooling water after being confirmed that the concentration of radioactive materials is below the level specified in the regulations.

5.2.3 Approaches to the radioactive waste processing

In IAEA’s Safety Requirements GSR-Part 5, predisposal management of radioactive waste covers all the stages from generation to disposal including processing, storage and transport.

The processing of radioactive waste includes its pretreatment, treatment and conditioning and it is necessary to produce a waste form that is compatible with the selected or anticipated disposal option. The radioactive waste may be stored during its management, and will also have to be in a form that is suitable for transport and storage. In relation to the safety principles on radioactive waste disposal explained in Section 5.2.1, the approaches to the radioactive waste processing can be summarized as follows based on IAEA’s Safety Requirements GSR-Part 5.

i) The main purpose of processing is to produce a waste form to meet the acceptance criteria for safe waste processing, transport, storage and disposal and to ensure the safety for the waste disposal.

ii) It is necessary to appropriately incorporate the characteristics of waste and the requirements during the management stages (pretreatment, treatment, conditioning, transport, storage and disposal) to the approach to processing. When determining the approach to processing, all requirements to be expected in each stage should be considered as much as possible. Not only the health effects caused by radiation, but also various other factors such as the environmental impact that may be caused by the content of non-radioactive materials or social and economic impacts must also be considered.

iii) The extent of processing is determined based on the amount of radioactive waste subject to processing, physical and chemical properties of radiation, technologies available, storage capacity, and availability of disposal facilities.

iv) Even though the extent of waste processing is determined according to iii) above, if processing is to be conducted with no disposal requirements established, it must be possible to carry out processing that conforms the disposal requirements upon its establishment.

v) Before processing the radioactive waste, it may be stored until the radioactivity is attenuated below a certain level, and it may as a result be removed from regulatory control of the clearance.

Since the ultimate goal of radioactive waste management is the safe disposal, it is of primary importance that processing is in conformity with the disposal management. Therefore, even when taking measures to reduce risks of leakage or scattering of water-containing materials during storage for the purpose of enhancing safety, it requires flexibility to comply with the management of disposal. Also, processing by volume reduction needs to be studied from viewpoints of the restrictions on the storage capacity and economic reasonability while maintaining consistency with the management of disposal.

5.3 Assessments and issues on the action status based on the Roadmap

The basic policy and specific plan on storage and processing and disposal of solid radioactive waste are described in 4-3 (4) “Plan for management and processing and disposal of solid radioactive waste” of the current Roadmap. In addition, some important HP are set as decision-making points for transition to next step, such as to establish a basic concept for processing and disposal of solid radioactive waste in FY2017 as target, and to confirm the prospect for safety of processing and disposal of radioactive solid radioactive waste in FY2021 as target.

In this section, action status is explained and assessed for each item described in the current Roadmap, and the issues that may have impact on the future actions or schedule of solid radioactive waste management are identified.

5.3.1 Storage

(1) Reduction of generated waste

a. Action status

As it is important to reduce the generated amount of waste as much as possible for the storage of the solid radioactive waste, measures for reduction of the solid radioactive waste are in progress, including minimization of packaging materials and equipment to be carried into the site and their reuse and recycle.

For minimization of carry-in materials, a vehicle maintenance center has been in service since June 2014 in order to reduce the number of additional vehicles entering the site, and measures to reduce the carry-in packaging materials and spare parts are also being taken. For reuse and recycle, the same heavy equipment is shared by different operations whenever possible, and the on-site system for shared use of materials and equipment is also in service. For volume reduction of the solid radioactive waste, an incinerator is now planned to be installed in 2015 to start treatment of burnable materials such as used protective clothing.

b. Assessment and issues of action status

Minimization of generated amount and on-site reuse are reasonable measures to reduce the amount of solid radioactive waste generated.

(2) Storage

a. Action status

As the measures for storage of the generated solid radioactive waste, the waste is stored separately in the storage facility or the interim storage facility depending on its dose rate and installation of a facility for appropriate storage is planned.

For the storage of secondary waste generated from the water treatment during the early stage, a fundamental research on heat and gas generation, and corrosion of the container was conducted.

b. Assessment and issues of action status

For future construction works, it is important to carry out measures for storage of generated solid radioactive waste in advance and in a planned manner from a view point of making effective use of the limited space of the site.

In parallel with continued efforts to reduce waste generation, it is required to appropriately implement storage of the generated solid radioactive waste until the management of processing and disposal are specified. With regards to the storage container for secondary waste generated from the water treatment system, necessity of countermeasures on the corrosion control has to be continuously studied.

5.3.2 Processing and disposal

(1) Waste characterization

a. Action status

For waste characterization, analysis of rubbles, evaluation of properties of secondary waste generated from the water treatment system, and development of analytical technique for radioactive materials which are difficult to be measured (‘difficult-to-measure’), etc. are under way.

In addition, in order to evaluate the inventory of radioactivity, studies on the inventory evaluation method are in progress based on the identification of the radioactive materials to be focused on, the case research for the inventory evaluation methods and uncertainty factors, modeling, and results of analyses, etc.

b. Assessment and issues of action status

For the study on the solid radioactive waste disposal management, waste characterization is extremely important. At this point, although the easily collectable waste has been sampled and analyzed, there remain a number of locations where sampling has not been possible due to its high dose (i.e. sludge in the basement of the R/B and secondary waste sludge generated from water treatment system). There are also waste to be generated by fuel debris retrieval and secondary waste generated by decontamination.

Current analytical capability (equipment, technology, and human resources) is not sufficient to collect data for waste properties analysis required for the study on the processing and disposal management of solid radioactive waste and establishment of the regulatory system.

(2) Study on processing and disposal management

a. Action status

For processing and disposal management of solid radioactive waste, investigations of the existing treatment technologies including waste conditioning, fundamental test on technologies for waste conditioning, investigation and study on the existing concept on waste disposal and its safety assessment method, investigation and study on safety of handling and disposal of fuel debris as waste as a future handling option have been carried out.

b. Assessment and issues of action status

Based on the understanding of solid radioactive waste properties, above mentioned actions must be steadily carried out and the basic concept on the solid radioactive waste processing and disposal needs to be established. It is also important to study the technical prospect with respect to the safety of waste processing and disposal, and to conduct studies that will contribute to regulatory preparation. In addition, it will be necessary to actively provide the regulatory authorities with information related to progress of studies and technical data for establishment of processing and disposal management in order to share understanding on the matter.

Table 5.2-1 Progress of study on processing and disposal of radioactive waste

Reported: Reports of the advisory board are submitted/ Established: Necessary regulations are established

Categories of radioactive waste			Atomic Energy Commission: Disposal policy	Nuclear Safety Commission of Japan: Approaches to safety regulations			Nuclear Safety Commission of Japan: Upper limit of radioactive concentration		Nuclear Safety Commission of Japan: Safety guideline	Laws on safety regulations: Cabinet order	Laws on safety regulations: Regulation
High-level radioactive waste			Reported (May 1998)	Provisionally reported (Nov. 2000)	Important items in common Reported (Jun. 2004)				To be studied	Established (Dec. 2007)	Established (Mar. 2008)
Low-level radioactive waste	Wastes from the nuclear power station	Comparatively high-level waste (Intermediate depth disposal)	Reported (Oct.1998)	Reported (Sept. 2000)		Reported (Jul. 2007) (Except for uranium waste)	Reported (Sept. 2000)	Reported (May 2007)	Under study	Established (Dec. 2000)	Established (Mar. 2008)
		Comparatively low-level waste (Near surface disposal)	Reported (Aug.1984)	Reported (Oct. 1985)			Reported (Feb.1987, Jun. 1992)		Reported (Mar. 1988)	Established (Mar. 1987, Sept. 1992)	Established (Jan.1988, Feb. 1993, Mar. 2008)
		Very low-level waste, such as concretes (Near surface trench disposal)					Reported (Jun. 1992)		Reported (Jan. 1993)	Established (Sept. 1992)	Established (Feb.1993, Mar. 2008)
		Very low level waste, such as metals (Near surface trench disposal)					Reported (Sept. 2000)		Under study	Established (Dec. 2000)	Established (Mar. 2008)
	TRU waste		Reported (Mar. 2000, Apr. 2006)	Reported (Apr. 2006)			(Except for uranium waste)		Partially under study	Established (Dec. 2007)	
	Uranium waste		Reported (Dec. 2000)								To be established
	Waste from research institutes, etc.		Reported (Jun. 1998)						To be studied		
	RI waste			Reported (Jan. 2004)						Established (May 2005)	Established (Jun. 2005)

Categories of radioactive waste			Atomic Energy Commission: Disposal policy	Nuclear Safety Commission of Japan: Clearance level		Laws on safety regulations: Cabinet order*	Laws on safety regulations: Regulation
Wastes not necessary to be treated as radioactive waste	Waste from reactor facilities	Major reactor facilities (including research reactor)	Reported (Aug. 1984)	Reported (Mar. 1999)	Reported (Dec. 2004)	Established (May 2005)	Established (Dec. 2005)
		Heavy water reactor, Fast reactor		Reported (Jul. 2001)			
	Waste from nuclear fuel facility	Nuclear fuel use facility (Facilities to handle irradiated fuels and materials)		Reported (Apr. 2003)			
		Other facilities		Under study			To be established
	Waste from RI facility	RI facility		To be established		To be established	

* Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors, Act on Prevention of Radiation Disease Due to Radioisotopes, etc.

Source: Agency for Natural Resources and Energy (http://www.enecho.meti.go.jp/category/electricity_and_gas/nuclear/rw/gaiyo/gaiyo04-1.html)

5.4 Action policy from a mid- to long-term viewpoint for waste management of the Fukushima Daiichi NPS

Based on the international safety principles and the issues identified by the assessment on the action status in previous sections, and recognizing the necessity to conduct the entire waste management as planned, action policies on the matters that may have a significant impact on the future measures to be taken (i.e. matters to be addressed rigorously and matters already being addressed but requires special attention) over the course of the mid-to long-term solid radioactive waste management of the Fukushima Daiichi NPS, are explained below.

5.4.1 Storage

(1) Reduction of generated waste

a. Minimization of carry-in materials

Since a certain degree of effectiveness of minimization of carry-in of packaging materials and spare parts from the outside can be expected for the storage of radioactive waste, reduction of generated amount to be disposed, and efficient use of the on-site space, it is rational to make further efforts to thoroughly carry out these measures. In addition, promotion of on-site recycle should also be pursued in order to help minimize the carry-in materials from the outside of the site and to prevent the increase in the waste storage capacity.

b. Considerations on the secondary waste

If an incinerator is introduced for volume reduction, off-gas filters and consumables from equipment and installations will become secondary waste after a certain operation period. For the secondary waste, it is important to take into account of the possible impact on the effectiveness of volume reduction or disposal of the waste and also to consider the processing of the secondary waste. In the future the needs for decontamination are expected to grow for the exposure reduction and preparation work for fuel debris retrieval. If water is used on concrete surface when performing decontamination, infiltration of contamination may occur and result in the increase in the amount of the solid radioactive waste which will be yet another burden to disposal. Depending on the type of decontamination, organic materials and harmful substances are carried into the waste, possibly impacting the performance of the barrier of the disposal facility. Therefore, it must be noted from the viewpoint of optimization that the secondary waste may be generated when introducing the volume reduction facilities for solid radioactive waste. Although priority is given to the achievement of target decontamination performance when decontamination is carried out, it is important to select appropriate technologies and to respond to the need of decontamination considering the impact on solid radioactive waste disposal by assessing the secondary waste properties and impact on the disposal in addition to controlling the secondary contamination.

