Subsidy Project of Decommissioning and Contaminated Water Management
in the FY2016 Supplementary Budgets

Advancement of Retrieval Method and System of Fuel Debris and Internal Structures

FY2018 Final Report

July 2019

International Research Institute for Nuclear Decommissioning (IRID)

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I. Research Background and Purpose

[Background]

In the project of the last fiscal year, the methods and systems for retrieving fuel debris and reactor internals (hereafter referred to as “fuel debris”) for decommissioning the Fukushima Daiichi Nuclear Power Station (1F) were studied. In the results, feasibility issues and risks were identified.

[Purpose]

To solve the identified issues, this project focuses on finding solutions for the following technological requirements, which are among the technologies necessary to upgrade the methods and systems and specifically to ensure safety: a reliable confinement function, safe collection and removal of dust, and accurate monitoring of α-nuclides (a collective name of radioactive nuclides that emit α-rays). Element tests will be conducted as necessary. By reflecting the results of these development activities and the outcomes of other related projects, optimization of the methods and systems (e.g., re-evaluating the results of activities and evaluation on given subjects in the previous project, comparatively evaluating the methods and systems, and developing an overall scenario related to fuel debris retrieval) is performed in terms of radiation exposure and maintenance, among other things, to ensure the safety of the methods and systems.

I. Research Background and Purpose (Relationship with the Project in the Last Fiscal Year)

The relationship between this project and the one in the last fiscal year is shown below.
There are four components in this project ((1)–(4) below), and they can be classified into two categories (1) and 2) below).

[Project in the last fiscal year]

Issues identified through activities

Studied methods and systems

[This project]

1) Essential technology development concerning feasibility of the system to reduce emission into the environment
(Essential technology development is detailed below)

(1) Technology development for confinement functions
(2) Technology development for collection/removal of dust derived from fuel debris
(3) Study on α-nuclide monitoring system associated with Fuel debris retrieval

Other projects*

Reflection of development results

2) Comprehensive study of fuel debris retrieval methods and systems

(4) Optimization study on ensuring safety of methods and systems*

Optimization

*** Issues related to the methods (for which a measure development plan was drawn up in last year's project) will be addressed by linking with the Fundamental Technology PJ.**

II. Project Goals

The objective of the project is to complete the conceptual study of fuel debris retrieval methods and systems. The key subject is how to ensure their safety, and technologies to meet the following requirements must be developed for this purpose: a reliable confinement function, safe collection and removal of dust, and accurate α-nuclides (a collective name of radioactive nuclides that emit α ray) monitoring. In addition, these technologies will be subjected to comparative evaluation in terms of exposure level and maintainability in order to optimize the methods and systems and achieve safe fuel debris retrieval.

Specific goals for each of the Implementation details to achieve the project objectives are listed in the following pages.

[Implementation details and their main contents (based on the subsidy application form)**]**

(1) Technology development for confinement functions

(i) Technology development for ensuring a reliable confinement function

(ii) Technology development concerning dose reduction*

(2) Technology development for collection/removal of dust derived from fuel debris

(i) Technology development to reduce and remove gas-phase radioactive materials

(ii) Technology development to reduce and remove liquid-phase radioactive materials

(3) Study on α-nuclide monitoring system associated with fuel debris retrieval

(i) Conceptual study of gas-phase α-nuclide detection technology and system and development planning

(ii) Conceptual study of liquid-phase α-nuclide detection technology and system and development planning

→ (4) Optimization study on ensuring safety of methods and systems

* The dose reduction level needs to be closely monitored as an index of optimization of methods and systems. Thus, Item (1)-(ii) "Technology development concerning dose reduction" is integrated with Item (4) for review. [The item is not independently listed in IV. Implementation Details of this document.]

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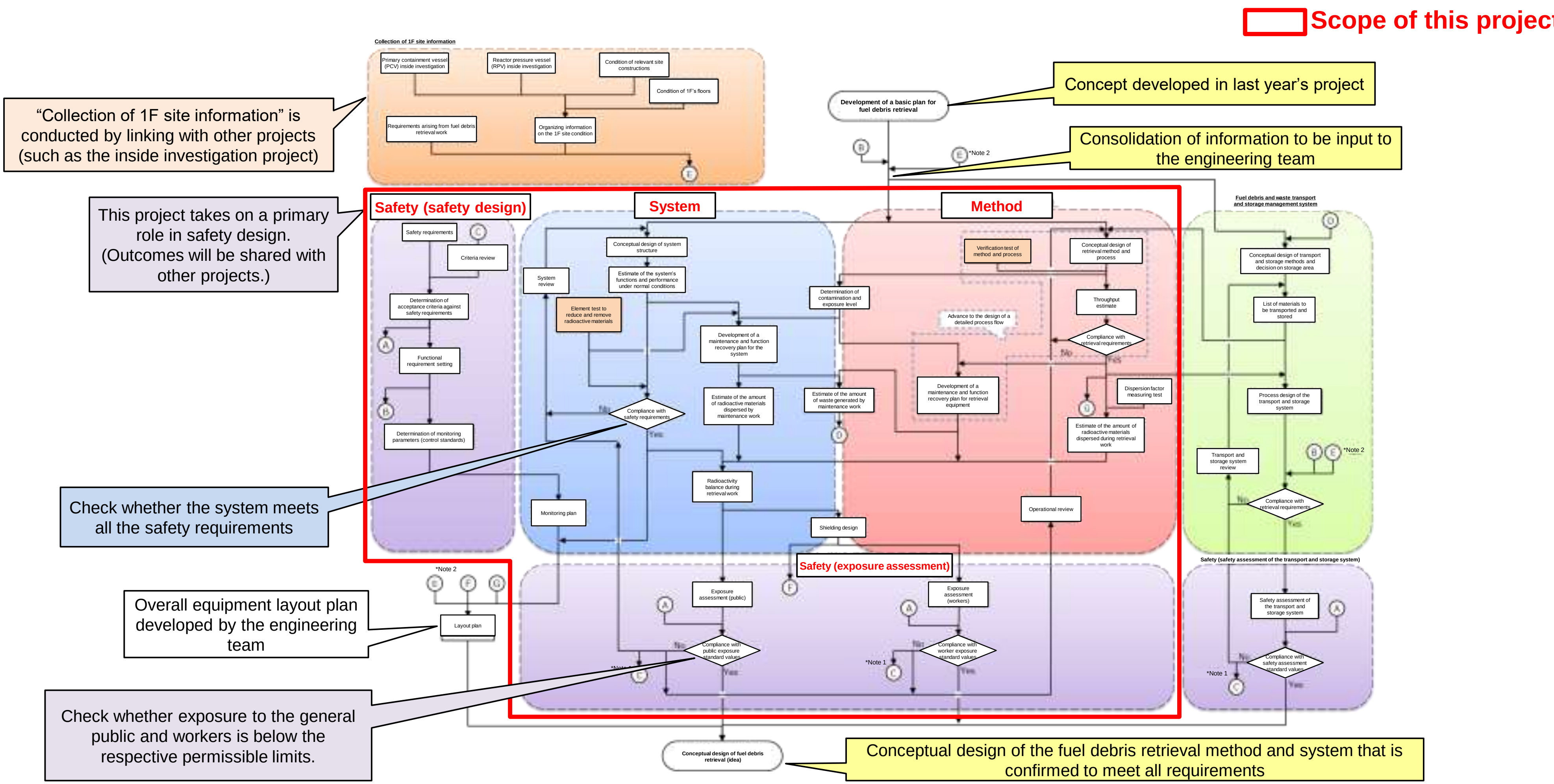
II. Project Goals (Overall Positioning)

- **The following diagram illustrates the scope of this project in the entire fuel debris retrieval project. This project undertakes the process to ensure the feasibility of the methods and systems through a conceptual study.**

  (A drilled-down study [detailed design] is required for each process before applying the methods and systems.)



Figure—General flow diagram of the fuel debris retrieval method and system development (in-depth protection Level 1) [simplified version]

II. Project Goals (Essential Technology Development: Implementation Details (1)–(3))

Essential technology development concerning the system is planned to be developed based on existing technologies, and knowledge necessary to assess their applicability to fuel debris retrieval will be gathered through experiments and other means in this project.

TRL1 Basic study → TRL2 Application study → TRL3 Application study → TRL4 Practical application study → TRL5 Simulated validation → TRL6 Field test → TRL7 Practical use

Existing technologies (TRL1–TRL2)

This project (TRL2–TRL3)

- **Collection of information necessary to assess the applicability of existing technologies, and their upgraded versions, to fuel debris retrieval**

Nuclear operator engineering (or by subsidized projects) (TRL4–TRL7)

- **Verification of the technologies is conducted in a step-by-step approach from an inside investigation of the actual reactor, sampling, and trial retrieval in a small scale, which is required due to insufficient information about the actual condition, toward the practical application. (The way to proceed will be discussed in preliminary engineering.)**
- **The development of basic technologies is left to projects in the next year or later.**

Item	Objectives of this project	Things to be done after this project (tentative plan)
1) Development of confinement technology	• Evaluation of the effect of differential pressure control • Development of an airflow analysis method	• Evaluation of effectiveness in a step-by-step approach
2) Development of collection and removal technology	• Selection of equipment, collection of information to estimate the amount of materials • Up to the primary screening in americium for the removal of soluble nuclides	• Determination of detailed specifications in a step-by-step approach, mock-up tests • <u>There are some issues for which additional research is required for practical application in the next year or later (identified issues as of now).</u>
3) Development of α-nuclide monitoring technology	• Conceptual study of the monitoring system • Assessment of the applicability of existing detection technologies	• Detailed designing in a step-by-step approach

II. Project Goals (Essential Technology Development: Implementation Details (1)–(3))

(1) Technology development for confinement functions	
(i) Technology development for ensuring a reliable confinement function	Differential pressure control targets must be set for the reactor building and the inside of primary containment vessel (PCV). The effectiveness of the differential pressure control system to achieve a reliable confinement function and of the PCV safety function to prevent local hydrogen gas accumulation and subsequent fire/explosion in it must be confirmed. Measures to improve the sealability of the reactor building and the PCV must be studied, and the sealability must be securely established. (Technology readiness level (TRL) target at the end of the project: Level 3)
(ii) Technology development concerning dose reduction	Scenarios related to the dose reduction of workers and the public during fuel debris retrieval work and on the occurrence of an accident must be established, and dose reduction levels must be estimated for each scenario. (TRL target at the end of the project: Level 3)
(2) Technology development for collection/removal of dust derived from fuel debris	
(i) Technology development to reduce and remove gas-phase radioactive materials	Regarding liquid-phase contaminant cleaning, an effective dust collection/removal method must be studied taking into account safety and the reduction of waste. (TRL target at the end of the project: Level 3)
(ii) Technology development to reduce and remove liquid-phase radioactive materials	Regarding liquid-phase contaminant cleaning, an effective soluble and insoluble radioactive material (α-nuclides) collection/removal system must be studied taking into account safety and the reduction of waste. (TRL target at the end of the project: Level 3)

(3) Study on systems for monitoring α-nuclides associated with fuel debris retrieval	
(i) Conceptual study of gas-phase α-nuclide detection technology and system and development planning	Regarding gas-phase α-nuclide monitoring, the use of existing technologies must be considered. Issues in developing an gas-phase α-nuclide monitoring system that fits the fuel debris retrieval work must be identified along with a plan to develop measures to solve these issues. (TRL target at the end of the project: Level 3)
(ii) Conceptual study of liquid-phase α-nuclide detection technology and system and development planning	Regarding liquid-phase α-nuclide monitoring, the use of existing technologies must be considered. Issues in developing a liquid-phase α-nuclide monitoring system that fits the fuel debris retrieval work must be identified along with a plan to develop measures to solve these issues. (TRL target at the end of the project: Level 3)

II. Project Objectives (Method/System Study: Implementation Details (4))

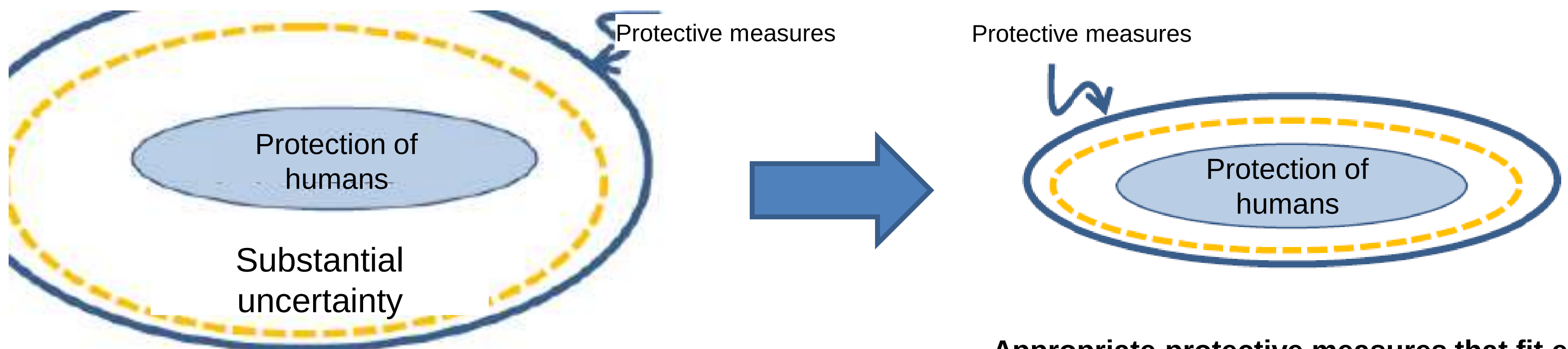
Regarding system development, a conceptual study was conducted with the aim of verifying the feasibility of the system based on currently available information (testing the system with respect to all judgment criteria in the development flow diagram on page 7 and verifying that all are met).

TRL1 Basic study → TRL2 Application study → TRL3 Application study → TRL4 Practical application study → TRL5 Simulated validation → TRL6 Field test → TRL7 Practical use

Subsidized projects in the past	This project	Nuclear operator engineering
• Study of the basic concept of methods and systems	• **Conceptual study to verify feasibility. (based on the most conservative condition estimated from currently available information about the reactor condition)**	• **Optimization of equipment** based on a step-by-step approach taken on the actual reactor, including inside investigation, sampling, and trial retrieval on a small scale • **Elaboration of the project plan** that harmonizes with the progress of preparatory constructions in 1F toward fuel retrieval (architectural design of new buildings, removal of interfering objects, etc.)

Conceptual image of project objectives

System image of the nuclear operator



Large-scale protective measures to ensure safety by overcoming any uncertainty

Appropriate protective measures that fit each step and reduce uncertainty

II. Project Objectives (Method/System Study: Implementation Details (4))

(4) Optimization study on ensuring safety of methods and systems
High-level optimization shall be achieved on methods and systems to ensure their safety, taking into account outcomes from activities in this project and other projects. (TRL target at the end of the project: Level 4)

<Supplemental information> Definitions of Technology Readiness Levels (TRL)

Level	Definition in terms of this project	Phase
7	Practical application is complete.	Practical use
6	Developed methods and systems are tested in the actual environment.	Field trial
5	Real-scale prototypes are built, and validation tests are performed in a plant or lab using them under conditions that simulate the actual environment.	Simulated validation
4	Functional tests are performed using testing mock-ups as part of the development and engineering processes.	Practical application study
3	Development and engineering work is performed within the range of conventional experiences or their combination, or development and engineering work in new areas virtually without past experience.	Application study
2	Development and engineering work is performed, and the required specifications are developed in areas where there is almost no applicable past experience.	Application study
1	Basic requirements and necessary technologies are identified for the methods and systems to be developed and engineered.	Fundamental study

III. Implementation Items and Related Items (Relationship between Items)

It is necessary to have the system equipped with a function to confine radioactive materials (emission suppression function) to establish the means of protection against radiation. In this project, element technologies are developed in relation to important items as input conditions for system development (Implementation items (1)–(3)), and the results will be reflected in the optimization of methods and systems (Implementation item (4)).

Input conditions (particularly items related to feasibility) *Some of the input conditions are set by linking with other projects.

[Terminology] DF: decontamination factor

Safety requirements 1F reactor condition
- Setting of safety objectives
- In-depth protection requirements
- State of fuel debris
- Damage of PCV/building

Functional requirements

Implementation details (1)
- Differential pressure needed to ensure reliable confinement
- Ventilation rate needed to reduce hydrogen gas concentration
- Requirement on the range of detectable activity concentration based on exposure assessment
- Required DF based on exposure assessment

Detailed information
- Performance of collection and retrieval technology (Implementation details (2))
- Performance of detection technology (Implementation details (3))
- Properties of radioactive particles (amount, size, transfer rate into air and water, specific gravity, and chemical form)
- Properties of materials other than radioactive particles (impurities such as oil)
- Environmental conditions

Development process flow (Facility specification)

Concept of confinement → System specifications → Equipment specifications → Feasibility study

Implementation details (3)

Output (Example)

Concept of confinement:
- Method to form boundaries
  Gas-phase: differential pressure control
  Liquid-phase: water level control
- System configuration (outline)

System specifications:
- Target differential pressure
- Target DF
- Target ventilation rate
- Target detected (controlled) activity concentration

Equipment specifications:
- DF
- Type
- Pretreatment method

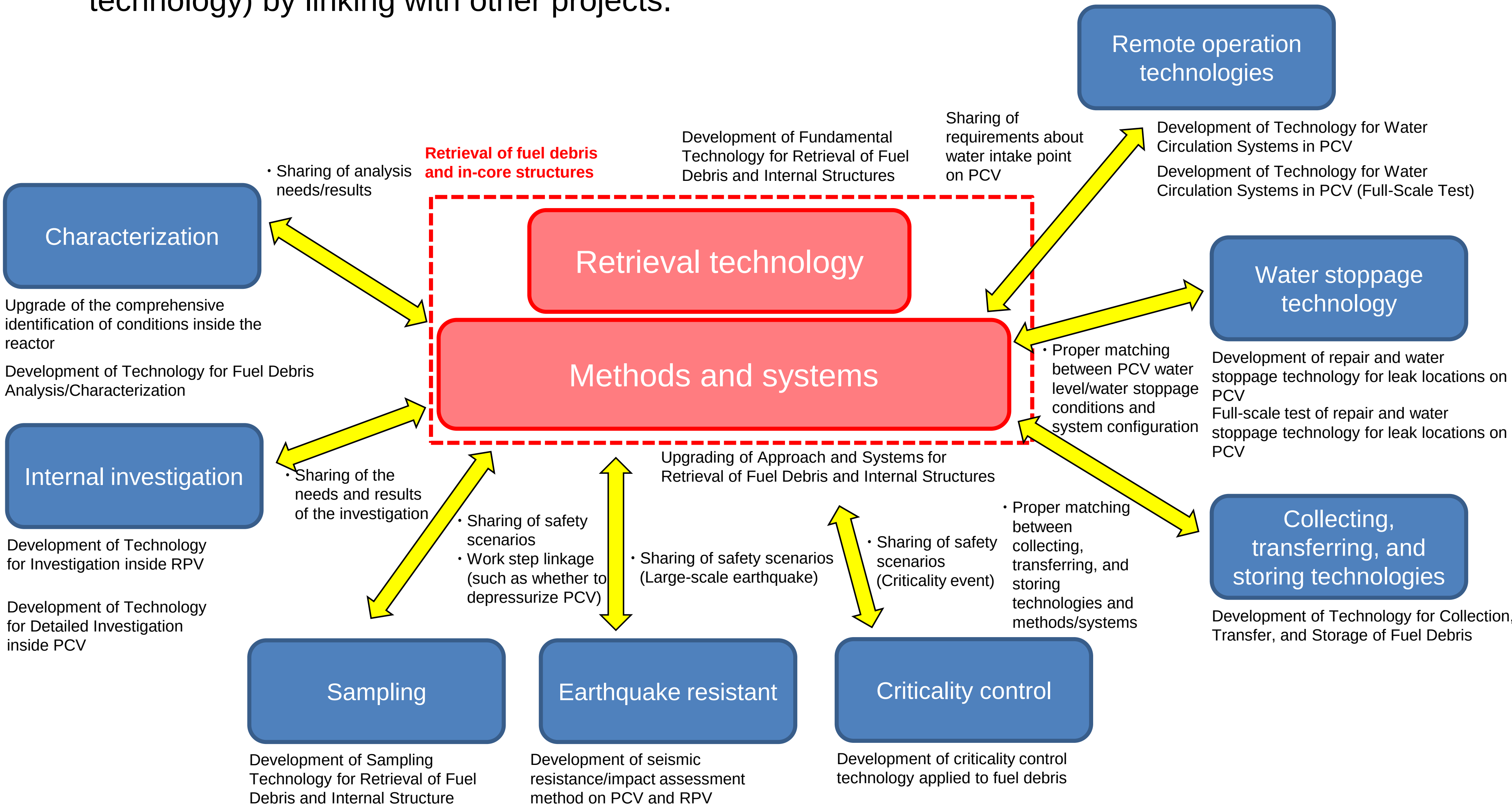
Feasibility study:
- System specification
- System diagram
- Layout drawing
- ...

Implementation details (4)

This process flow is followed in the Implementation details (4) "Optimization Study on Ensuring Safety of Methods and Systems"

III. Implementation Items and Related Items (Relationship to Other Studies)

- The project shares the conditions of development (such as safety concepts and essential technology) by linking with other projects.



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III. Implementation Items and Related Items (Relationship to Other Studies)

- The table below shows the results of cooperative activities with other projects.

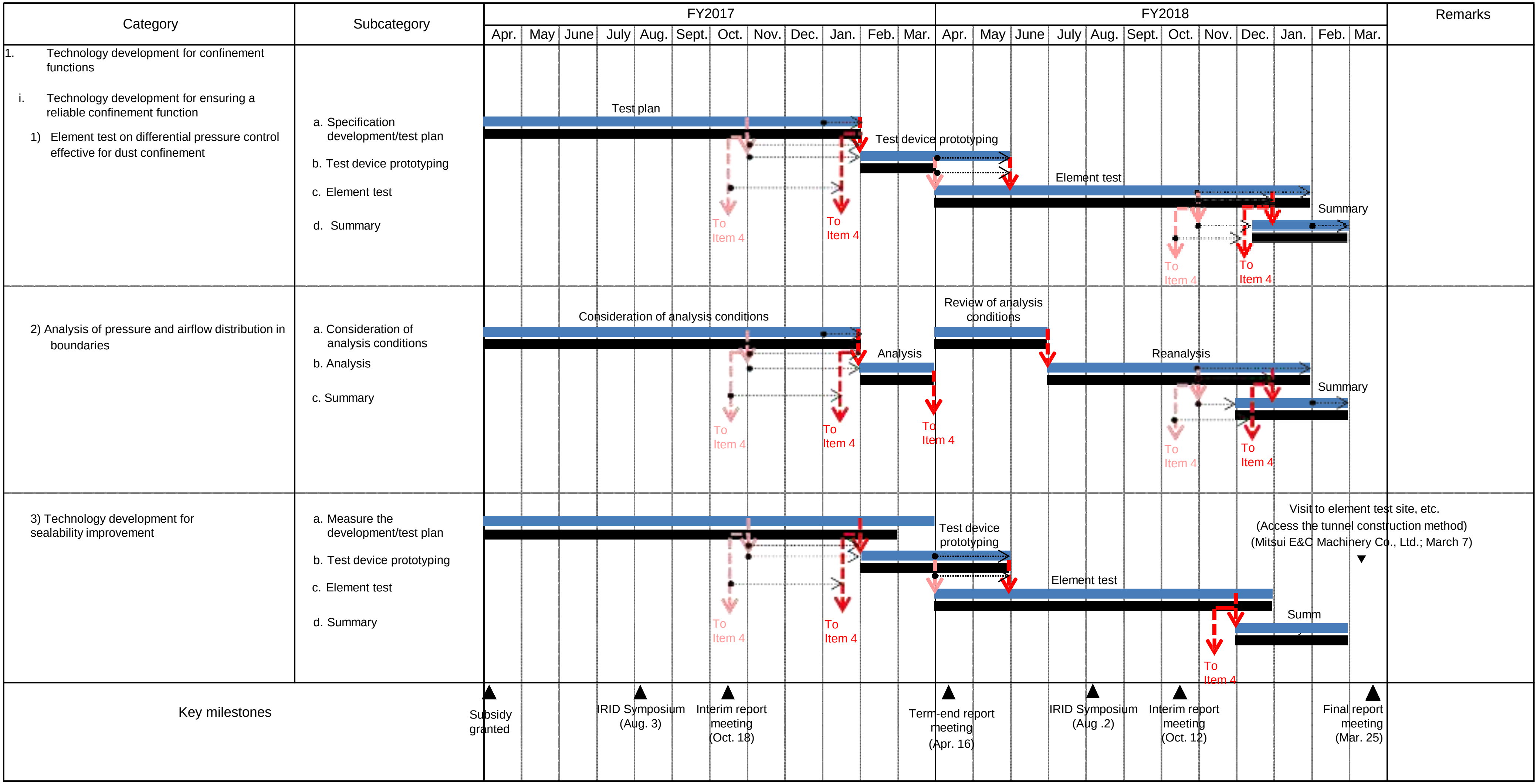
No.	Contact	Key linkages	Linking method*	Main input to and output from this project
1	Fundamental Technology PJ	• Reflect technologies (in the general field) developed by the Fundamental Technology PJ in the method development of this project • Reflect technologies (mainly for processing and local collection equipment) developed by the Fundamental Technology PJ in the system development of this project	Hold regular joint project meetings (once a month)	Input: Amount and size of particles generated by processing fuel debris Output: Requirements for data collection during processing technology development, etc.
2	Sampling PJ	• Submit requests to Sampling PJ for information necessary in the development of methods and systems		Input: Sampling plan (PCV pressure, etc.) Output: Needs of sampling
3	Criticality Control Project	• Study safety concepts, etc., in cooperation • Share and adjust specifications in consideration of the interface between equipment and system	Participate in the meeting mentioned in No. 1 and No. 2 as appropriate	Input: Safety policy with respect to criticality control, neutron detector specifications, and system specifications Output: Conditions to design gas monitoring (discharge flow rate, etc.)
5	Internal Investigation Project	• Submit requests to the Internal Investigation Project for information necessary in developing methods and systems • Reflect the results of internal investigation in method and system development	Hold inter-project meetings as necessary	Input: Results of internal investigation (fuel debris location, etc.) Output: Needs of internal investigation
6	Fuel Debris Characterization Project Reactor Inside Condition Investigation Project	• Ask these projects to conduct research on literature and papers about the behavior of α-nuclides during fuel debris processing (details and timing are under discussion), and reflect such information in method and system development.		Input: Composition of fuel debris, transfer rate from water to gas, etc. Output: Temperature condition for retrieval, etc.
7	Collecting, Transferring, and Storing Technologies Project	• Reflect the size of a storage canister, restrictions on hydrogen gas-suppression measures, etc., in method development		Input: Storage canister specifications, etc. Output: Retrieval amount, etc.
8	Water Circulation Project	• Share safety requirements about the water intake point on PCV and other information, and reflect them in the development conditions for remote operation technologies		Input: Design of water intake point, etc. Output: Required flow rate, etc.
9	PCV Repair Project	• Share safety requirements about debris retrieval and other information, and address appropriate matching between the PCV repair (water stoppage) plan and methods and systems		Input: Achievable PCV water level during retrieval work and PCV repair methods Output: PCV pressure (differential pressure) and discharge flow rate
10	Seismic Resistance Project	• Share information about system configuration in fuel debris retrieval and the impact of an earthquake on it, and develop safety scenarios based on it		Input: Seismic resistance evaluation result and probable case of damage on large equipment Output: System configurations in fuel debris retrieval