(2) Storage

a. Storage planning

The solid radioactive waste with a high dose rate is segregated and stored in the existing solid radioactive waste storage facility or the soil-covered interim storage facility. In order to realize more appropriate storage, construction of the 9th solid radioactive waste storage facility capable of storing about 110,000 drums has started. The conceptual study is in progress for future storage facilities based on current storage status and estimated amount of waste to be generated. As more waste is generated with the progress of the site restoration works, the timing, amount and properties of waste generated from each restoration work are currently estimated and formulation of a program for storage is planned. This is important from a viewpoint of making effective use of the limited space of the site and performing systematic and smooth storage.

b. Storage planning for the waste generated from fuel debris retrieval

After the fuel debris retrieval begins, a large amount of solid radioactive waste is expected to be generated. The peripheral objects will be removed for the retrieval work, and these objects as well as the equipment and materials used will become wastes. Since some of them will be heavy loads with high dose and high concentration of radioactive materials, it is important to make due consideration for the storage and disposal measures. In parallel with studies on the fuel debris retrieval method, the place and storage method suitable for the waste need to be considered for smooth and effective fuel debris retrieval.

5.4.2 Processing and disposal

(1) Waste characterization

a. Waste sampling plan

It is extremely important to understand the waste properties since some of the waste may affect storage or processing and disposal depending on the radioactive materials contained in the waste such as sludge in the basement of the R/B. For the waste from which samples has not be taken, although sampling may be difficult due to limited access because of high dose, it is important to investigate and study sampling methods and formulate a sampling plan, along with the confirmation of the applicability of the studied sampling methods.

The sampling and analysis plan needs to be formulated focusing on the acquisition of data that will be useful for studies on the processing and disposal management even with a small amount of samples, with the consideration for the acceptance capacities of the analytical centers and new analytical and research facility to be constructed, transport capacity, etc.

b. Analytical capability for waste characterization

The waste properties obtained by the analysis will be an important information not only as a foundation of the solid radioactive waste disposal method but also for development of plans for dismantling of the facility, reduction of exposure to the workers, solid radioactive waste disposal and segregated storage. Analysis for waste characterization is currently under way with a pace of approximately 50 samples per year[1], but it is considered that the demand for the analysis will increase in the number and quality such that there will be more types of samples to be analyzed and quantitative determination at lower concentration may be required. In order to respond to this demand, it is important to reinforce the analytical capability by utilization of unused analytical facilities, establishment of new analysis and research facility, and reinforcement and development of operational system of these facilities.

It is also important to improve analytical techniques and pretreatment technologies, to develop analytical techniques for radioactive material for which the methods have not been established, and to formulate analysis method appropriate for analyses of samples with high dose rate.

Furthermore, securing and development of human resources in charge of these development and analyses also need to be carried out continuously.

The status of analyses of waste samples is shown in Table 5.4-1.

(2) Study on processing and disposal management

a. Processing and disposal management in accordance with the characteristics of the waste at the Fukushima Daiichi NPS

In the current Roadmap, basic concept for processing and disposal of solid radioactive waste is to be established in FY2017 and prospect for the safety is to be confirmed in FY2021 as target.

Processing and disposal management of solid radioactive waste needs to be safe and reasonable. It is necessary to understand the attribute and chemical properties of the waste and concentration of radioactive materials, and consider the appropriate disposal management based on such understanding. Approach to processing should be studied with the consideration for the disposal management. It is essential to develop the processing and disposal management by means of collaboration and comprehensive studies among the concerned organizations.

b. Classification management and history information management

Since the amount of solid radioactive waste is increasing due to decontamination of facilities, fuel debris retrieval, and progress in dismantling of facilities in addition to daily operations, it is important to implement appropriate classification management for safe storage and disposal. This must be done by recording and managing the information based on attributes such as origin of waste, contamination history, and concentration of contained radioactive materials.

The waste origin information will be important when processing and disposal are actually carried out, therefore it is useful to develop and utilize a database containing information on the waste properties, technical information on treatment and conditioning, and management information on the waste disposal.

[1] "Research and Development on Processing and Disposal of Radioactive Waste," IRID Annual Symposium (July 2014)

c. Regulatory system

In the current Roadmap, it is defined that information required for establishing framework of safety regulations for processing and disposal of solid radioactive waste will be clarified by around FY2021. The study on safety regulations is being carried out by Nuclear Regulation Authority, not on the waste generated from the facility that caused accident itself but for the disposal of waste generated by the related activities of decommissioning.

Sharing recognition of all the issues on the waste processing and disposal is believed to be critical for the purpose of smooth development of a regulatory system for solid radioactive waste. Hence, it is very important to appropriately and proactively provide the regulatory authorities with necessary information, such as the status of waste characterization, status of study on the processing and disposal management, and technical data on related investigations and R&D.

The basic concept of radioactive waste management described in the Strategic Plan has to be shared with the regulatory authorities since it will be related to fundamental concept on the regulatory system and criteria to be established in the future.

Table 5.4-1 Analysis status of waste samples

Category	Samples	No. of samples	Year
Contaminated water	Units 1 to 4 turbine building stagnant water, etc.	13	2011–2012
	High-level contaminated water in the basement of the Centralized waste treatment facility	2	2013
	Concentrated waste water (RO)	1	
	High-level contaminated water in the basement of the Centralized waste treatment facility Stagnant water in the basement of the High-temperature incinerator building	5	2013
	Treated water (Cs adsorption system, secondary Cs adsorption system)	4	
Rubbles	Rubbles around Units 1, 3 and 4	15	2011–2013
	Rubbles in the Unit 4 fuel pool	2	
	Boring core (1st floor of Unit 1 (floor, wall) 1st floor of Unit 2 (floor))	3	2013
	R/Bs (Units 1 and 3) Boring core (5th floor of Unit 2 (floor))	10	2014
Plant	Fallen trees (Branches and leaves)	5	2011–2013
	Unseasoned wood (branches) around Unit 3	2	
	Trees on the premises (Branches and leaves, fallen leaves, and surface soil)	121	2013−2014

Source: Documents from Decommissioning and contaminated water treatment team meeting.

5.5 Future actions of waste management in preparation for decommissioning of the Fukushima Daiichi NPS

Toward the decommissioning of the Fukushima Daiichi NPS, the necessary measures for risk reduction and optimization of overall facility have to be carried out promptly and effectively. Safe and steady storage of solid radioactive waste is required for waste management, and it is important to study the processing method and disposal concept from the mid- to long-term perspective.

As described in Section 5.3, storage is being progressed as planned in general except for the delay in the introduction of the incinerators. Waste characterization and study on the disposal concept have been steadily in progress toward the establishment of the basic concept for the processing and disposal targeted in FY2017.

This section describes the overall future actions for solid radioactive waste management and R&D based on the safety principles explained in Section 5.2 and the action policy from the mid- to long-term viewpoint explained in the Section 5.4.

The future actions for the waste management in this strategic plan are shown in Figure 5.5-1.

5.5.1 Storage

(1) Waste reduction

The reduction and reuse of carry-in materials must be conducted systematically on-site and the solid radioactive waste reduction measures are expected to settle as customary activity of the site.

For the waste reduction measures, volume reduction and decontamination may become necessary in some cases while the disposal management is not established. In order to make efficient on-site judgments in such cases, a guideline shall be established as necessary by NDF for selection of technologies for volume reduction and decontamination.

(2) Storage

Since waste will continue to generate by the progress of the decommissioning work, NDF shall support the resolution of issues which may arise in the future over the course of promotion of the storage program.

For the secondary waste generated from water treatment, it is important to continue R&D on the measures necessary for the long-term storage.

5.5.2 Processing and disposal

(1) Waste characterization

The samples of rubbles, fallen trees, secondary waste generated from contaminated water treatment are to be collected based on the sampling plan to analyze the concentration of radionuclide, chemical composition, physical properties, etc. Characterization of waste is to be carried out by evaluation of inventories based on the analytical data and modelling approach.

Since analytical data is expected to further accumulate by utilization of the analytical and research facility to be established, it is necessary to develop the operational system of the facility at an early stage and to maintain the system. It will also be important for NDF to play the central role in dividing the roles among the related parties.

Development of analytical technologies for difficult-to-measure nuclides, improvement of the accuracy of waste characterization and estimation of inventory will also be necessary.

(2) Studies on the processing and disposal management

In preparation for establishment of the basic concept for the solid radioactive waste processing and disposal in FY2017 and confirmation of the prospect for safety of processing and disposal of radioactive solid radioactive waste in FY2021, necessary investigations, R&D and studies are to be conducted.

Waste characterization is to be steadily conducted, while study on the disposal concept and safety assessment method based on the results of characterization, studies and R&D of the processing technology suitable for disposal concept are carried out as well. Based on the outcomes obtained by the studies on the series of waste management and handling method from waste generation/storage to processing/disposal (waste stream), safe and reasonable waste processing and disposal management shall be formulated with NDF playing the central role in such process.

In addition, NDF shall provide necessary information to the regulatory authorities so that the preparation of regulatory system will be smooth and successful.