* As to general progress and matters related to Input/Output, the results of IRID's internal discussion are shared. **Conditions and other information exchanged as Input/Output are listed along with the reasons and sources and shared.**

IV. Project Process Schedule (Progress schedule—1/3)

[Legend]
Plan
Could be accelerated
Pushed back
Actual result
Lines to indicate links

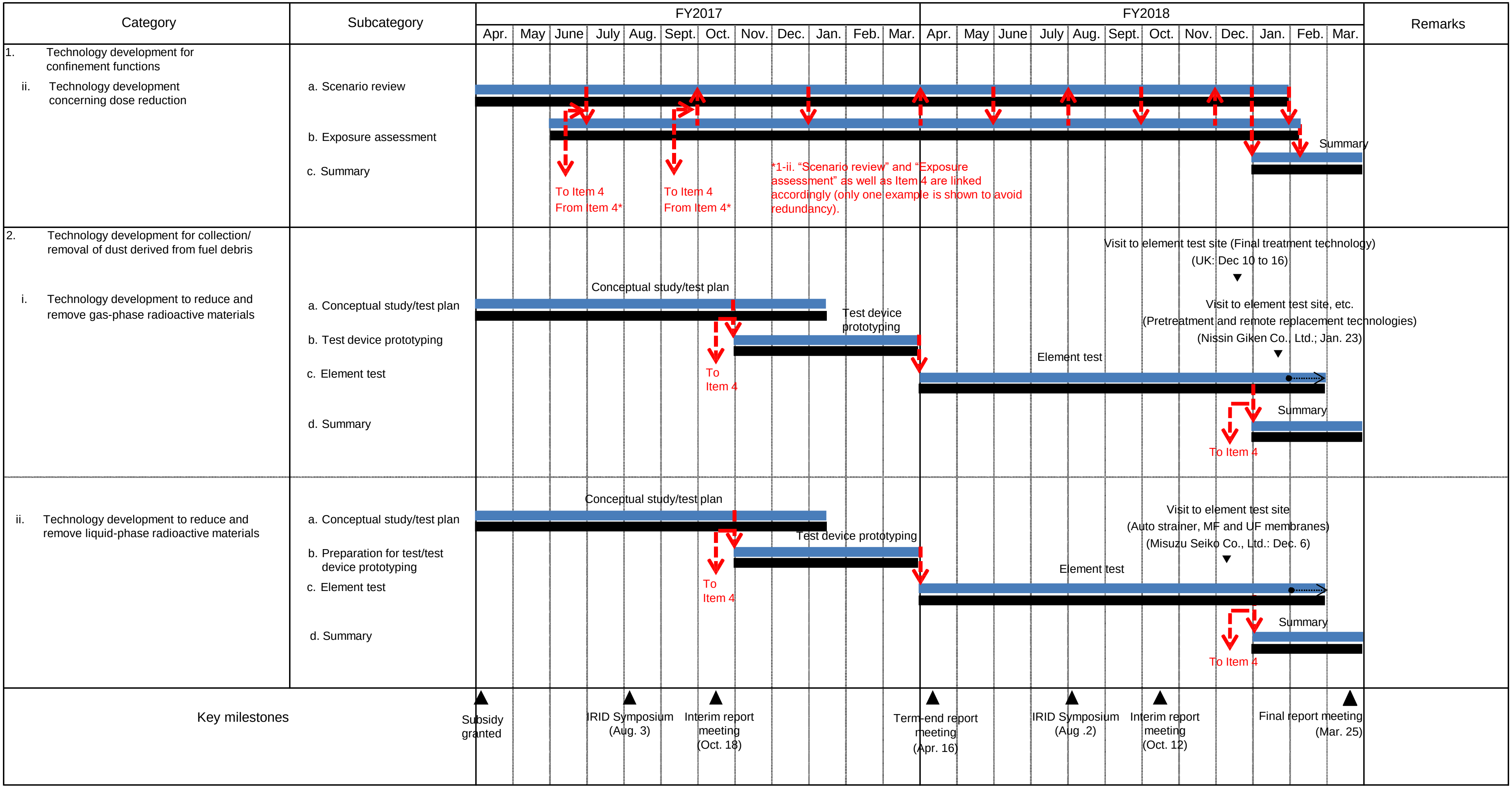
Upgrading of methods and systems for retrieval of fuel debris and internal structures—Process Chart (Actual Result) 1/3 (as of March 2019)



IV. Project Process Schedule (Progress schedule 2/3)

[Legend]
Plan
Could be accelerated
Pushed back
Actual result
Lines to indicate links

Upgrading of methods and systems for retrieval of fuel debris and internal structures—Process Chart (Actual Result) 2/3 (as of March 2019)



IV. Project Process Schedule (Progress schedule-3/3)

[Legend]
- Plan
  - Could be accelerated
  - Pushed back
- Actual result
- Lines to indicate links

Upgrading of methods and systems for retrieval of fuel debris and internal structures—Process Chart (Actual Result) 3/3 (as of March 2019)

Category	Subcategory	FY2017 (Apr.–Mar.) / FY2018 (Apr.–Mar.)	Remarks
3. Study on α-nuclide monitoring system associated with fuel debris retrieval i. Conceptual study of gas-phase α-nuclide detection technology and system and development planning	a. Conceptual study b. Development plan formulation c. Summary	Conceptual study; Summary; To Item 4; To Item 4; To Item 4 "b. Development plan formulation" should have been implemented on an as-needed basis originally, but was removed from the planned process because an existing technology was found to be applicable.	"b. Development plan formulation" should have been implemented on an as-needed basis originally, but was removed from the planned process because an existing technology was found to be applicable.
ii. Conceptual study of liquid-phase α-nuclide detection technology and system and development planning	a. Conceptual study b. Development plan formulation c. Summary	Conceptual study; Summary; To Item 4; To Item 4; To Item 4 "b. Development plan formulation" should have been implemented on an as-needed basis originally, but was removed from the planned process because an existing technology was found to be applicable.	"b. Development plan formulation" should have been implemented on an as-needed basis originally, but was removed from the planned process because an existing technology was found to be applicable.
4. Optimization study on ensuring safety of methods and systems	a. Optimization of methods b. Optimization of systems c. Summary	From Item 2; From Item 1; From Item 3; From Item 1; From Item 1-2); Optimization of methods; From Item 3; From Item 1-1), 2); From 3) of Item 1; From Item 1-1), 2) and Item 2; Optimization of systems; Summary; From Item 1-ii To Item 1-ii*; From Item 1-ii To Item 1-ii* *1-ii. "Scenario review" and "Exposure assessment" as well as Item 4 are linked accordingly (only one example is shown to avoid redundancy).	
Key milestones		Subsidy granted (Apr.); IRID Symposium (Aug. 3); Interim report meeting (Oct. 18); Term-end report meeting (Apr. 16); IRID Symposium (Aug .2); Interim report meeting (Oct. 12); Final report meeting (Mar. 25)	

V. Project Organization

International Research Institute for Nuclear Decommissioning

International Research Institute for Nuclear Decommissioning (Headquarters)

- Coordination of general planning and overall technology management
- Coordination of technology administration including technology development progress management

Tokyo Electric Power Company Holdings, Inc.

Hitachi-GE Nuclear Energy, Ltd.

- Engineering support for retrieval method evaluation and element test (Hitachi Power Solutions Co., Ltd.)
- Dust confinement test (Hitachi Plant Technologies, Ltd.)
- Technology development to improve sealability (Mitsui E&S Shipbuilding Co., Ltd., Chugai Technos Corporation, Shimizu Corporation)
- Backwash HEPA test (Cavendish Nuclear Ltd., UK)
- Performance test of method to remove particles from solution (Misuzu Seiko Co., Ltd.)
- Pedestal reinforcement method (Shimizu Corporation)

Toshiba Energy Systems & Solutions Corporation

- Measurement of change in nitrogen gas feed rate and the differential pressure of PCV (Shin Nippon Air Technologies Co., Ltd.)
- Analysis of pressure and airflow distribution in boundaries (Toshiba Plant Systems & Services Corporation)
- Development of the reactor building sealability improvement method and element test (Kajima Corporation)
- Engineering support for exposure assessment (Toshiba Technical Services International Corporation)
- Element test related to the backwashable dry dust collector (Shin Nippon Air Technologies Co., Ltd.)
- Downsizing of the wet electric dust collector (IHI Corporation)
- Development of a method to replace the HEPA filter remotely (Shin Nippon Air Technologies Co., Ltd.)
- Element test for sludge collection technology (Kurita Water Industries Ltd.)
- Test to evaluate the impact of boron on the existing facility (Kurita Water Industries Ltd., Ebara Corporation)
- Analysis related to the soluble nuclide removal test (Toshiba Nanoanalysis Corporation)
- Engineering support for method and system optimization (Toshiba Development & Engineering Corporation)
- Engineering support for method and system optimization (Toshiba Development & Engineering Corporation)
- Engineering support related to safety requirements and safety design (MPR Associates, Inc., USA)

Mitsubishi Heavy Industries, Ltd.

- Engineering support for confinement function development (MHI NS Engineering Co., Ltd.)
- Engineering support for dust collection/removal method development (MHI Solution Technologies Co., Ltd., Chugai Technos Corporation, Nuclear Development Corporation)
- Engineering support for element tests related to the dust collection/removal method (MHI Solution Technologies Co., Ltd.)
- Engineering support for element tests related to the dust collection/removal method
  Removal of liquid-phase particles: liquid cyclone separator/bagfilter test (Fuji Filter Manufacturing Co., Ltd.); MU membrane test (Nihon Pall, Ltd., Applied Technologies Research Center); particle measurement (Hosokawa Micron Corporation)
  Removal of gas-phase particles: washing tower (OKAMURA Co., Ltd., Miura Chemical Equipment Co., Ltd.)
  Soluble nuclide removal test (Nuclear Development Corporation)
- Engineering support for method and system optimization for ensuring safety (MHI NS Engineering Co., Ltd.)

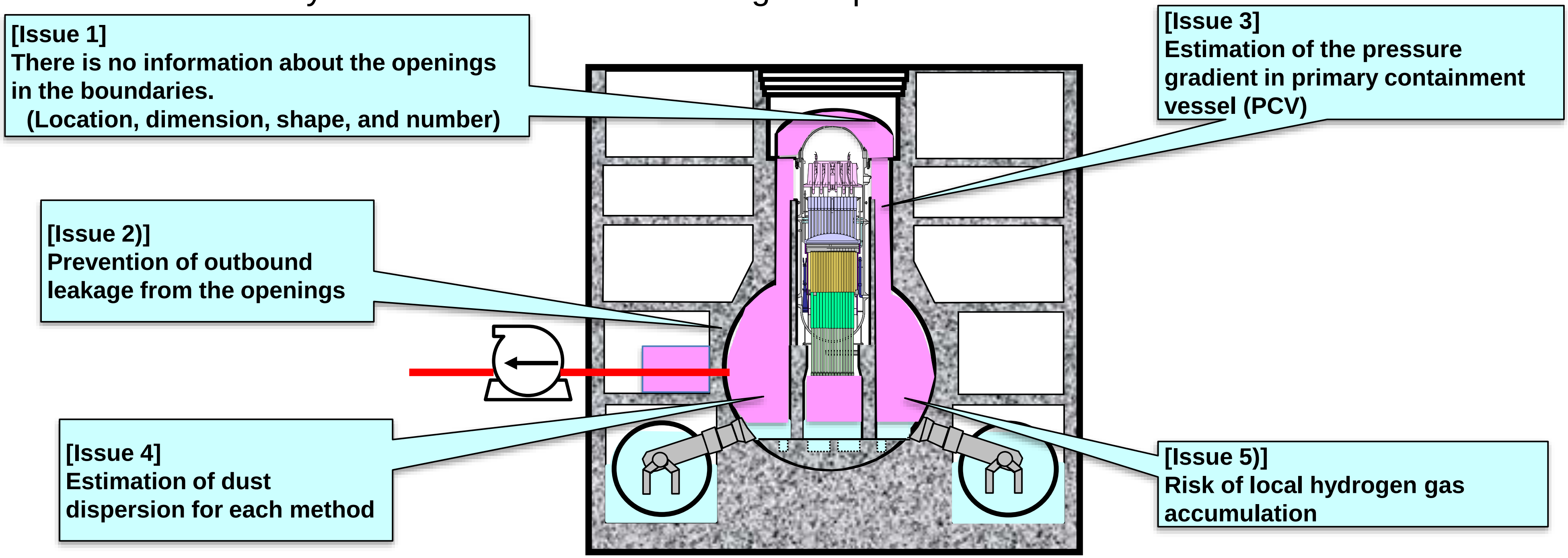
(i) Technology development for ensuring a reliable confinement function

(a) Element test on differential pressure control effective for dust confinement and analysis of pressure and airflow distribution in boundaries

1. Identifying Issues

Challenge to be solved by technology development

- It is a strategy to confine dust generated by fuel debris retrieval by building boundaries at proper locations with proper sizes and controlling their negative pressure by providing proper discharge according to the openings in them.
- The following issues (common to Units 1–3) need to be solved to achieve reliable confinement by the boundaries and their negative pressure control.



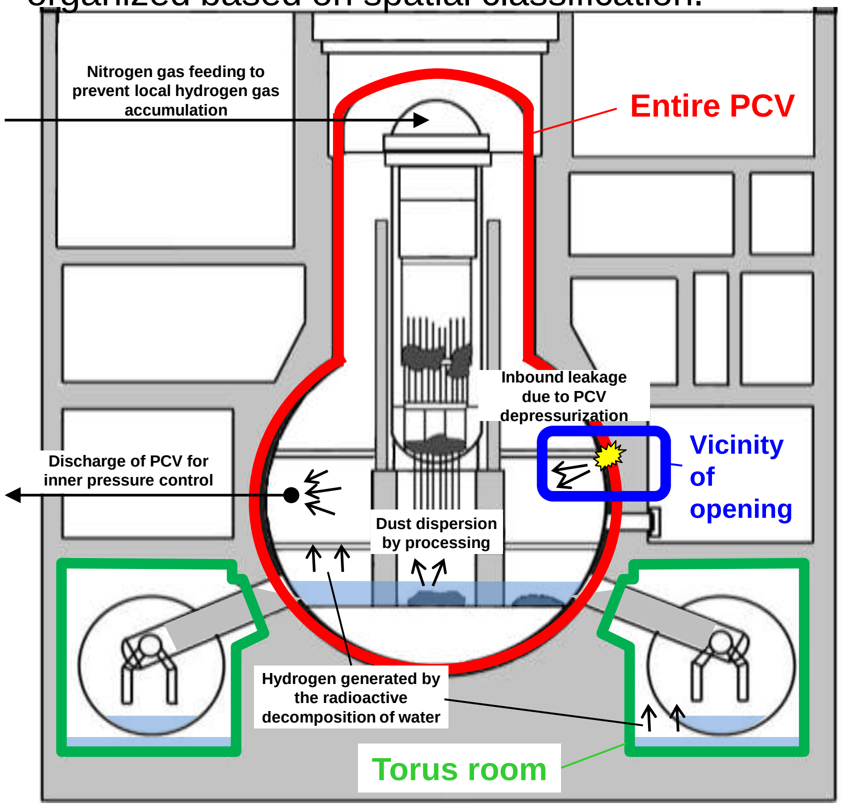
(i) Technology development for ensuring a reliable confinement function

(a) Element test on differential pressure control effective for dust confinement and analysis of pressure and airflow distribution in boundaries

2. Project Overview and Positioning

<Spatial classification of technology development items>

- The conditions illustrated below are expected in fuel debris retrieval operation.
- Approaches in this project are listed on the right as organized based on spatial classification.



Figure—Expected phenomena in fuel debris retrieval operation and the positional grouping of investigations to address the phenomena

Primary containment vessel (PCV) as a whole (analysis + actual machine test by TEPCO HD Engineering)

Issues	Approach classification	Remarks
1) No information about the openings in the boundaries	Actual machine test [TEPCO HD Engineering]	The role of this project is to suggest a test method to estimate information on the openings. (by TEPCO HD)
3) Estimation of the pressure gradient in PCV	Analysis	See the attached document for how to use analysis codes (lumped-parameter model and distributed-parameter model) selectively.
4) Estimation of dust dispersion for each method		
5) Risk of local hydrogen gas accumulation		

Vicinity of opening (analysis and element test)

Issues	Approach classification	Remarks
2) Prevention of outbound leakage from openings	Analysis + element test	The accuracy of the simulation code is examined by comparing the analysis result of local simulation with the result of the element test.

Torus room (analysis)

Issues	Approach classification	Remarks
5) Risk of local hydrogen gas accumulation	Analysis	

(i) Technology development for ensuring a reliable confinement function

(a) Element test on differential pressure control effective for dust confinement and analysis of pressure and airflow distribution in boundaries

3. Strategies for Resolving Issues

- Strategies to address the issues described on the previous page (i.e., strategies on obtaining the necessary information to reach the expected design objective) are studied.
- Detailed actions of the strategies are classified into analysis, element test, and investigation of 1F PCVs, and listed in a table.
- The objective is to establish technologies that enable obtaining the necessary information by analysis, element test, or investigation of 1F PCVs.

Issues	Information necessary for design	Analysis	Element test	Investigation of 1F PCVs	Remarks
1) Information about the openings in the boundaries	Information on openings that determines the discharge flow rate necessary to maintain negative pressure	(Information on actual openings in 1F PCVs cannot be obtained by analysis.)	(Information on actual openings in 1F PCVs cannot be obtained by element tests.)	**Test to estimate information on openings**	
2) Prevention of outbound leakage from openings	**Negative pressure to ensure inbound leakage even for locally existing openings**	**(The accuracy of the simulation code is examined by comparing the analysis result of local simulation with the test results.)**	**The targeted negative pressure is validated by element tests using test equipment that simulates local structure.**	**<<Operation with the determined differential pressure>>**	Implemented for verification of the feasibility of the dynamic boundary that needs to function in place of damaged boundaries
3) Estimation of the pressure gradient in PCV	**Confirmation of no local pressure variation to establish reasoning for negative pressure control**	**Evaluate the pressure distribution in PCV and ensure that the necessary negative pressure is achieved in the whole part of PCV.**	(Checked using proven analysis code)	**<<Pressure monitoring at representative points>>**	
4) Estimation of dust dispersion for each method	**Information to estimate the location and size of dust floating in the air**	**Evaluate dust distribution in PCV by dust behavior analysis.**	Information collection about dust amount generated by each method (Fundamental Technology PJ)	**<<Dust concentration monitoring>>**	Confirmation of difference in dust dispersion between local retrieval operation and systematic retrieval operation
5) Risk of local hydrogen gas accumulation	**Location of local hydrogen gas accumulation, nitrogen gas feed rate, and feed point for effective hydrogen purge**	**Estimate the probable locations of hydrogen gas accumulation and consider nitrogen gas feed rate and feed point.**	(Checked using proven analysis code)	**<<Monitoring of hydrogen concentration in discharged air; measurement of local hydrogen concentration is difficult>>**	

Items in << >> are proposed actions in fuel debris retrieval operation

(i) Technology development for ensuring a reliable confinement function

(a) Element test on differential pressure control effective for dust confinement and analysis of pressure and airflow distribution in boundaries

4. Project Outputs and Feedback of System Design

Implementation details

Airflow distribution analysis (airflow behavior in the whole PCV)

- Selection of code and creation of analysis models applicable to the analysis of the air convection condition in PCV during fuel debris retrieval operation
- Sensitivity analysis using conditions of the simulated opening in PCV and others as parameters; rough estimate of the convection field (Pressure and velocity distribution in PCV, oxygen concentration distribution, and aerosol behavior)

Element test (vicinity of opening)

- Production of test equipment that roughly simulates the shape of openings estimated to be present in 1F PCVs
- Estimation of a local flow field near the opening using negative pressure level and conditions of the simulated opening and others as parameters (Pressure drop at the simulated opening, visualization of the internal condition of equipment)

Output

- Establishment of an analysis method capable of evaluating the air convection condition in the whole part of PCV during fuel debris retrieval operation

- Estimation of the least negative pressure to ensure inbound leakage at the simulated opening; pressure drop at the simulated opening

Feedback of system design (after completion of this project)

- Study of the inner gas discharge system configuration and specifications of equipment applicable to large-scale fuel debris retrieval operation
- Application to prediction of the flow condition after determination of the inner gas discharge system for large-scale fuel debris retrieval operation

(i) Technology development for ensuring a reliable confinement function

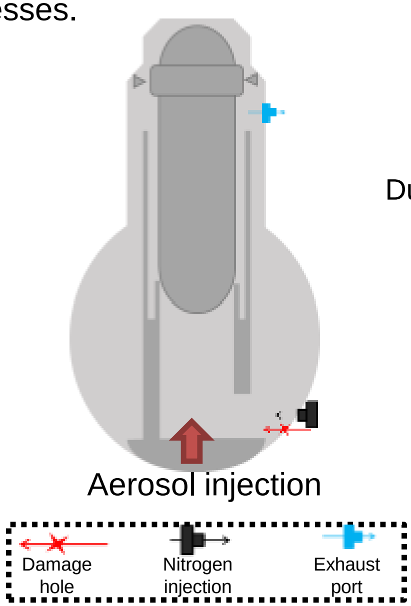
(a) Element test on differential pressure control effective for dust confinement and analysis of pressure and airflow distribution in boundaries