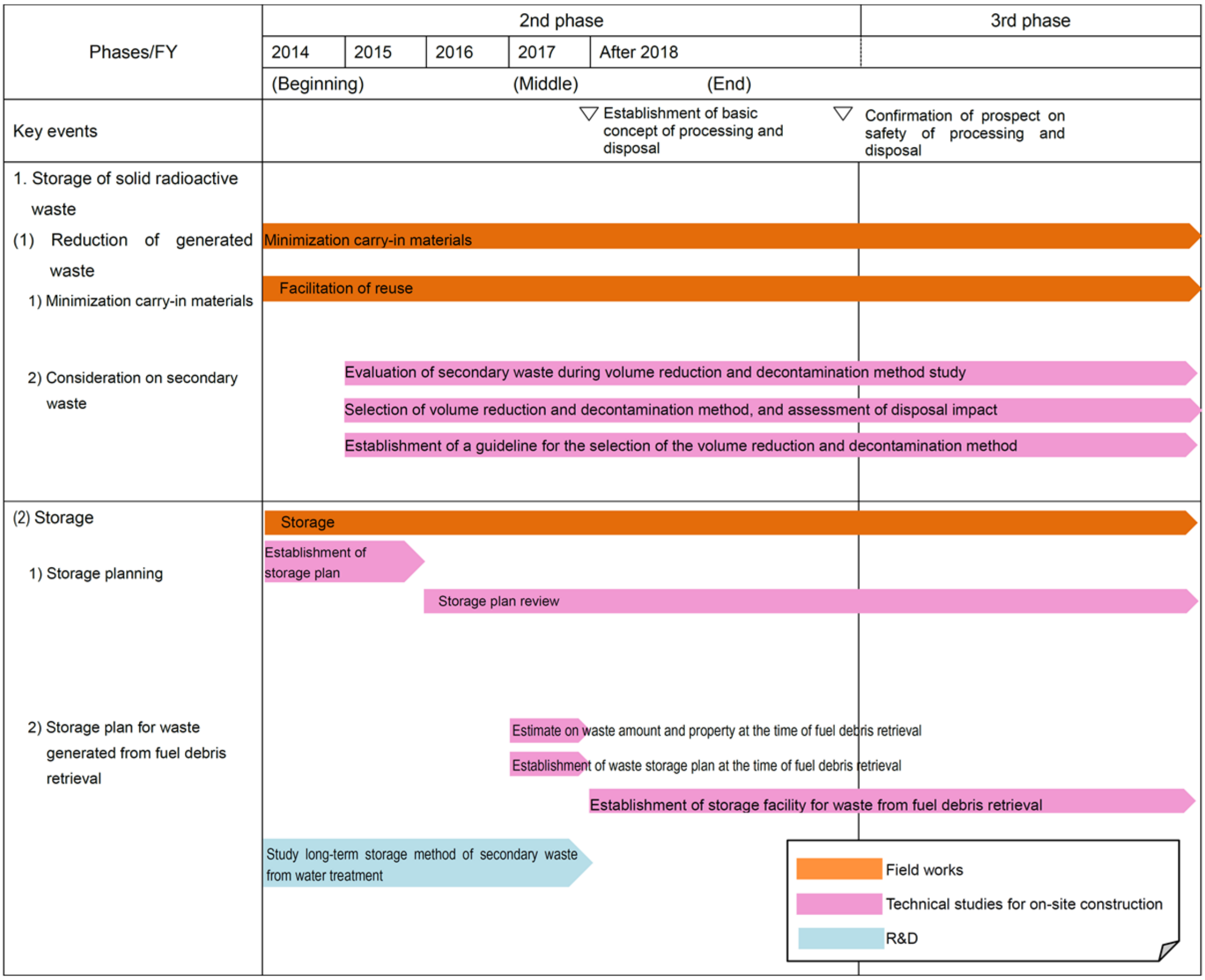


Figure 5.5-1 Future actions in the strategic plan for waste management (1/2)

Figure 5.5-1 Future actions in the strategic plan for waste management (2/2)

6. Approach to R&D and its overall plan

6.1 Approach to R&D

Since there are a number of highly technical and challenging issues involved in the decommissioning of the Fukushima Daiichi NPS, R&D for highly reliable technologies is underway through the subsidized projects of the government and the preparation of the facilities, aiming at the practical application of the technologies to the site.

The current Roadmap issued by the government includes the "R&D plan," and multiple R&D projects are now being carried out. To improve the management system among the R&D implementation organizations, IRID was established in August 2013, and the development of the research center and basic research are being carried out by JAEA.

Under these situations, it was stipulated that one of NDF's statutory works shall be "R&D of the technologies required for implementation of decommissioning." "Approaches to the R&D of the technologies required for decommissioning (hereinafter referred to as "R&D duties execution policy")" was formulated at the time of foundation of the organization and the approaches to the R&D planning, coordination and management (optimal R&D management) were defined.

This chapter describes the overall plan for R&D which is to be addressed based on the R&D issues identified in the strategic plans for fuel debris retrieval and waste management.

Section 6.2 Overview of R&D activities related to the decommissioning of the Fukushima Daiichi NPS

Section 6.3 Review policy for current R&D

Section 6.4 Optimal R&D management for practical application to the site based on the stable promotion of R&D

Section 6.5 The research and R&D center required as a base for long-term decommissioning work, and current status and optimal approach to human resource development

6.2 Overview of R&D

This section outlines the overview of R&D activities related to the decommissioning of the Fukushima Daiichi NPS.

6.2.1 Categories of R&D

Various organizations have been implementing the different types of R&D as listed below, bearing in mind to contribute to the decommissioning of the Fukushima Daiichi NPS which has many challenging issues in technical areas. The R&D stages and implementing organizations are shown in Figure 6-1.

For the facilitation of R&D, NDF is in charge of integrated management and review of these R&D projects. Overall optimization is to be carried out by clear division of roles based on the features of each organization and expected results and close cooperation among the concerned organizations.

<Examples of R&D>

(1) Development of equipment and device for remote operation under high radiation environment

(2) Development of assessment method of safety and reliability of structures and systems

(3) Obtaining data such as of fuel debris properties which will serve as the basis for decision of strategies, and research by analysis and evaluation

(4) Research on the behavior of radioactive materials and mechanism of corrosion, and physical phenomena by investigation and characterization.

<Examples of R&D for each organization>

(1) R&D implemented by TEPCO and plant manufacturers

(2) R&D led by research institutes such as IRID assuming practical application to the site as subsidized projects

(3) Development of R&D center and R&D promotion of basic technology by JAEA

(4) R&D promoted by research institutes and universities

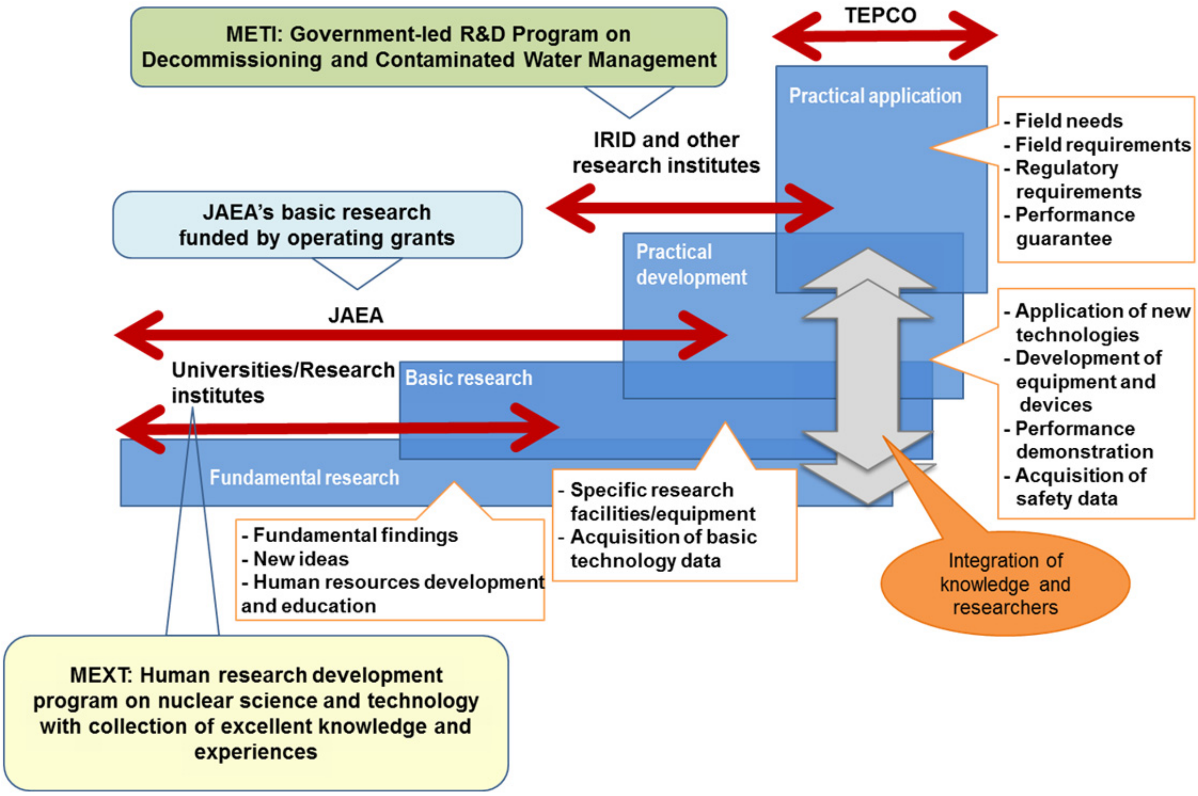


Figure 6-1 Whole picture of R&D projects related to the decommissioning of the Fukushima Daiichi NPS

6.2.2 Whole picture of government-led R&D programs

Out of the various kinds of activities carried out by multiple implementation organization, following programs have been implemented by Ministry of Economy, Trade and Industry (METI) and Ministry of Education, Culture, Sports, Science and Technology (MEXT) as R&D financed by the government budget (the budgetary history is shown in Table 6-1).

(1) Decommissioning and contaminated water management program (METI)

The program that supports the development of essential technologies and systems to be applied to the site for addressing the highly technical issues.

a. Technical development programs
   - i) Removal of fuels from SFP
   - ii) Retrieval of fuel debris
   - iii) Waste management

b. Conceptual study on alternative fuel debris retrieval method and FS on essential technologies (international tender)

c. Verification of technologies for contaminated water management program (international tender)

Note: In addition to the above, the large-scale demonstration program on the frozen-soil method at land-side impermeable walls and advanced multi-nuclide removal system (ALPS) have been carried out under the Contaminated water management and demonstration program (METI).

(2) Program of development of R&D center (METI)

The program to establish a facility for demonstration of remote operation equipment and device, and analysis and research on the radioactive materials such as waste and fuel debris.

(3) Basic research funded by operating grants and projects for research center development funded by grants for facility establishment (JAEA)

Basic research on decommissioning implemented by JAEA based on their past research results, a project on new facilities to be established in Hama-dori as well as on the existing facilities in Tokai/Oarai area, and the project for establishing a base where the researchers from various fields may be gathered.

(4) Human resource development program on nuclear science and technology by gathering knowledge and experiences (Decommissioning Basic Research: Human resource development program up to FY2014) (MEXT)

A program to support human resource development by the cooperation between the industry and academia as well as to facilitate R&D for addressing nuclear related issues by collaboration of researchers from various fields including international joint research.

Table 6-1 Budgetary history of related programs

(unit: 100 million)

	FY2011	FY2012	FY2013 (incl. FY2012 supplementary budgets)	FY2014 (incl. FY2013 supplementary budgets)	FY2015 (incl. FY2014 supplementary budgets)
(1) Program for decommissioning and contaminated water management (subsidized program)	20 (revised)	20 (initial)	87 (initial)	215 (FY2013 revised)	Included in 231 (FY2014 revised)
(2) Program for development of R&D center (JAEA's program funding)			850 (FY2012 revised)		
(3) JAEA operating grants (base technology research), R&D center establishment		Included in 50 (initial)	Included in 60 (initial)	Included in 61 (initial)	61 (budget)
(4) Base technology research and human resources development in universities				3 (initial)	20 (budget)
(Reference) Contaminated water management and demonstration program (subsidized program)			206 (reserve fund)	264 (FY2013 revised)	

6.3 The Next Phase Plan for R&D project

For the R&D issues provided in the strategic plans of fuel debris retrieval and waste management, it is important to divide the roles and consider implementation structure based on the degrees of importance and difficulty of the issues, and address them promptly and effectively towards the target to be achieved. It is necessary to address the issues with high difficulties by covering them in the R&D project appropriately. This section explains the steps of study on the R&D project in "Project of Decommissioning and Contaminated Water Management" to be carried out aiming toward on-site application and the important points to be considered in the study.