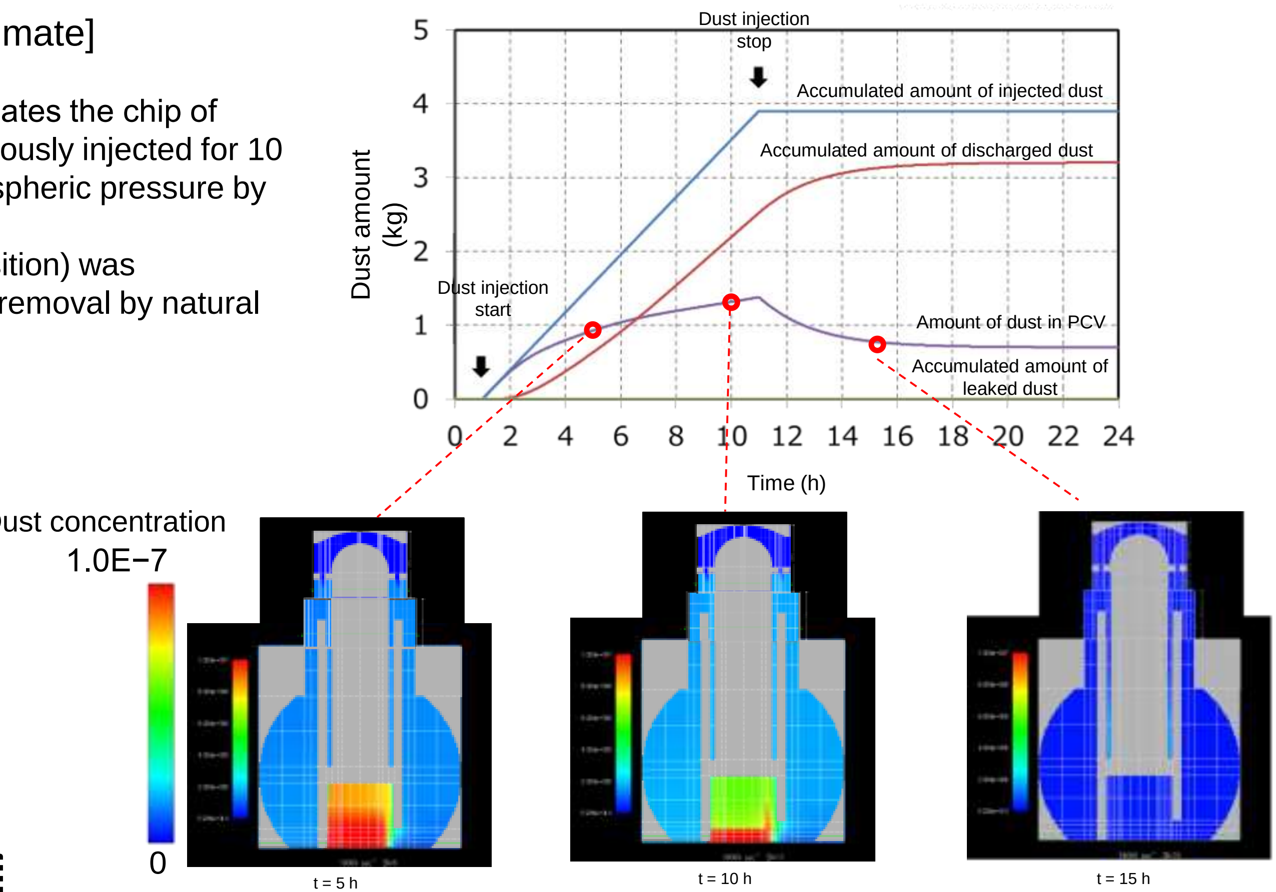
5. Implementation Details

- Analysis and element tests were performed in combination with the aim of developing technologies to solve the issues.
- Analysis methods applicable to the prediction of airflow distribution and dust dispersion and estimation of local hydrogen gas accumulation were almost established, and differential pressure to ensure the confinement of radioactive dust was obtained by the element tests.

[Example of dust dispersion estimate]

- Dust (diameter of 1 μm) that simulates the chip of processed fuel debris was continuously injected for 10 h under the condition below atmospheric pressure by 0.1 kPa.
- Only gravity sedimentation (deposition) was considered as a model of aerosol removal by natural processes.





Dust concentration distribution in the structure that simulates the Unit 3 reactor

At a 4 h lapse after the stop of cutting

6. Final Outcome of Technology Development for Ensuring a Reliable Confinement Function

The following four issues* were identified as technology development objectives in relation to airflow behavior in primary containment vessel (PCV) under negative pressure, in order to verify the function to confine dust generated by fuel debris retrieval operation.
Analysis methods to solve the issues were selected, and their applicability was assessed through the two-year-long subsidized project.

- Issue 2): Prevention of outbound leakage from openings
  Element test: The flow condition near openings and in PCV and the pressure drop at the simulated opening were understood using the simulated opening in PCV and negative pressure level as parameters. The least negative pressure of 50 Pa, at which no occurrence of outbound leakage was confirmed by flow visualization (PIV measurement), was determined as the limit of negative pressure level.
  Analysis: A model to simulate the actual 1F PCV in detail was created using Generation of Thermal-Hydraulic Information for Containments (GOTHIC) code, and various types of sensitivity analysis were performed. The trend shown by the element test results was nearly obtained in the analysis of pressure drop at the simulated opening.

- Issue 3): Estimation of the pressure gradient in PCV
  A model to simulate the structural system of the actual 1F PCV in detail was created.
  In addition, the pressure distribution in PCV was evaluated with different locations of the opening. In all locations, significant pressure unevenness was not shown in PCV, which indicates that the necessary negative pressure can be retained in all parts of PCV.

* Issue 1) is not mentioned here because it is planned to be addressed by TEPCO HD Engineering, and not in this project.

(i) Technology development for ensuring a reliable confinement function

(a) Element test on differential pressure control effective for dust confinement and analysis of pressure and airflow distribution in boundaries

6. Final Outcome of Technology Development for Ensuring a Reliable Confinement Function

- Issue 4): Estimate of dust dispersion for each method

  The aerosol behavior simulation model of Generation of Thermal-Hydraulic Information for Containments (GOTHIC) code was used to analyze how dust generated by fuel debris processing spreads in primary containment vessel (PCV) . The adequacy of the model was also assessed. As a result, it was found that dust size especially has a significant impact.

  In addition, analysis using a model to simulate the structural system of actual PCV was confirmed as capable of providing the following functions when gravity sedimentation is taken into account: estimation of the amount of dust expelled out of PCV with discharged air, that deposited in PCV by gravity, and that leaked out of PCV from openings; and evaluation of the effect of stopping nitrogen gas feed by stopping inner gas discharge on the suppression of radiation emission.

  Further, potential issues that may arise in more practical evaluation were identified.

- Issue 5): Risk of local hydrogen gas accumulation

  Hydrogen gas diffusion behavior in PCV, oxygen concentration distribution caused by inbound airflow through openings (including those in the transient state after stopping inner gas discharge), and hydrogen gas concentration in the torus room were evaluated.

Airflow analysis by GOTHIC code was confirmed as capable of evaluating the following qualitatively: impact of geometric information, such as the internal shape of PCV and the location of damage holes, and the amount of injected nitrogen and the flow rate of PCV inner gas discharge, etc., as well as variation thereof, on flow condition, hydrogen and oxygen concentration distribution, and dust behavior.

As described above, an airflow analysis and evaluation method that contributes to the systematic design of nitrogen gas feed and the PCV inner gas discharge system was established to ensure a high-quality dust confinement function during fuel debris retrieval operation.

7. Area of Engineering Design where the Outcomes are Reflected

The developed models can be used in confining gas within the primary boundary, in designing a boundary for measures against hydrogen, in designing an air conditioning and nitrogen gas feed system, and in suggesting monitoring requirements. It is important to design methods and systems with a safety margin taking into account uncertainty because there is uncertainty in the conditions used for the analysis, such as the location and area of damage holes.

[Primary boundary design]

- Evaluation of the impact and the degree of sensitiveness of the location and areas of damage holes in the primary boundary
- Evaluation of the impact of access door open and close
- Evaluation of the impact of increase in the area of openings in the primary boundary due to an unexpected event or the like

[Systematic design of air conditioning and nitrogen injection systems]

- Consideration of gas discharge port and nitrogen injection port locations
- Consideration of system specifications and interlock

[Monitoring requirement]

- Consideration of monitoring equipment installation position, criteria for warning, and permissible time delay in detection

(i) Technology development for ensuring a reliable confinement function

(a) Element test on differential pressure control effective for dust confinement and analysis of pressure and airflow distribution in boundaries

8. Action Policy to Address Issues

[Airflow distribution analysis]

- It appears difficult to reduce uncertainties in estimating the area and location of damage holes in a short period of time. It is important to effectively utilize the developed models and perform facility design work taking into account these uncertainties.
- Although a model to analyze airflow in PCV was developed using Generation of Thermal-Hydraulic Information for Containments (GOTHIC) code, it was found effective to develop a model that enables evaluation of the impact of heat generation and transfer and inbound flow from other than the primary boundary in order to expand the applicable scope of analysis models. With such a model, simulation of the chimney effect under even pressure distribution and of the impact of atmospheric pressure variation on leakage will be possible.

[Reduction of uncertainties in analysis input conditions]

- There is a great deal of uncertainty in the particle size distribution of dust generated by the processing of fuel debris in the 1F reactors. Particle size has a significant impact on the behavior of dust. A long-term and step-by-step strategy to reduce this uncertainty needs to be established.

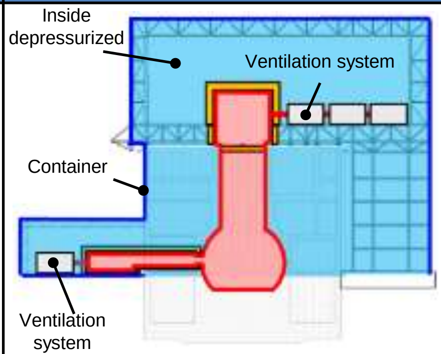
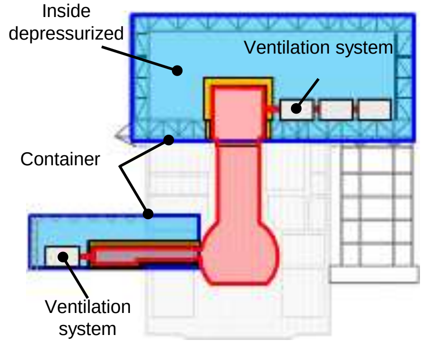
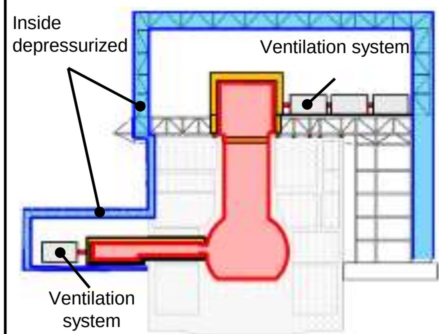
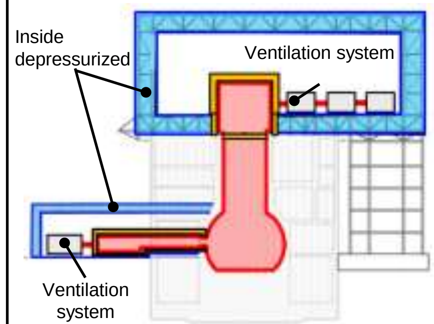
[Development of an aerosol modeling method]

- Practical aerosol behavior analysis, which is also used to analyze the refloating of aerosol and the effect of a moist environment (such as condensation), needs to be upgraded with respect to the improvement of monitoring accuracy (aerosol behavior from its occurrence point to measuring point). The adequacy of the GOTHIC code model also needs to be assessed in this regard.

VI. Implementation Details (1) Technology Development for Confinement Functions
(i) Technology development for ensuring a reliable confinement function
(b) Development of the sealability improvement method
1) Conceptual study of container design

The conceptual design of the container structure was performed with the aim of improving sealability during fuel debris retrieval operation.

- Single large container: covering the whole part of existing facilities by a single container
- Individual containers: covering only fuel debris retrieval cells by separate containers
- SSC: the walls of the container are constructed with single-layer panels
- WSC: the walls of the container are constructed with double-layer panels

	Single large container Single-skin container (SSC)	Individual containers Single-skin container (SSC)	Single large container Double-skin container (WSC)	Individual containers Double-skin container (WSC)
Proposed structure	 • Covering the fuel debris retrieval cell and all auxiliary facilities thereto (full-scale container) • Can be constructed without exerting any load on the building	 • Covering the cells for top-access and side-access fuel debris retrieval equipment separately • Reinforcement of the building structure and construction of an additional platform are required.	 • Covering the fuel debris retrieval cell and all auxiliary facilities thereto • This method was adopted at Chernobyl. • Can be constructed without exerting any load on the building	 • Covering the cells for top-access and side-access fuel debris retrieval equipment separately • Reinforcement of the building structure and construction of an additional platform are required.
Confinement	The entire internal space of the container is depressurized to ensure confinement.	The internal space of the individual fuel debris retrieval cells is depressurized separately to ensure confinement.	The space surrounded by the container panels is depressurized to ensure confinement.	The space surrounded by the container panels is depressurized to ensure confinement.

(b) Development of the sealability improvement method

2) Development of the sealability improvement method for newly built structures

It is planned to build a new building with sealability and shielding capability, separately from the reactor building and as an extension thereof, and to connect it with PCV via an access tunnel with similar sealability and shielding capability. A conceptual study on the access tunnel and element tests to assess the feasibility of construction methods quickly is planned.