6.3.1 Steps for study

The plan for the next phase of the R&D project to be addressed under the "Project of decommissioning and contaminated water management (technical development project)" (hereinafter referred to as "Next Phase Plan") is to be developed as shown in Figure 6-2.

(1) Extract and identify the issues by confirmation and review on the ongoing R&D projects based on the latest information for site condition.

(2) Identify and organize the R&D issues to be addressed as priorities, through the course of studies on the "Strategic Plan."

(3) Based on the above steps, propose a review plan for each R&D project which should include actions for further issues.

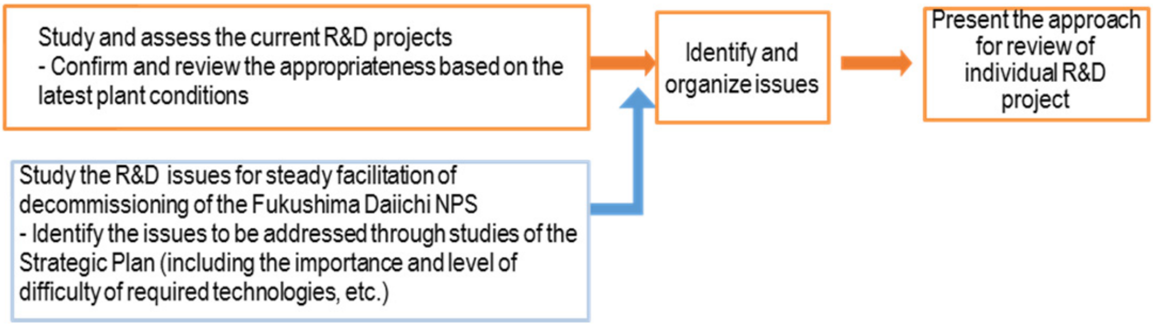


Figure 6-2 Development flow for the Next Phase Plan

6.3.2 Viewpoints to be considered in the plan

Following points should be considered in the Next Phase Plan in order to promptly and accurately work on the resolution of the R&D issues described in the sections on the strategic plans for fuel debris retrieval and waste management.

Specifications for the government-led R&D projects

<Common key points for all projects>

(1) Clarify the objectives and goals of R&D projects

a. R&D plans and specifications should sufficiently reflect the demands extracted from technical studies on the on-site construction works.

b. The organization should be able to reflect the latest plant and other on-site conditions on timely basis.

c. Due consideration should be given to determine the timing to utilize the outcome of development in site works.

(2) Clarify the division of roles between the studies for on-site construction work and related R&D to be implemented by TEPCO.

a. The main target of R&D is to develop equipment and devices and assessment method. Determine the division of roles and target schedule including the interactions with the regulatory authorities assuming the on-site utilization of the development results by TEPCO.

(3) Major target schedule

a. Feasibility study and decision on approaches to the retrieval method to determine the fuel debris retrieval method during the first half of FY2018.

b. The basic concept for solid radioactive waste processing and disposal is formulated within FY2017.

<Key points for fuel debris retrieval>

(1) Progress in identification of the internal conditions of the reactor vessels (Sections 4.2 and 4.3.1)

a. In order to understand the conditions inside the reactor vessels and of the fuel debris as much in detail as possible, and to continuously confirm that they are in stable conditions, clarify objectives and goals for each of the projects, update the data and information acquired on-site and achievements from researches in the works and cooperate and coordinate with the concerned parties.

b. Especially for internal investigations of PCV and RPV to make a direct visual inspection of the condition of fuel debris using measurement equipment (e.g. cameras and sensors) and sampling of the fuel debris, routinely update the investigation plan based on the order of priority of the locations to be investigated, and plan for further development and application of the technology.

c. Identify the location and FP distribution to help the study on the fuel debris retrieval method.

(2) Feasibility study for the retrieval method and ensuring the safety during retrieval work (Sections 4.3.2-4.3.5)

a. Obtain required data and information regarding the Submersion and Partial submersion methods (access from the top and the side) to assess the feasibility of each technical requirement for determination of the fuel debris retrieval method in the first half of FY2018. In specific, technical feasibility of PCV repair and water leak blockage, integrity of PCV, shielding and containment function should be evaluated and confirmed appropriately.

b. Carry out R&D to achieve safe and reliable fuel debris retrieval.

<Key points for waste management>

a. Obtain necessary data and information in preparation for establishment of a basic concept for processing and disposal of solid radioactive waste in FY2017 and confirmation of the prospect for safety of processing and disposal of solid radioactive waste in FY2021.

b. Conduct studies especially on waste properties, processing and disposal method to provide candidates for entire scenario on a series of waste management and handling method from waste generation/storage to processing/disposal (waste stream).

c. Establish approaches for long-term stable storage and processing of the secondary waste generated from the water treatment.

6.3.3 The Next Phase Plan for each field of work

The Next Phase Plan was drafted for each R&D project carried out under the “Decommissioning and contaminated water management program” based on the study flow and viewpoint mentioned in the previous section. The draft was then reflected in the Next Phase Plan for the R&D project which was finalized at the 15th Contaminated Water and Decommissioning Issues Team meeting held on February 26, 2015. A list of R&D projects and systematic diagram for each field are shown in Figures 6-3 to 6-5.

(1) Fuel debris retrieval

a. Decontamination and dose reduction
   - i) 1) Development of remote decontamination technologies for use inside R/B

b. Water leak blockage
   - i) 2)-1 Technical development for repair and leak blockage of PCV
   - ii) 2)-2 Full-scale test for repair and leak blockage of PCV

c. Internal investigation
   - i) 3)-1 Technical development for internal investigation of PCV
   - ii) 3)-2 Technical development for internal investigation of RPV
   - iii) 3)-3 Sophistication of the internal investigation of the reactor vessels using accident progression analysis and actual plant data
   - iv) 3)-4 Technical development of fuel debris detection inside the reactor vessels (muon)

d. Fuel debris retrieval method
   - i) 4)-1 Technical development for fuel debris retrieval and reactor internals removal
   - ii) 4)-2 Technical development for collecting, transporting and storing the fuel debris
   - iii) 4)-3 Technical development for integrity evaluation of RPV/PCV
   - iv) 4)-4 Technical development for fuel debris criticality control

e. Fuel debris analysis
   - i) 5) Fuel debris characterization (Characterization using simulated debris and actual debris analysis)

(2) Waste management

a. R&D projects on processing and disposal of solid radioactive waste
   - i) Consolidation of R&D results (provide basic concept for processing and disposal)
   - ii) Waste characterization
   - iii) Study on processing and long-term storage
   - iv) Study on waste disposal

Fuel debris retrieval-related R&D system I: Progress in identification of the internal conditions of the reactor vessels

- In each unit, the temperature inside the PCV remains low. It is confirmed that there is no recriticality and fuel debris is in a stable condition based on the measurements of the radioactive materials.
- On the other hand, access into the R/B is limited and there are technical issues in visualization of the internal conditions. Especially for identification of fuel debris locations, comprehensive analysis and evaluation are being conducted considering the temperature measured on-site and distribution of radioactive materials in addition to estimation by the improved accident progression analysis code.
- A remotely operated visualization and measurement equipment which can be inserted through the accessible penetrations as well as muon imaging technology for scanning the reactors are to be developed for the purpose of detecting the fuel debris locations in specific areas inside the PCV.
- Other than the above, since integrity evaluation of PCV, dose reduction to secure access into of the building, identification of damaged areas and leakages in PCV are important, and its evaluation method, equipment and device are to be developed.

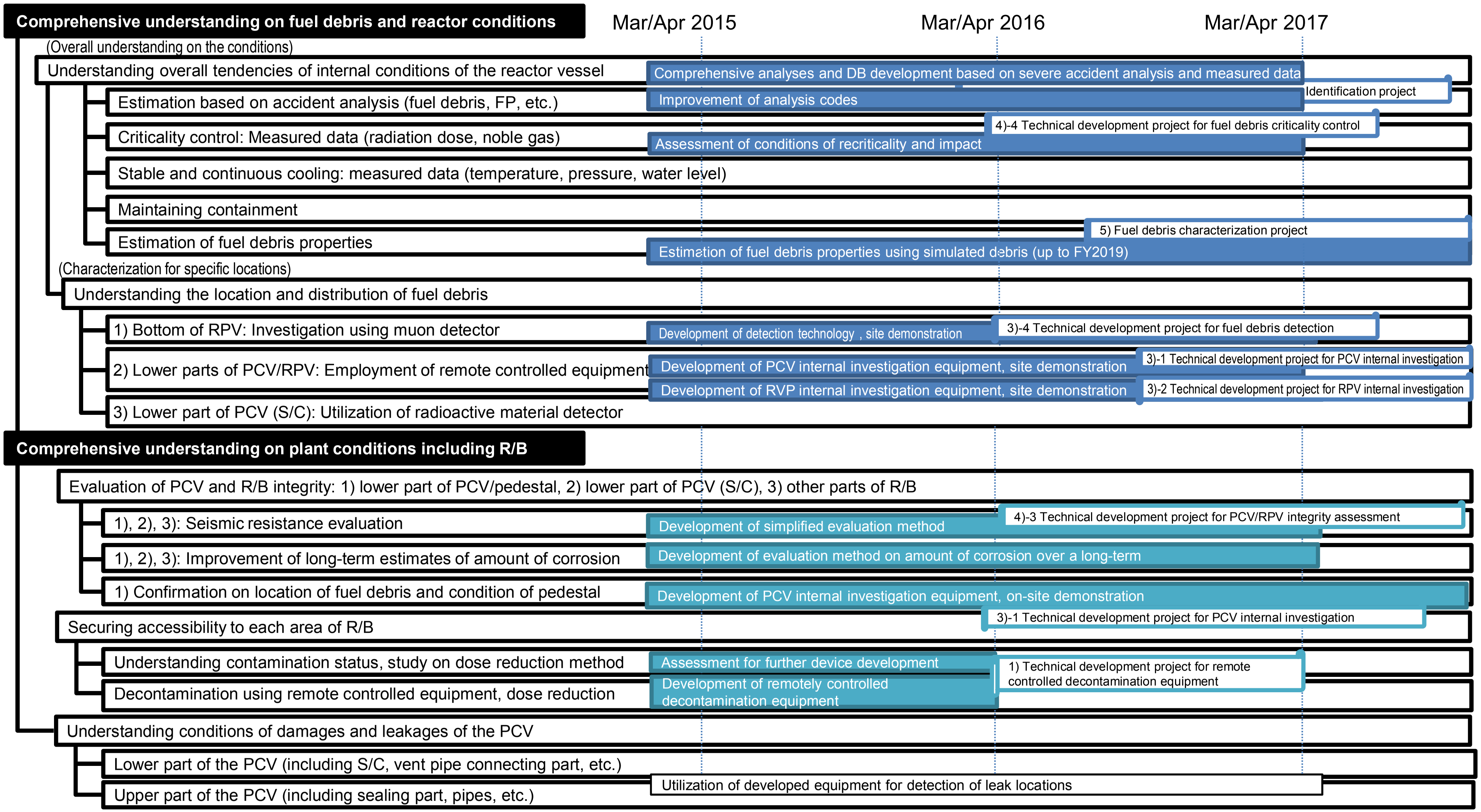


Figure 6-3 Fuel debris retrieval-related R&D system I: Progress in identification of the internal conditions of the reactor vessels

Fuel debris retrieval-related R&D system II: Safe and reliable fuel debris retrieval

- The current Roadmap sets the HP as follows.
  Second half of FY2016: Fix the repair method for the lower part of the PCV (HP DE-1), fix the method of internal investigation of PCV (HP DE-2)
  First half of FY2018: Fix the repair methods for the upper part of PCV (HP DE-3), determine the retrieval methods for fuel debris and reactor internals (HP 3-2)
- Evaluate the feasibility of the Partial submersion method (accessing from the top and side) in addition to the Submersion method, and obtain data and information required for comprehensive evaluation to ensure the work safety (including securing structural integrity such as of PCV, prevention and management of criticality, feasibility of water leak blockage for submersion, and radiation protection) and assessment of the feasibility of technologies and systems for retrieval works to select a scenario for optimum fuel debris retrieval method for each unit (at least for the first unit) based on the assumption of the evaluation of the internal condition of the reactor vessel.
- Develop the fuel debris retrieval equipment and devices, storage canisters and transfer devices in preparation for the implementation of safe and reliable fuel debris retrieval.

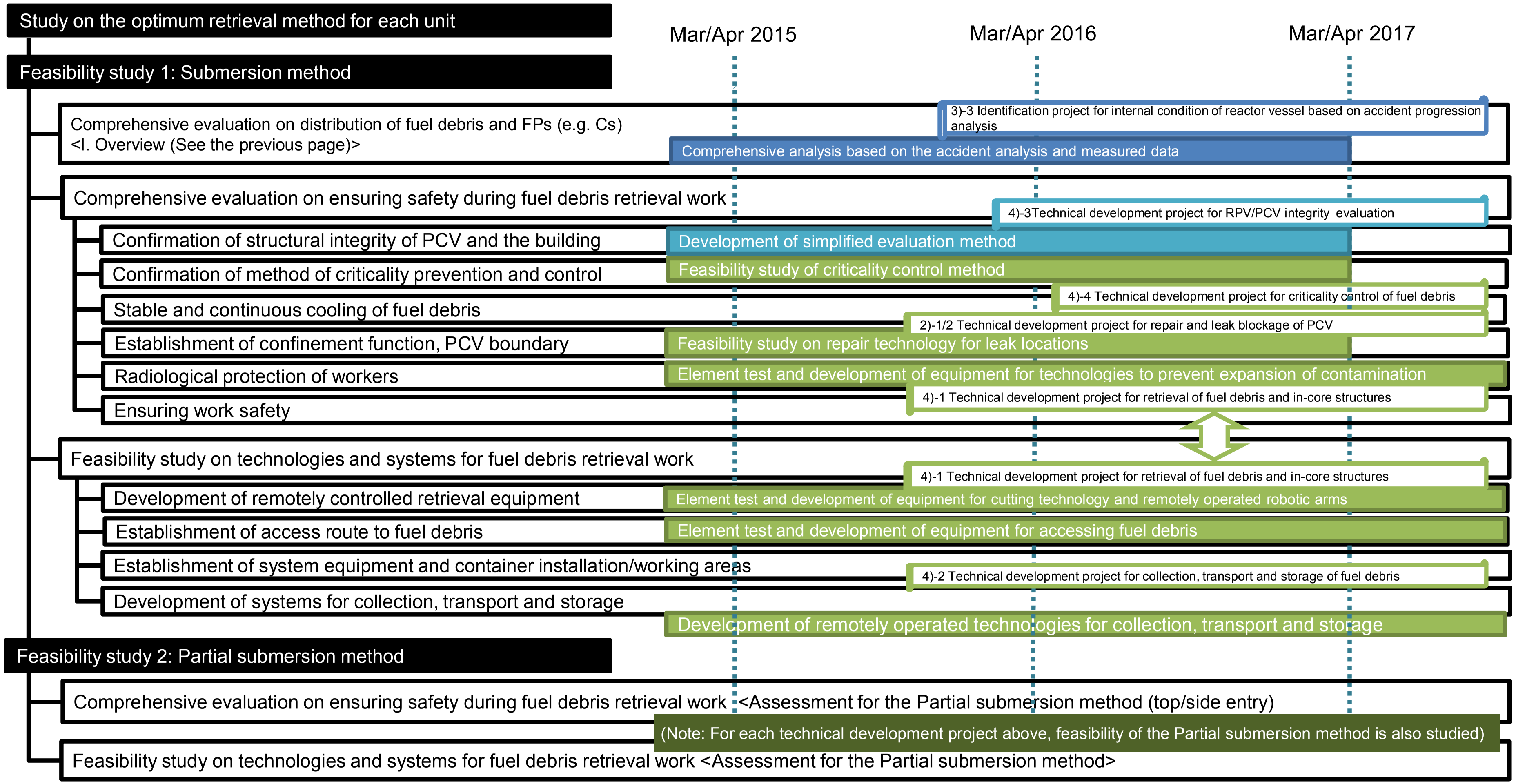


Figure 6-4 Fuel debris retrieval-related R&D system II: Safe and reliable fuel debris retrieval

Waste management-related R&D system

- It is essential to develop new technologies and establish systematic response since it is difficult to manage various and large amount of waste generated by the accident at the Fukushima Daiichi NPS with the current system and technology.
- In the current Roadmap, the basic concept of solid radioactive waste processing and disposal is to be established in FY2017 and prospect for safety for the processing and disposal are to be confirmed in FY2021 as a target.
- Comprehensive studies on predisposal management including characterization, storage and processing, and disposal method of solid radioactive waste are to be carried out. These results are then sorted, integrated, and reflected to the basic concept for the solid radioactive waste processing and disposal. By carrying out the investigations and studies on the disposal concept, information necessary for establishment of safety regulations will be clarified.
- Characterization and studies on the long-term stable storage and processing of secondary waste generated from water treatment are to be carried out as well.

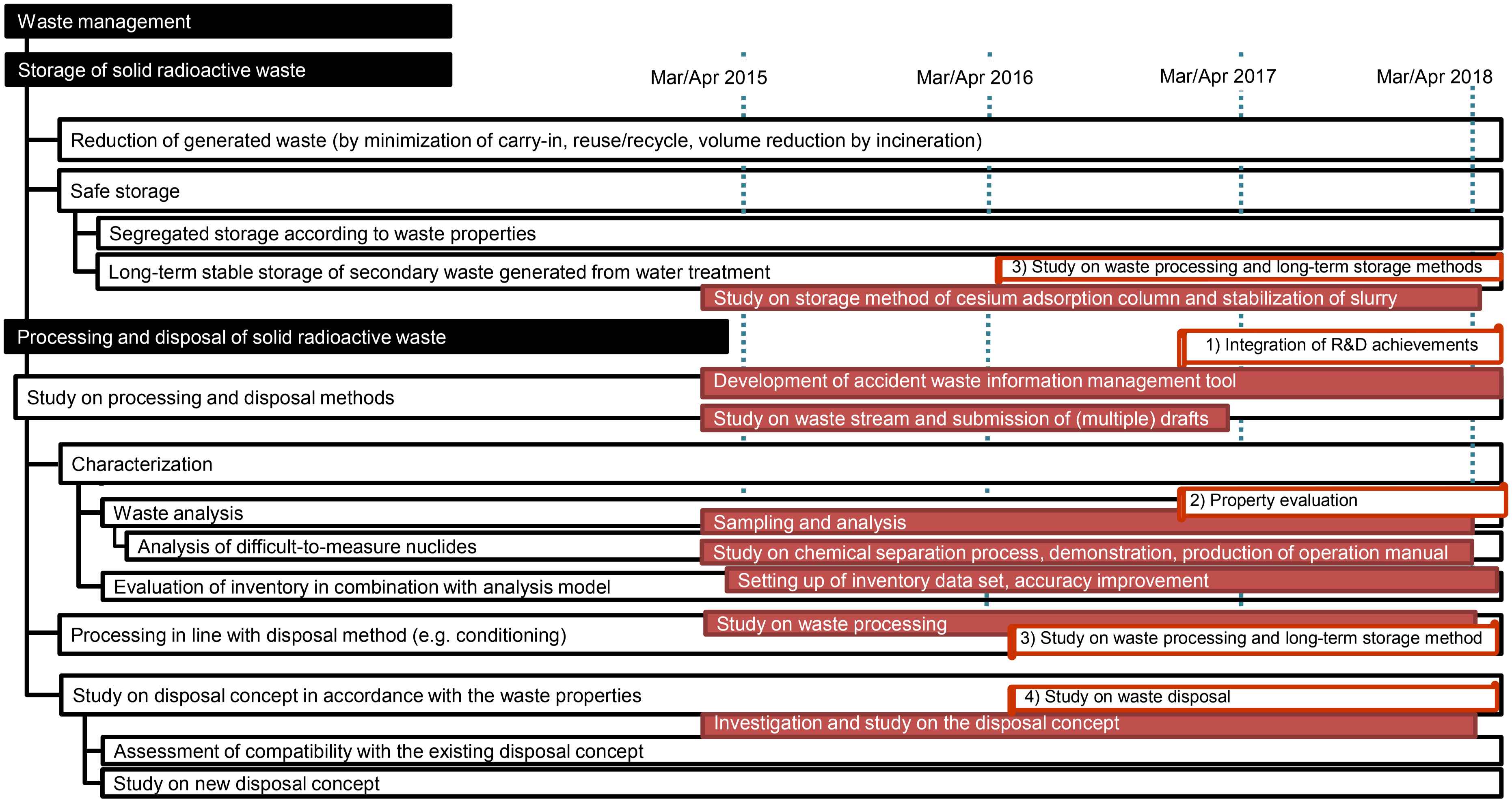


Figure 6-5 Waste management-related R&D system

6.4 R&D management

This section describes the key items to be focused for the management of smooth and successful R&D aiming toward practical application at the decommissioning site of the Fukushima Daiichi NPS which is the central part of the government-led R&D program on "Decommissioning and Contaminated Water Management."

6.4.1 Items to be focused based on the R&D duties execution policy

NDF developed the "R&D duties execution policy" at the time of its establishment. In order to manage R&D appropriately toward practical application on site in preparation for decommissioning of the Fukushima Daiichi NPS, items listed under Table 6-2 should be focused in addition to the basic approaches in line with the R&D duties execution policy. The outline of the items to be focused in the R&D duties execution policy is described below.