- Development objectives
  - ➢ Assessment of the applicability of the access tunnel to fuel debris retrieval operation
    - ✓ Evaluation of the access tunnel installation procedures
    - ✓ Evaluation of procedures to install the access tunnel by remote operation
- Issues to be solved
  - ➢ The access tunnel is a heavy structure. It must be designed such that the weight never exceeds the maximum load capacity of the reactor building floor.
  - ➢ Procedures to realize installation of the heavy access tunnel need to be considered.
  - ➢ The access tunnel needs to be installed by remote operation taking into account the radiation exposure to workers during installation.
- Expected outcome
  - ➢ Feasibility of the access tunnel construction method

VI. Implementation Details (1) Technology Development for Confinement Functions

(i) Technology development for ensuring a reliable confinement function

(b) Development of the sealability improvement method

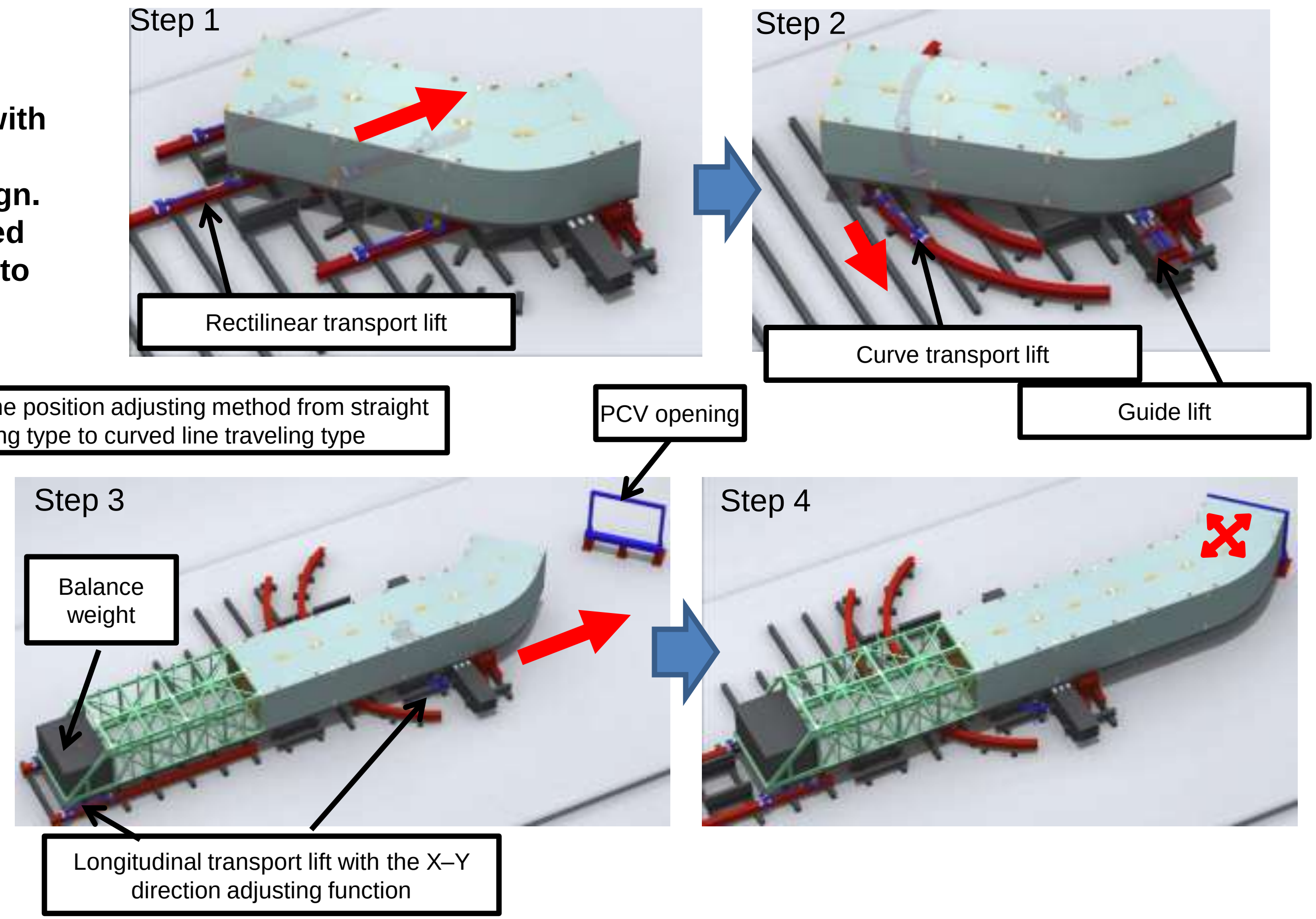
2) Development of the sealability improvement method for newly built structures

(1) Element test plan (1/2)

Upgraded testing facility by progress in design

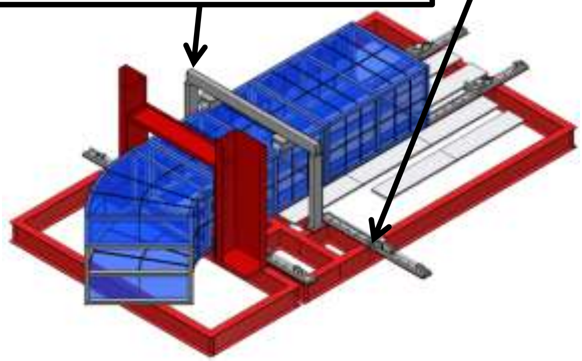
Points of improvement and the main steps of verification by element tests are described below.

- **The position adjusting mechanism was changed from one that is movable along only a straight line to another that is movable along a curved line to match it with the curved structure of the tunnel as a result of the progress of conceptual design.**
- **The load bearing mechanism was changed from one that bears the load by columns to another that uses balancing weight.**



Change of the load bearing mechanism from column type to balancing weight type

Change of the position adjusting method from straight traveling type to curved line traveling type



Originally proposed testing facility

VI. Implementation Details (1) Technology Development for Confinement Functions

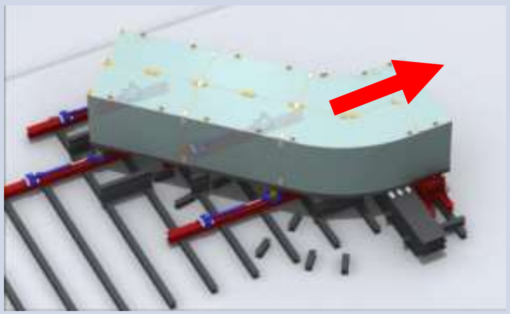
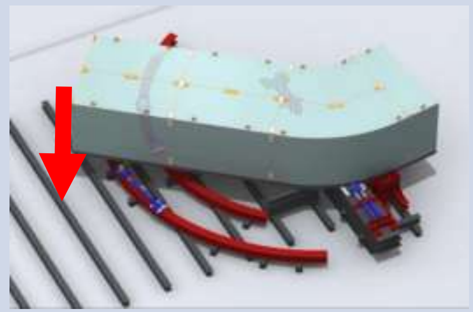
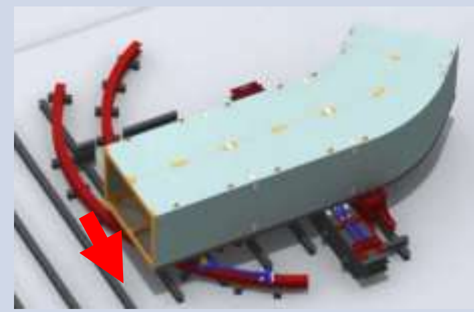
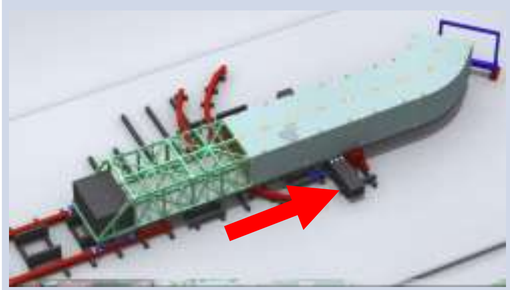
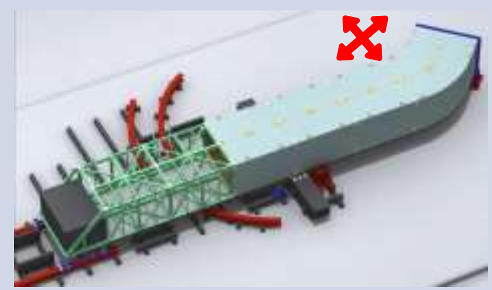
(i) Technology development for ensuring a reliable confinement function

(b) Development of the sealability improvement method

2) Development of the sealability improvement method for newly built structures

(1) Element test plan (2/2)

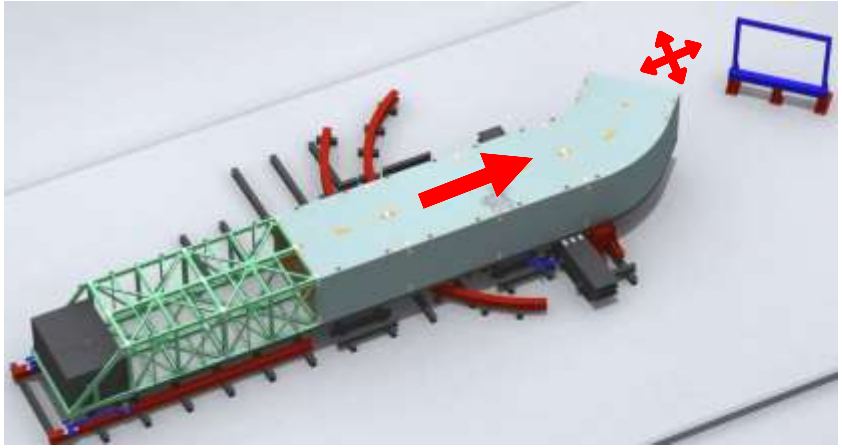
The main work steps to move the access tunnel to the final installation position are

Work step	Transporting the tunnel forward (Rectilinear motion)	Curved surface transport 1) (Circular motion)	Curved surface transport 2) (Circular motion)
Illustration of each step			
Work step	**Rectilinear part feed 1) (Rectilinear motion)**	**Rectilinear part feed 2) (Rectilinear motion)**	**Biological shielding wall (BSW) remote connecting operation**
Illustration of each step			

VI. Implementation Details (1) Technology Development for Confinement Functions
(i) Technology development for ensuring a reliable confinement function
(b) Development of the sealability improvement method
2) Development of the sealability improvement method for newly built structures

(2) Element tests—Test equipment and test procedures

A sketch of the mock-up used for the "transporting straight part forward" test, a photo of the "BSW remote connecting operation" test, specifications of the test equipment, and test procedures are shown below.



Outlines of test procedures

- Operate and control multiple rectilinear transport lifts simultaneously to move the tunnel approx. 8,000 mm to the predetermined position (near the BSW opening).
- After confirming the relative position and distance of the tunnel to the BSW opening, operate the position adjusting lift in manual mode to move the tunnel to the connecting position within a predetermined tolerance and connect it with BSW.

Main specifications of the lifts

Rectilinear transport lift with the position adjusting function (4 units)
- Horizontal traction force (per unit): 30 and 50 kN (two types)
- Transport distance: 1,000 mm
- Lifting capacity (per unit): 2,000 kN
- Vertical stroke: 230 mm

Position adjusting lift (2 units)
- Adjustable range: ±100 mm in the X–Y direction
- Lifting capacity (per unit): 2,000 kN
- Vertical stroke: 230 mm

* These specifications are the same as those of lifts planned for use in the actual tunnel installation at 1F.

VI. Implementation Details (1) Technology Development for Confinement Functions

(i) Technology development for ensuring a reliable confinement function

(b) Development of the sealability improvement method

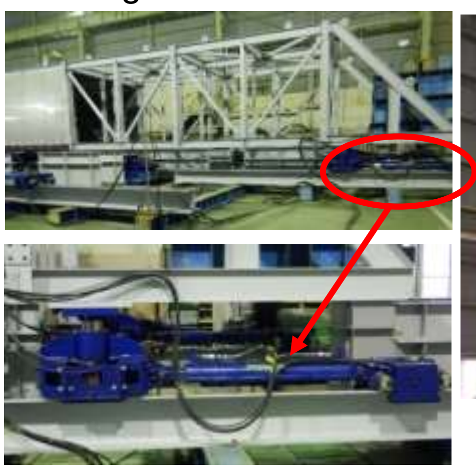
2) Development of the sealability improvement method for newly built structures

(3) Element tests—Test results

The results of element tests for “transporting straight part forward” and “biological shielding wall (BSW) remote connecting operation” are shown below:

■ Tunnel parts transport test

■ Lifting test



■ Tunnel–BSW joint part

■ Transport time (only as a reference)

Item	Time per run (min)	Number of repetitions (runs)	Subtotal (min)
Rectilinear transport (190 mm)	1	40	40
Direction change (only X–Y adjustment)	2	32	64
Direction change (X–Y adjustment and forward transport)	10	7	70
Rectilinear transport (190 mm)	1	2	2
Rectilinear transport (50 mm)	1	2	2
Direction change	4	6	24
Position adjustment	1	3	3
		Total	205

VI. Implementation Details (1) Technology Development for Confinement Functions

(i) Technology development for ensuring a reliable confinement function

(b) Development of the sealability improvement method

2) Development of the sealability improvement method for newly built structures

(4) Development objectives and results

[Technology Readiness Levels (TRL)]
Methods whose feasibility is being planned to be verified by element tests shall be those whose feasibility has been found to be high, whose issues have been identified, and whose development plan has been formulated. (TRL target at the end of the project: Level 3)*

Test item	Development objectives	Conditions to be met to ensure feasibility	Results	Rating
Tunnel parts transport	**To confirm the feasibility of the tunnel parts transport method using multiple cylinders**	**The tunnel parts were able to be transported to the predetermined position.**	**The tunnel parts were able to be transported to the predetermined position by controlling multiple cylinders in harmony. (Inching operation with an accuracy of several millimeters was confirmed possible.)**	**Good**
Transport of the curved tunnel through a narrow opening	**To confirm the feasibility of the method to transport the curved tunnel part through a narrow opening**	**The curved tunnel part was able to be transported to the predetermined position.**	**The curved tunnel part was able to be transported through the narrow opening while maintaining a predetermined clearance to the opening (approx. ±2 mm).**	**Good**
Remote operation monitoring	**To confirm the feasibility of remote operation monitoring (position of cameras and lights)**	**The whole process of tunnel transport to the predetermined position was able to be monitored.**	**The position of the access tunnel (including deviation from the designed transport path), clearance to the building wall, and distance and relative position to the BSW opening were confirmed to be measurable by cameras and laser devices.**	**Good**
Positioning accuracy	**To confirm tunnel positioning accuracy being within the designed tolerance so that it can be connected with BSW**	**The tunnel positioning accuracy at the final transport position shall be within ±50 mm. (The positioning accuracy of ±50 mm is needed because the cross-section of the tunnel that mates the BSW opening is designed to have a margin of approx. 100 mm.)**	**The positioning accuracy of ±20 mm or better was achieved against the target, ±50 mm.**	**Good**

* The stage of development and engineering work being performed within the range of conventional experiences or their combination or development and engineering work in new areas virtually without past experience.