The R&D project conducted under the government-led R&D program on Decommissioning and Contaminated Water Management will be managed through Fund Establishment Organization and Management Office selected by METI centering on the R&D implementation organization. It is necessary for NDF to support and cooperate in the project to strengthen the R&D management system.

(1) Activities addressed for the practical application

a. Study the applicability of method and technology assuming the Submersion and Partial submersion methods.

b. Set objectives and priorities based on the site needs.

c. Improve efficiency of R&D project for technologies and systems common to all the plants.

d. Establish standards for maintenance and operation of equipment and facilities, work safety, etc. as well as evaluation method for operation of the equipment and facilities.

(2) Approaches focusing on ensuring the safety

a. Consider safety when identifying R&D issues and objectives.

b. Maximize the safety of the workers by prioritizing the dose reduction.

(3) Implementation of appropriate management

a. Introduce a method for the integral management of a number of various R&D projects and establish the organizational structures.

(4) Gathering knowledge and experiences from Japan and abroad for facilitation of smooth decommissioning work

a. Incorporate the technologies, knowledge, and experiences utilized all over the world, and cooperate with related institutions and experts.

b. Utilize technologies with high TRL through the technical investigation and international RFI/RFP (request for inquiry/request for proposal)

c. Reinforce collaboration with the research institutes and universities for the basic studies

(5) Approaches to securing human resources

a. Reinforce development and securing of human resources through basic research in collaboration with research institutes and universities.

(6) Archiving and dissemination of information obtained from decommissioning of damaged reactors and research achievements, including contribution to the investigation of the accident to improve safety of the reactor facilities

a. Establish a system to manage and disseminate information comprehensively by effective collection and organization of information.

6.4.2 Management at each stage of R&D

In the R&D for decommissioning of the Fukushima Daiichi NPS, there are multiple R&D projects whose goal is, for example, to identify the internal conditions of RPV/PCV. Since these projects have the "common objective" such as to make contribution to the study on the fuel debris retrieval method, it is important to set a reasonable objective for each of the R&D project which directly leads to the achievement of this common objective.

In addition, R&D management scheme that covers the entire project including technical studies for on-site construction works should be established.

More specifically, in addition to the proper management at the planning stage before the R&D project starts, it is necessary to periodically confirm the issues and objectives to be achieved and to coordinate and adjust as necessary after the project is started. Following are the items to be studied and confirmed for the management (See Figure 6-6).

(1) Planning stage before the startup of the R&D project

a. Identify the issues from the objectives of fuel debris retrieval and waste management, and establish implementation plans and milestones for the approaches to resolving issues with the risks taken into account. Based on this plan, set individual R&D project targets and division of roles.

b. Confirm if the needs from the technical studies for on-site construction are considered sufficiently in setting the division of roles for each R&D project.

   i) Scopes of R&D (equipment and devices, systems, assessment method, data acquisition)

   ii) TRL, developmental stages based on TRL, judgement criteria for stage transition

iii) Establishment of a common base of equipment and devices (see Note 1), optimum technical demonstration method (see Note 2), methodology of confirmation and endorsement of safety assessment method by a third party (see Note 3).

c. Study the feasibility of each R&D project and identify risks and alternative solution as necessary.

d. Create interface control documents (documents on information transmitted) among the R&D projects.

(2) Implementation stage after the startup of the R&D project

a. Monitor the progress and issues of each R&D project, site conditions and needs on a periodic basis.

b. Determine the necessity to change the individual R&D project objective on the basis of the "common objectives" (the relationship between R&Ds needs to be considered as well) when the critical issues are confirmed in the process above.

c. Report to the upper management in case there is any impact on the "common objective."

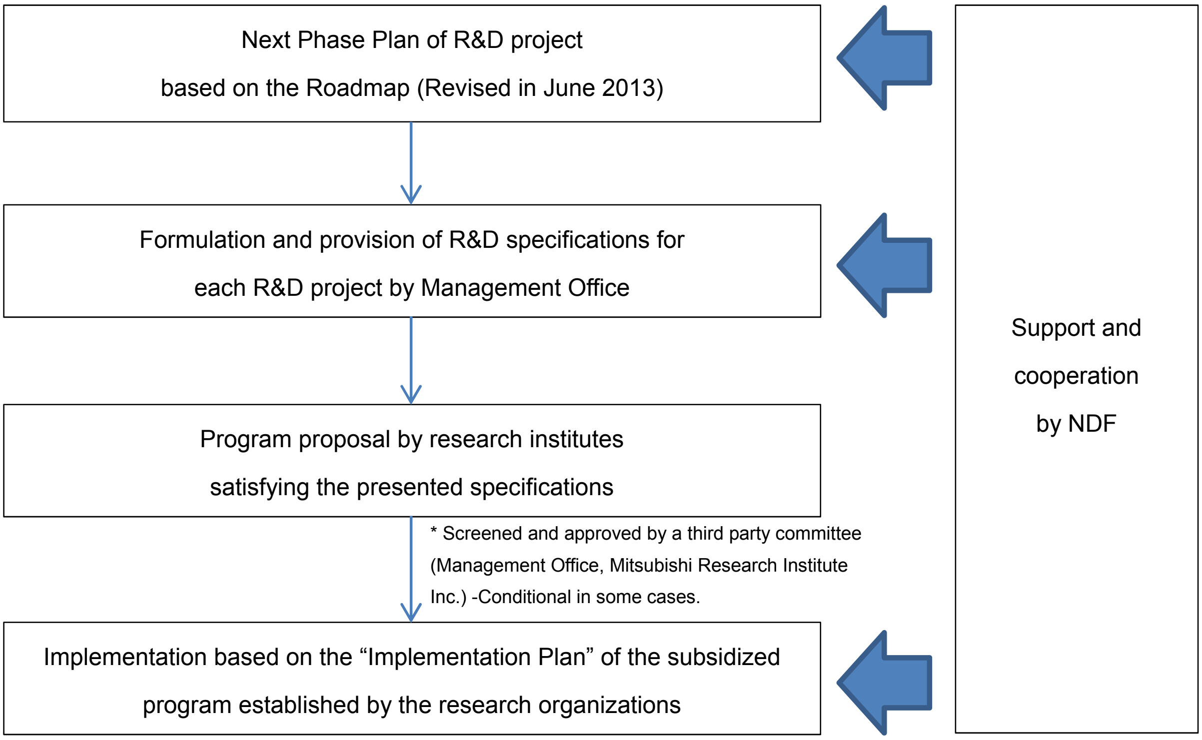


Figure 6-6 R&D project planning and implementation flow under the government-led R&D program on Decommissioning and Contaminated Water Management

Note 1: Establishment of "common base" of equipment and devices

(1) A common base of equipment and devices is believed to be the key to the efficient development and operation of a remote technology and system for fuel debris retrieval.

a. Examples of the "common base" are as follows.

i) Sharing common equipment and devices among the plants (e.g. motors can be shared and replaced)

ii) Sharing common equipment and devices among the systems with the same function (e.g. use the same type of work platform)

iii) Application of the existing technologies including general-purpose products (e.g. Wireless interface)

(2) The appropriate development of equipment and devices is to be studied to make the best possible use of the common base while creating a database for equipment and devices which completed the investigation, development and trial use of the existing technologies (including general-purpose products).

(3) "Division of roles between humans and equipment under the severe work environment" needs to be clarified for the successful development of the equipment and devices.

Note 2: Optimum technical demonstration method for equipment and devices

When presenting a basic concept on the on-site demonstrations and the mock-up test which will be necessary for development and demonstration of equipment and devices and for training of the workers, and to formulate a detailed R&D plan, it is important to carry out activities in effective combination at the following facilities.

(1) Small- and medium-scale mockup at manufacturers' factories and research facilities

(2) Full-scale mockup at the mockup test facility (partial mockup is available)

(3) Demonstration and training using Units 5 and 6 (Note that they are radiation control facilities)

In specific, following examples may be possible for the basic concept described above but it will be subject to further studies. (For detailed concept, see attachment.)

Note 3: Confirmation and endorsement on safety and reliability assessment method by a third party

(1) Development of integrity assessment method needs be carried out in collaboration with the Academic Society in Japan and other international organizations so that the validity of the study results will be widely acknowledged, and this effort needs to be incorporated into the milestones of R&D.

(2) The procedure for the final confirmation and endorsement by a third party should be studied when developing the assessment method with an intention to utilize the method in the preparation of the future licensing application.

6.5 Basic R&D activities

This section describes the current status and future plans for the development of R&D center which will contribute to the decommissioning of the Fukushima Daiichi NPS, basic research activities and development and securing of human resources from mid- to long-term perspective.

6.5.1 Development of R&D center

A concept is being developed for the establishment of "International Joint Research Center on Decommissioning" as an R&D center which will contribute to the decommissioning of the Fukushima Daiichi NPS.

In addition to the existing facilities of JAEA located in Tokai and Oarai (Ibaraki), it is planned to establish a mock-up test facility currently under construction in Naraha in Hama-dori area (Fukushima), and the radioactive materials analysis and research facility to be constructed in Okuma. This concept also includes a plan to use the International Joint Research Center as a base where the researchers of various areas of study may gather from the universities, research institutes and companies in Japan and overseas. After the launch of this center in April 2015 as one of the organizations developed by JAEA, a full-scale base will be established in Fukushima whose operation is planned to begin in FY2016.

The mock-up test facility under the plan is for demonstration of remote operation of equipment and devices, and full-scale tests are planned be conducted for the equipment and devices for repair and water leak blockage for PCV. Partial operation of the facility will start in the summer of FY2015, and full-scale operation from FY2016.

Analysis and research facilities will also be established for the purpose of analysis and research of radioactive materials generated from decommissioning, and the development of analytical method for difficult-to-measure nuclides and characterization of fuel debris, and development of processing and disposal technologies are planned in the future. The first building for analysis and research of radioactive materials with comparatively low dose and the second building for radioactive materials with relatively high dose are being developed, and their operations are planned to begin from FY2017 and FY2020 respectively.

It is important to create a framework where human resources and organizations are gathered from different fields, roles and expertise to share information of their research achievements and try to maximize the ability as a team by supplementing each other's performance beyond the borders of their roles. In specific, research activities are expected to be carried out with a formation of a core base, so that the community of the field will be activated and recruitment and flexible management of human resources will be encouraged. It will also be necessary to develop a skill for high level management and support by referring to the functions required in an open innovation hub in order to maintain and enhance the function of the core base. Moreover, since basic research and human resource development are closely related, a base should be developed to integrate the basic research and human resource development with the cooperation from the universities.

It is expected that if more organizations and human resources including researchers and engineers are involved in the process of development and operation of the R&D center, they may be able to contribute to the restoration of the local communities as well. Therefore, it is essential to coordinate the R&D projects in conjunction with the restoration of Fukushima and its neighboring areas and research base concept (for environmental recovery, health management, regional economic promotion).

6.5.2 R&D for base decommissioning technology

As described in the Section 6.2.1, R&D for the decommissioning of the Fukushima Daiichi NPS is aimed at the practical application of the technologies, and the projects such as "R&D promoted by TEPCO and plant manufacturers" and "R&D led by IRID as subsidized projects, aiming at practical application" are carried out. On the other hand, R&D of the base decommissioning technology is also ongoing under the "Development of R&D facilities and R&D of base technology promoted by JAEA" and "R&D promoted by research institutes and universities," and the advanced research to help accelerate the decommissioning work and various possibilities for alternative decommissioning technologies are being pursued and the academic knowledge is being provided. JAEA, as a member of IRID, is working on the development of the technologies aiming at the practical application to the site as well as basic research based on their past achievements (see Note 4).

<u>Note 4: Annual operation plan for FY2014 (Excerpt)</u>

...Conduct the following basic research to facilitate decommissioning of the Fukushima Daiichi NPS Units 1-4.

・Continue corrosion tests of irradiated materials to examine the long term integrity of fuel assemblies to address the issues related to the fuel removal from the SFP.

・For the cutting technologies of fuel debris and reactor internals, conduct cutting test using simulated debris and complete the applicability assessment. Continue improvement of the recriticality behavior analysis method for criticality control of fuel debris. For nuclear fuel material measurement for accountancy and control, conduct fundamental tests for the applicability assessment of each candidate technology. Improve accident progression analysis code and conduct tests to accumulate data.

・Establish a base and continue technical studies for safe and optimal processing and disposal of radioactive waste generated by the severe accident and dismantled waste to be generated in the future.

・For the remote technology required for decommissioning work, conduct demonstration tests using the test model for internal investigation of RPV. Utilize the facility which has a similar working environment with the current Fukushima Daiichi NPS and continue to collect data necessary for acceleration of the decommissioning of the Fukushima Daiichi NPS.

The R&D for decommissioning is being carried out by other research institutes and universities as well. For example, High Energy Accelerator Research Organization (KEK) conducted a research on the material visualization using muon particles, and IRID adopted the research results to their technical development and demonstration to detect the locations of fuel debris with the support of KEK. Also, Fukushima University developed and proposed a device that can quickly analyze the radioactive material (Sr90), which was demonstrated jointly with TEPCO, and it is currently used in the actual site construction works as an alternative method to the existing analytical method which used to take more time. As described above, the results of basic R&D obtained by the research institutes and universities are being applied for the site construction works and R&D toward the decommissioning of the Fukushima Daiichi NPS.

Moreover, recognizing that the decommissioning of the Fukushima Daiichi NPS will take a long time, Tohoku University has been working on mathematical modeling of the reaction mechanism of corrosion and development of the corrosion mechanism analysis technology and corrosion mode assessment technology in order to develop base technologies for the anti-corrosion for the PCV and injection pipes and long-term life prediction, in addition to investigations on the mechanism to stop the corrosion reaction as part of a mid-to long-term basic research. This R&D provides mathematical modeling for phenomena based on the principles, and evaluates the evolution of the phenomena and its countermeasures for the purpose of supporting the decommissioning site with engineering technologies related to the decommissioning from the academic perspective.

Since there are a lot of other issues to be addressed in the decommissioning of the Fukushima Daiichi NPS, it is considered important to conduct R&D for extracting unidentified issues and to make proposals for the decommissioning work and R&D.

These activities are examples of the basic R&D based on the investigation of the conditions and needs of decommissioning (see Note 5), and are expected to supplement and reinforce the decommissioning technologies.

Note 5: Examples of R&D for base decommissioning technology

(1) Alternative and innovative research which may improve decommissioning process drastically.

Examples:

a. Essential technologies such as of visualization utilizing muon

b. Analysis and measurement of radioactive materials

c. Technologies contributing to the volume reduction of radioactive waste

d. Essential technologies of control and transmission which will help develop the remote operating equipment and devices

(2) R&D to provide data for the phenomena and insight from academic perspectives to promote decommissioning work and R&D reliably and smoothly.

Examples:

a. Development of base technologies for prevention of corrosion of PCV and injection pipes and of long life time prediction.

b. Identification of basic properties of radioactive materials such as fuel debris and FP.

(3) Research aiming to find and extract the unidentified issues and make proposals for the decommissioning work and R&D.

Since the R&D for the base decommissioning technologies represented by the R&D categories in Note 5 is highly expected, it is important to promote proactive R&D activities in broad range of fields and encourage innovation by the researchers. It will then be necessary to promote utilization of these achievements and knowledge obtained from the research in the actual on-site construction works and further R&D.

Thus, by integrating the different activities conducted by the nuclear industry, universities and academic societies, it is important to arrange a venue for information sharing and discussion amongst the research institutes, university researchers and actual organizations who engage in the decommissioning work on the status and needs of the decommissioning site and research institutes as well as on the research achievements and knowledge obtained by the research institutes and universities. The results of R&D in various fields are expected to apply to the decommissioning site by promotion of active communication among the organizations concerned to participate in the R&D activities.

In addition the R&D for base decommissioning technology will not only serve the decommissioning work of the Fukushima Daiichi NPS but it may also contribute to many other areas, such as the cultivation of innovative academic insights, experience of decommissioning and safety enhancement of nuclear facilities in Japan and abroad, breakthrough in other fields of research. Therefore, the researchers from broad range of fields shall be encouraged.

6.5.3 Development and securing of human resources

In order to realize smooth decommissioning, besides the activities related to the R&D described in the previous sections, it is also important to develop and secure human resources with skills and knowledge through the implementation of R&D from mid- to long-term perspectives.

MEXT has started the “Decommissioning Basic Research: Human resource development program” in FY2014 for the purpose of development of human resources necessary for resolving issues to facilitate safe and steady decommissioning work and for gathering knowledge and experiences from various fields on mid- to long-term basic research. This is one of the areas focusing on human resource development specializing in decommissioning of which private organizations may have difficulty in starting by themselves. In this program, the R&D described in the previous section is carried out at the universities based on the needs of the decommissioning site. Establishment of basic R&D center has also begun in FY2014 with core research bases in the following universities to develop human resources capable of assuming the leading role in the decommissioning work, under the collaboration with the R&D institutions for the decommissioning of the Fukushima Daiichi NPS.

- Tokyo Institute of Technology: Enhancement of higher-level human resource development and basic research for decommissioning engineering
- The University of Tokyo: Human resource development on the entire decommissioning project with basis on remote control technology and various analytical technology
- Tohoku University: Basic research for the maintenance of reliability of PCV and R/B for decommissioning and waste processing and disposal and program for core human resource development.

Following programs are carried out as FS in FY2014 to establish human resource development center.

- Japanese Geotechnical Society: Development of new geotechnical engineering technology and human resource development covering the contaminated water management and fuel debris retrieval to decommissioning
- Fukushima University: Priority research and multi-phased progressive human resource development program for the practical application of a quick measurement method for radioactive Sr
- University of Fukui: Development of basic research and human resource development center for the decommissioning of the Fukushima Daiichi NPS
- Fukushima National College of Technology: Human resource development program through the basic research on decommissioning

In order to carry out mid- to long-term development and securing of human resources for decommissioning, it is important to have a comprehensive perspective on the entire future decommissioning processes and to clarify specific images of human resource which will be necessary in the future and the technical fields to be developed in priority. It is then necessary to promote human resource development such as training at the companies and research institutes, as well as human resource development at the educational institutions such as universities. It is desirable if the companies and research institutes which accept the human resource and the educational institutions which develop the human resource work closely together and carry out specific measures in the university education, company recruitment and trainings in an integrated manner.

In specific, as described in (2) of Section 5.4.1, since a great number of human resources will need to be secured and developed for technical development and analysis work on radioactive materials, a structure for human resource development in this expertise needs to be developed as soon as possible. It must be noted that in addition to the human resource with technical expertise, the human resource capable in smooth management of multiple R&D projects will also be required.

In addition, in order to secure more human resources from various fields other than nuclear industry who wish to work in decommissioning-related areas, it is necessary to appeal to the people that the works and R&D involved in the decommissioning of the Fukushima Daiichi NPS are “attractive” in a way that it is an extremely technical challenge the world has never seen before. It will also be important to show them the possible route for active and successful engagement in the decommissioning of the Fukushima Daiichi NPS by, for example, specifically presenting various “career paths” that are available for the researchers and engineers to succeed in their areas of work.

They are expected to not only play the key roles in the future decommissioning works but their commitments should also facilitate further reinforcement of international relationships by joint research as well as the improvement of safety of nuclear facilities. Furthermore, they are also expected to become the leaders who would contribute to the breakthroughs in the relevant technical areas or the development of related technologies and industries as well as to the restoration of Fukushima.

<Concept of mockup test and on-site demonstration for the development and demonstration of equipment and device>

The development and demonstration of equipment and devices have to be carried out step by step with the clarification of what is to be developed and demonstrated.

(1) The functions and performance evaluation of essential technologies

a. To demonstrate the function and performance of an essential technology itself, an evaluation test and repeated tests should be conducted on the improved technology of the already existing technology or newly developed technology under various environments. If a mock-up facility becomes necessary, a small or medium scale mock-up should be used to conduct the evaluation test promptly and practically.

b. For example, in the development of fuel debris retrieval technology, an element test to confirm the function and performance of cutting equipment and manipulator themselves has begun in FY2014. In the future, use of small or medium scale mock-up may need to be considered for devices for shielding and dust dispersion prevention or removal equipment for reactor internals.

(2) The functions and performance evaluation of the retrieval method and the entire system

a. When confirming the feasibility and consistency of the retrieval method and the entire system through all the work steps, it is necessary to identify the issues which cannot be identified from the studies or tests on single technology by mock-up test.

b. When confirming the function and performance of all the steps in a workflow, use of scale model (small-scale model) or partially simulated model in full-scale may be efficient and practical. Also, procedures of demonstration test should be determined taking into account of the contamination of equipment and devices, exposure to the workers, budget, time and impact in the event of failure in the test.

c. For example, feasibility and consistency of all the work steps may be evaluated comprehensively using scale model to confirm the feasibility of fuel debris retrieval method and entire system.

(3) Demonstration considering actual workability, operation and maintenance.

a. Demonstration must be conducted considering the actual workability, operation and maintenance of the equipment and devices required for works under the severe conditions due to the radiation, space or structural challenges.

b. In such case, although the demonstration in the actual plant is desirable, the demonstration test should to be conducted using better equipment and facilities with similar scale and environment, considering the actual work environment.

c. For example, if demonstration test with complete specification needs be carried out under the simulated environment of the actual site before the practical application of the fuel debris retrieval method and its system, use of similar types of equipment and facilities on- or off-site should be considered.

(4) Confirmation and endorsement of safety and reliability assessment method by a third party

a. Improvement of analysis and development of integrity assessment method needs be carried out in collaboration with the Academic Society in Japan and other international organizations so that the validity of the study results will be widely acknowledged, and this effort needs to be incorporated into the milestones of R&D.

b. When developing an assessment method, study how the final confirmation and endorsement should be obtained from a third party.