(5) Development plan based on issues

Development/review results	Issues	Action policy to address issues
Conceptual study • Development of the connecting method with primary containment vessel (PCV)	The possibility of remotely implementing the connecting method with the PCV that was devised by the conceptual study is examined.	Verification of elements to realize the connecting method with PCV (planned in the next fiscal year or later)
Element test • Tunnel parts transport • Curved tunnel transport through a narrow opening • Remote operation to connect with BSW and equipment hatches (position adjustment) • Remote monitoring	Transport methods and lift control methods have been almost established. Note that the friction coefficient of the sliding contact surfaces where load concentration occurs needs to be at the same level on the transport equipment used in the actual 1F site as those of the equipment used in the test. A possible increase in the tunnel weight may have an impact on the transport performance due to the additional elastic deformation of the structure. The selection of materials and mechanical design used for the concerned parts needs to be done by taking into account this possibility and further verified by tests.	Heavy weight object handling element verification (planned in the next fiscal year or later)
Others • Expansion of access tunnel applicability	The expansion of the application of technical advantages brought about by development activities on the access tunnel (mainly its radiation shielding performance and the remote installation method thereof for dose reduction to workers) to other methods for the decommissioning needs to be considered (including application to other PCVs). For example, the use of different materials for shielding needs to be considered to increase the applicability and redundancy of the access tunnel.	Heavy weight object handling element verification (planned in the next fiscal year or later)

VI. Implementation Details (2) Technology Development for Collection/ Removal of Dust Derived from Fuel Debris

- During retrieving fuel debris, dust (and molten materials) will flow into the gas/liquid phases, therefore, necessary information on the system development is being collected.
- The technologies needed to achieve the objective of this project component are largely grouped into items (i)–(iii) below, and element tests for them were performed in FY2018.

<Grouping of technologies to be developed>

(i) Gas-phase particle removal technology*1

(ii) Liquid-phase particle (insoluble particles) removal technology*2

(iii) Liquid-phase substance (soluble substances) removal technology*2

[Objectives] **Selection of advantageous technologies for fuel debris retrieval operation and collection of data used for system development**

FY2017: Selection of effective models and system development

Technology research:	Technology mapping and evaluation of advantageous technologies
Element test:	Test planning
System development:	System development based on the technical research results

FY2018: Data collection and system development

Technology research:	none (performed on an as-needed basis)
Element test:	To be performed
System development:	System development based on the element test results

[Approaches to technology development]

STEP-1: Technology mapping 1)
- Conduct research on literature and manufacturers based on the outcomes of the last fiscal year, and perform exhaustive technology review.

→

STEP-2: Technology mapping 2)
- Clarify evaluation items and perform primary evaluation of technologies according to the items (screening).

→

STEP-3: Test planning
- Review and identify issues and lack of data, and clarify data to be obtained by tests.
- Test plan development

→

STEP-4: Test
- Detailing of the test plan
- Execution of the test plan

*1. This corresponds to the description of Implementation details (p. 5) "Technology development to reduce and remove gas-phase radioactive materials" in the subsidy application form.

*2. This corresponds to the description of Implementation details (p. 5) "Technology development to reduce and remove liquid-phase radioactive materials" in the subsidy application form (further grouped into measures against soluble and insoluble materials).

VI. Implementation Details (2) Technology Development for Collection/ Removal of Dust Derived from Fuel Debris

(i) gas-phase particle removal technology

(a) Objectives of element tests related to gas-phase particle collection/removal and items to be tested

- The conceptual diagram of the PCV gas-phase system in relation to fuel debris retrieval operation is shown below.
- Of these, items that have been decided to be obtained by element tests*1 in last year's consideration are listed on the right.

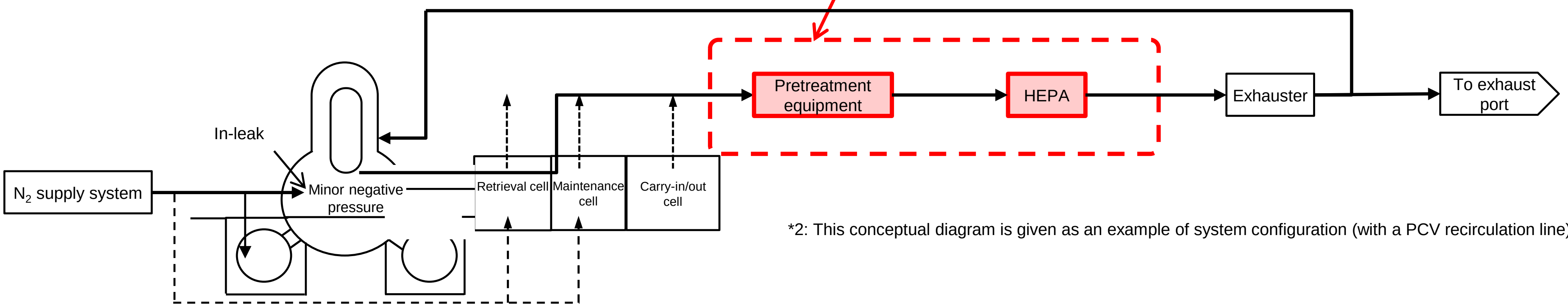
*1. These components are those, among information on advantageous technologies, whose evaluation is difficult even if the conditions of actual fluid are known

Classification	Type	Information and technologies to be obtained by element tests	Areas where the test results are reflected
Pretreatment equipment	Centrifugal dust collection	**Removal performance**	• System configuration • Exposure assessment
	Washing dust collection	**Removal performance**	• System configuration • Exposure assessment
	Filtering dust collection (Metal mesh)	**Backwashability (Differential pressure recovery performance)**	• Design of the waste liquid treatment system (proposed to be planned in the next fiscal year)
HEPA	HEPA filter (Metal mesh)	**Backwashability (Differential pressure recovery performance)**	• Replacement interval evaluation
Remote replacement technology	To be applicable to all types of square-shaped filters	**Remote replacement technology (including securing sealability after replacement)**	• Maintenance policy • Equipment layout

[Legend]

: Gas-phase particles under test

: Engineerable products



*2: This conceptual diagram is given as an example of system configuration (with a PCV recirculation line).

Figure—Conceptual diagram of the PCV gas-phase system in relation to fuel debris retrieval operation*2 and system components for which the element tests are intended

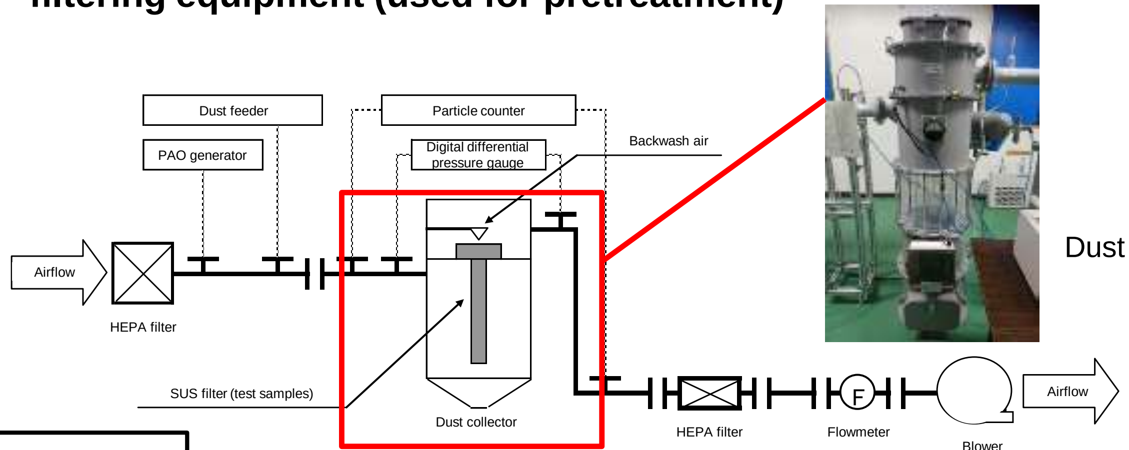
VI. Implementation Details (2) Technology Development for Collection/ Removal of Dust Derived from Fuel Debris

(i) Gas-phase particle removal technology

(b) Example of element tests related to gas-phase particle collection/removal

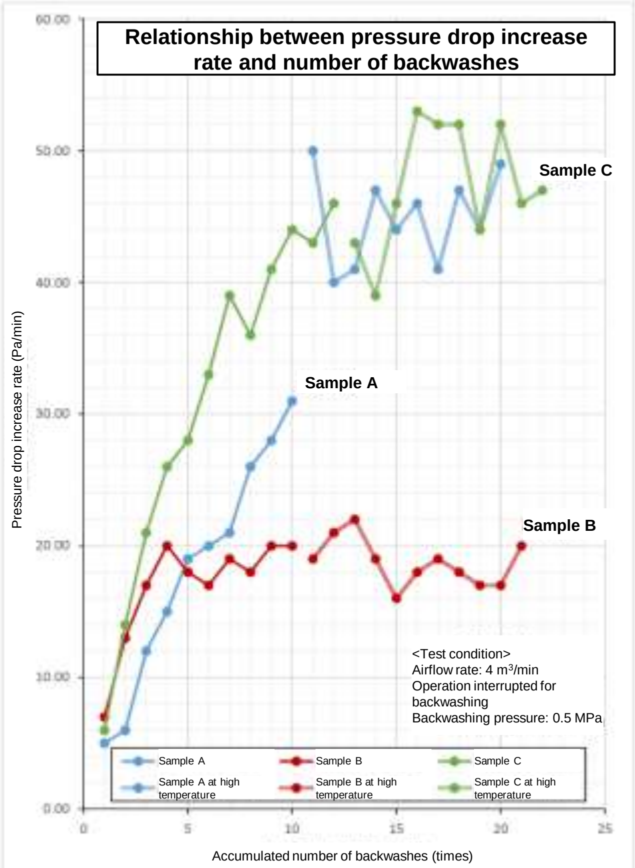
◆ **Backwashability (pressure drop recovery performance) test of dust filtering equipment (used for pretreatment)**

Metal filter



Dust collector

Figure—Test system flowchart



Test results

Three types of metal filter media (samples A, B, and C with filter fiber diameters of 2, 4, and 6 μm,*1 respectively) were tested.

Result 1): Dust removal efficiency

99.09%, 90.83%, and 57.85% for samples A, B, and C, respectively (All are data at the beginning of the test.)

Result 2): Backwashability

- Sample B showed good backwashability*2 in that the pressure drop increase rate (Pa/min) was the lowest and filter clog worsening was not accelerated by repeated backwashing with it.
- Samples A and C showed a pressure drop increase rate (Pa/min) about twice higher than that of sample C, and filter clog worsening was accelerated by repeated backwashing with them.

The possibility of making a metal filter with reasonable backwashability was confirmed.

*1: Samples with different fiber diameters were tested in the light of the objective of these tests, that is, to confirm the possibility of making an effective filter, as the fiber diameter was inferred to have a large impact on backwashability.