Table 6-2 “R&D duties execution policy” and items to be focused for the R&D project management

No. 1: Basic policy on the operations of NDF regarding the R&D for the technologies required for appropriate and steady decommissioning

1. Implementation of the operations aiming at the practical application

(1) Multi-layered approach

	Additional issues to be focused on
In order to deal with the highly uncertain situation with a number of unknown factors in the site conditions, take a multi-layered approach taking the risk assessment results into account as well.	1) In addition to the Submersion method, study the technical applicability for the Partial submersion method to help the scenario selection for the fuel debris retrieval method. 2) Develop multi-layered approach for the investigations and access into the reactor and the fuel debris.

(2) Prioritization of objectives and flexible review considering on-site needs

	Additional issues to be focused on
Determine the order of priority of the objectives based on the short-term and mid- to long-term needs and issues of the site and develop an R&D plan. In addition, review the objectives flexibly based on the feedbacks such as the latest findings or the knowledge obtained from the actual decommissioning process.	1) Before starting the R&D project, establish objectives to be achieved and the order of priority considering site needs, and share the objectives among the relevant organizations. Conduct integral management of multiple R&D projects and take note of the highly uncertain situation as well. 2) Since the needs for R&D will change according to the latest site conditions, it is important to flexibly and promptly review the objectives and the order of priority. Therefore, it is important to periodically follow the progress of R&D as well as to arrange venues to confirm the necessity of reviewing the issues to be addressed or the objectives to be achieved.

(3) Realization of efficient R&D

	Additional issues to be focused on
By conducting efficient R&D and appropriate division of roles, eliminate unnecessary work and achieve results so that the developed technologies can be applied in the decommissioning process.	1) Considering the target for the fuel debris retrieval from Units 1-3, it is important to promote efficient R&D of technologies and systems applied commonly for all plants. In specific, considering the operation and maintenance of equipment and devices to be required over a long-term, use of common parts and interface and modularization will be important as well.

	2) Also, it is necessary to establish the procedures of performance evaluation for development and demonstration of equipment and devices, to clarify the required mock-up test, possible training model for operators and concept for on-site demonstration and to carry them out properly.

(4) Approaches contributing to the establishment of the standards

	Additional issues to be focused on
In order to carry out proper and steady decommissioning of the damaged reactors, it is important to ensure the safety and reliability of the newly developed technologies and to establish the standards necessary for actual application of the technologies in a timely manner. To realize this, clarify the concept on the standards which will be necessary in the future decommissioning process of the damaged reactors, and carry out necessary activities for technical R&D that will serve the establishment of new standards.	1) The standards for maintenance and operation of equipment and facilities and for ensuring the work safety at the Fukushima Daiichi NPS, which are the Specified Nuclear Facilities, must be established by the site licenser, TEPCO, and it is necessary to carry out the operation and works in accordance with those standards. It is important to develop equipment and devices and the safety assessment method that will contribute to the establishment and application of these standards. 2) Methods of confirmation and endorsement by a third party should be considered for development of the safety assessment method.

2. Approaches focusing on ensuring the safety

(1) Prevention of high risk event

	Additional issues to be focused on
In order to prevent risks such as recriticality, leakage of highly contaminated water, re-dispersion of radioactive materials in the actual decommissioning and contaminated water management, assess these risks appropriately in the R&D planning to minimize them.	1) At the time of establishment of R&D issues and objectives, it should be arranged so that it will not lead to an event of high risk and priorities should be given to studies on activities which will contribute to risk reduction.

(2) Risk reduction of exposure to the workers

	Additional issues to be focused on
Establish a plan for R&D so as to reduce exposure risk involved in the operation, considering the safety for the workers for actual decommissioning and contaminated water management as well as for the workers to implement R&D.	1) Prioritize the measures to reduce risks of exposures, such as decontamination of radioactive materials and dose reduction and formulate and implement a plan considering the safety of workers as much as possible when conducting on-site demonstration for equipment and devices.

3. Implementation of appropriate management (coordination and control)

	Additional issues to be focused on
Establish a close cooperation among the Japanese and international organizations, such as the decommissioning licenser and R&D implementing organizations, and act as a coordinator in the field of R&D. Determine appropriate division of roles among the decommissioning licenser and R&D implementing organizations including JAEA, and a competitive relationship may be established as necessary.	1) Effective and efficient methods and measures should be introduced to manage a number of various R&D projects integrally, and an appropriate system should be established as well. 2) For sharing and dissemination of information with the other R&D projects and technical studies on the site construction works by TEPCO, it is especially important to have a documentation system to ensure dissemination of information. (e.g. Creating "interface control documents" is recommended.)

4. Gathering knowledge and experiences from Japan and overseas experts for smooth facilitation of decommissioning work

	Additional issues to be focused on
By collecting information necessary for addressing highly technical issues and collaborating with Japanese and overseas research institutes, incorporate the latest findings and technologies from all over the world including the field other than nuclear engineering and gather knowledge and experiences from wide range of fields.	1) It is important to conduct R&D by incorporating the technologies, knowledge and experiences which are already utilized around the world and to establish collaborative relationships with related companies, research institutes and experts. Increase the opportunities to share the information to encourage these activities. 2) Especially for the development of equipment and devices, it is important to utilize the technologies with comparatively high TRL (the best available technology) and reliability by the technical investigations and the international RFI/RFP, (Request for Information/ Request for Proposal). 3) For acquisition, analysis and evaluation of the data on basic technology, insights from research institutes and universities should be taken into account.

No. 2: Other important items in the R&D for the technologies required for proper and steady decommissioning

1. Approaches to securing human resources

	Additional issues to be focused on
To secure the human resources to achieve long term decommissioning work, promote human resource development of researchers and engineers.	1) It is important to enhance the development and securing of human resource through the promotion of basic research in

			collaboration with the nuclear industry, research institutes and universities.
	2. Creation of an archive and dissemination of information obtained from decommissioning of damaged reactors and research achievements		
		From the perspectives of utilizing the information and research results in decommissioning process of facilities other than damaged reactors, in responsive measures to the similar accidents occurred in and outside of Japan, as contribution to the investigation of the accident for the enhancement of the safety at nuclear facilities and in the human resource development as well, compile and archive the information and study results obtained from the decommissioning work of damaged reactors in collaboration with the decommissioning licenser and R&D implementing organizations including JAEA, and disseminate them within Japan and overseas appropriately.	Additional issues to be focused on 1) In multiple R&D, collection of data and information on the internal condition of reactor vessels, condition of fuel debris, contamination inside the R/B, radioactive waste analysis and inventory evaluation has been started. Continue these measures effectively and establish an integrated system to compile and disseminate the information. 2) Creation of an archive of literature and bibliographic information is currently carried out mainly by JAEA, and it is important to collaborate with this activity in the future.

7. Future Actions

The first version of the Strategic Plan (2015) deals with two of the most critical challenges in making technical judgments for the decommissioning of the Fukushima Daiichi NPS, namely, 1) fuel debris retrieval and 2) waste management. It explains the issues to be addressed and the concepts on the approaches as well as the action plans including the roles of the relevant organizations in those approaches.

The future project management will be built up on the action plans for these two areas specified in this Strategic Plan by defining more specific actions to be carried out and sharing information with the relevant organizations. Furthermore, the Strategic Plan will be periodically reviewed in light of the project assessment using the PDCA cycle and based on the site conditions and the progress of the research institutes.

Abbreviations and short forms

Abbreviations/Short forms	Definitions
ALPS	Advanced Liquid Processing System, a multi-nuclide removal system
CST	Condensate storage tank
D/W	Drywell
FP	Fission products
FS	Feasibility study
HP	Holding point
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IRID	International Research Institute for Nuclear Decommissioning
JAEA	Japan Atomic Energy Agency
NDA	Nuclear Decommissioning Authority
NDF	Nuclear Damage Compensation and Decommissioning Facilitation Corporation
PCV	Primary containment vessel
R/B	Reactor building
RPV	Reactor pressure vessel
S/C	Suppression chamber
SFP	Spent fuel pool
TMI-2	Three Mile Island Nuclear Power Plant Unit 2
Contaminated water in the buildings, contaminated water in the trenches	Highly contaminated water accumulated in R/B and seawater piping trenches
Contaminated water in tanks	Contaminated water stored in tanks to be purified
Fuel debris	Molten and solidified fuels
Fukushima Daiichi NPS	Tokyo Electric Power Company's Fukushima Daiichi Nuclear Power Station
Heavy nuclides	Actinide nuclides such as uranium and plutonium
Logic tree	A chart that shows the skeleton of the strategy
Next Phase Plan	A plan for the next phase of R&D to be carried out in "Decommissioning and contaminated water management (technical development project)"
R&D duties execution policy	Policy on the execution of research and development on technologies required for decommissioning
Reliability Improvement Program	A detailed plan on the prioritized matters to be addressed over mid-and-long-term for reliability improvement
Stagnant water	Highly contaminated water accumulated in the R/B
The Roadmap	Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1-4
The Strategic Plan	Technical Strategic Plan for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company
Waste adsorption column of water treatment system	Secondary waste generated from cesium and second cesium adsorption system
Waste sludge of water treatment system	Secondary waste in the sludge storage tanks of decontamination equipment

Terms and definitions

Terms	Definitions
Actual debris	Actual fuel debris retrieved from the reactor vessels as opposed to simulated debris
Clearance	Clearance system refers to a system under which the government confirms that the concentration of radioisotopes of materials used in a nuclear facility is below the “Clearance Levels” (the level at which the impact is negligible to human health). The materials confirmed by the government are removed from the regulations on nuclear reactors, and will be subject to regulations under laws on wastes and recycle as conventional industrial wastes or valuables
Defense in depth	One of the fundamental safety principles which means that all safety activities are subject to multiple layers of overlapping provisions, so that if a failure should occur it would be detected and compensated for or corrected by appropriate measures
Fuel debris	Nuclear fuels molten and mixed with parts of reactor internals due to loss of reactor coolant and resulted in a re-solidified state
Fuel debris detection technology using muon	A technology to identify the locations and shapes of fuels using the behavior of cosmic ray muons from space and the atmosphere to change the number of particles and trajectories when penetrating a material according to its density
Full submersion method Submersion method	Methods to retrieve fuel debris by filling water to the upper part of PCV
Hazard potential	Level of impact that the harmful materials may bring about
Partial submersion method Dry method	Methods to retrieve fuel debris while it is exposed in the air and without filling PCV with water
Project risk	A risk that may jeopardize the success of the project, such as a failure in technical development or substantial increase in cost
Risk-informed decision making	Decision making using risk information
Robustness	The capability to maintain the robust function even when the condition is changed to a certain extent from what is expected
Simulated debris	Artificial objects manufactured by estimating the chemical composition and forms based on the examples of TMI-2 accident
Sludge	Semi-solid materials containing radioactive materials
Technology Readiness Level (TRL)	Index to indicate the level of technical development
Well shield plug	A concrete lid on top of PCV installed for radiation shielding (a part of the floor of the uppermost floor of the R/B during operation)