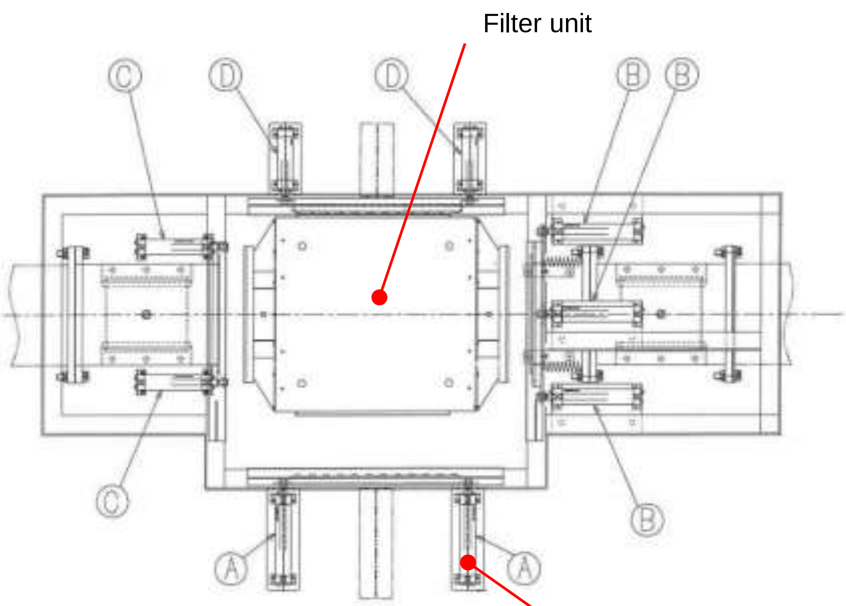
*2: If the pressure drop increase rate does not increase, the pressure drop of the filter that is subjected to periodic backwashing is retained at or under a constant value.

VI. Implementation Details (2) Technology Development for Collection/ Removal of Dust Derived from Fuel Debris

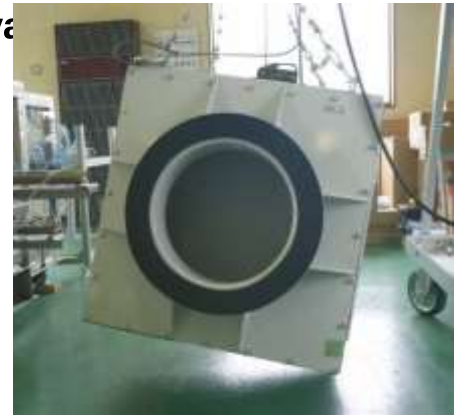
(i) Gas-phase particle removal technology

(b) Example of element tests related to gas-phase particle collection/remova

◆ Remote replacement technology test device



Figure—Remote filter replacement device (plain view)



Replacement filter unit

Remote filter replacement equipment

Summary

- It was confirmed that air cylinder-operated remote filter replacement equipment was capable of installing a new filter at the right position and securing sealability after installation without a problem.
- The requirement for the accuracy of filter unit positioning during its transport into the replacement equipment was obtained.

VI. Implementation Details (2) Technology Development for Collection/ Removal of Dust Derived from Fuel Debris

(i) Gas-phase particle removal technology

(c) Summary of element test results related to gas-phase particle collection/removal

Category	Subcategory	Summary	Objectives achievement status
Pretreatment technology	Washing dust collection (multi-stage washing tower) Particle removal performance data collection	✓ Particles with an average size of 8 μm were removed at a removal rate of approx. 90%. The removal performance was found to be stable and was not much affected by various parameters. ✓ The removal efficiency was low for particles with an average size of 0.8 μm.	Investigations on the impact of test conditions/parameters on the removal efficiency for particles with an average size of 0.8 μm and on the characteristics of waste liquid are pending.
	Centrifugal dust collection (Cyclone collector) Particle removal performance data collection	✓ Particle collection performance tests were conducted with different specific gravities, particle sizes, and flow rates as test parameters, and a high collection performance of 65% to over 95% was obtained. ✓ The adhesion of particles on the inner surface of the centrifugal dust collector was identified.	Investigations on unidentified information about collection performance and the impact of various parameters such as specific gravity, particle size, and flow rate on collection performance are pending.
	Filtering dust collection (backwashable dry dust collector) Backwashability data collection	✓ A type of metal filter that has sufficient removal efficiency as the pretreatment filter was found to be able to regain a reasonable level of pressure drop after repeated backwashing.	The selection of filter media and the investigation of pressure drop recovery by backwashing are pending.
Final treatment technology	HEPA filter (Metal mesh) Backwashability data collection	✓ A particle collection efficiency of 99.950% or higher and the effectiveness of backwash (long-term effect to suppress a pressure drop increase) by a pulse jet were confirmed for various types of simulated particles.	The estimation of collection efficiency and the backwash effect for potentially mixing particles (whose properties need to be defined as well) are pending.
Remote maintenance technology	Technology development of square-shaped filter remote replacement	✓ It was confirmed that the filter unit can be placed at the right position, and the sealability of the filter section after replacement can be secure by remote replacement operation.	Confirmation of the soundness of remote replacement operation and the installation condition of the filter are pending.

(i) Gas-phase particle removal technology

(d) Issues to be addressed in relation to the development of gas-phase particle collection and removal technologies

- The applicability of various particle removal equipment to the 1F environment and the characteristics of waste generated associated with these pieces of equipment were confirmed as the outcomes of this project.
- The following issues will need to be addressed before applying the methods and systems:
  - ✓ Selection of pretreatment equipment and consideration of ancillary systems based on the result of information collection on fuel debris processing characteristics (amount and particle size of generated dust, etc.) and site-specific environmental conditions
  - ✓ Study of the method to discharge accumulated particles after backwashing
  - ✓ Consideration of the applicability to test/inspection standards (nuclear power system specifications, etc.)

VI. Implementation Details (2) Technology Development for Collection/ Removal of Dust Derived from Fuel Debris

(ii) Liquid-phase particle (insoluble particles) removal technology

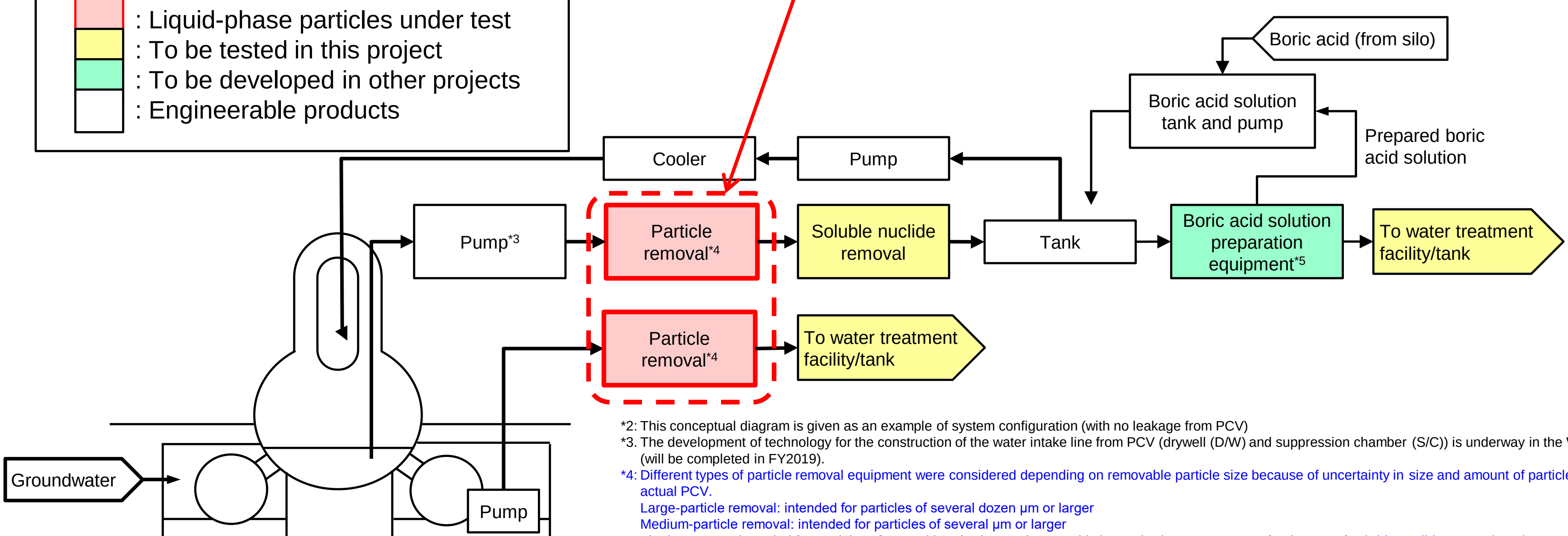
(a) Objectives of element tests related to liquid-phase particle collection/removal and items to be tested

- The conceptual diagram of the PCV liquid circulation system in relation to fuel debris retrieval operation is shown below.
- Of these, items that have been decided to be obtained by element tests*1 in last year's consideration are listed on the right.

*1. Of information on advantageous technologies, items that are difficult to evaluate even if the conditions of actual fluid are known

Classification	Type	Information to be obtained by element tests	Areas where the test results are reflected
Large-particle removal	Liquid cyclone collector Auto strainer	**Removal performance**	• System configuration • Exposure assessment
Large-particle removal	Liquid cyclone collector and auto strainer	**Filtration drainage water characteristics**	• Design of the waste liquid treatment system (proposed to be addressed in next year's project)
Medium-particle removal/final treatment	Sintered metal filter, MF and UF membranes	**Backwashability (Differential pressure recovery performance)** **Filtration drainage water characteristics**	• Replacement interval evaluation • Design of the waste liquid treatment system (proposed to be addressed in next year's project)

[Legend]
: Liquid-phase particles under test
: To be tested in this project
: To be developed in other projects
: Engineerable products



*2: This conceptual diagram is given as an example of system configuration (with no leakage from PCV)
*3. The development of technology for the construction of the water intake line from PCV (drywell (D/W) and suppression chamber (S/C)) is underway in the Water Circulation Project (will be completed in FY2019).
*4: Different types of particle removal equipment were considered depending on removable particle size because of uncertainty in size and amount of particles mixed in the water in actual PCV.
Large-particle removal: intended for particles of several dozen μm or larger
Medium-particle removal: intended for particles of several μm or larger
Final treatment: intended for particles of several hundred nm or larger *This is required as pretreatment for the use of soluble nuclide removal equipment (adsorption vessel).
*5: Boric acid preparation is being considered in the Criticality Project. Test to obtain performance data will be proposed in the next fiscal year.

Figure—Conceptual diagram of the PCV liquid circulation system in relation to fuel debris retrieval operation*2 and system components for which the element tests are intended

(ii) Liquid-phase particle (insoluble particles) removal technology

(b) Liquid-phase particle collection performance evaluation test

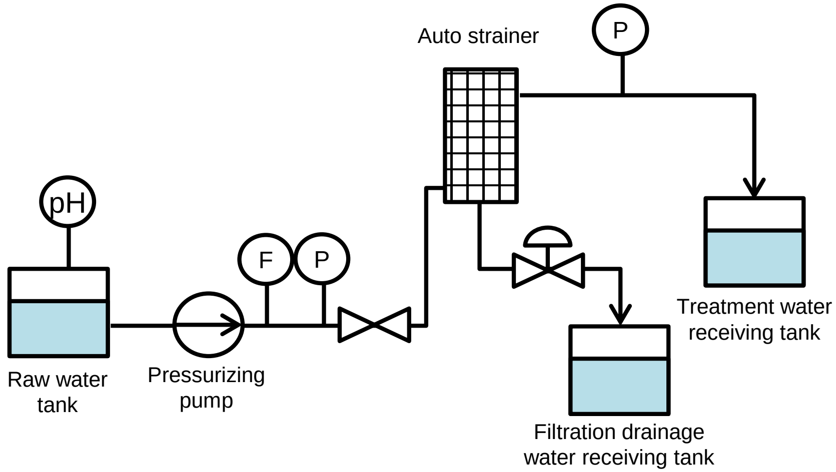
- Place particles in the raw water tank, pump, and feed the raw water to the filtering device; then, collect the particles.
- The particle collection efficiency is evaluated by the difference in the concentration of suspended solids (SS concentration) before and after the filter.
- Change the composition of particles and flow rate to evaluate their impact on particle collection efficiency

Evaluation of the influence of specific gravity

[Test condition]
SS concentration: 100 ppm
Particle size: 10 μm
Flow rate: 10 m^3/h
Equipment: 50 μm auto strainer

Evaluation of the influence of flow rate and particle size

[Test condition]
Equipment: 50 μm auto strainer
SS concentration: 100 ppm



System block diagram

Particle collection performance and influence of specific gravity

Simulating agent	Specific gravity	Particle collection efficiency
Tungsten carbide	15	45%
SUS316L	8	12%
Silica sand	3	1%
Mixture*	—	20%

* Three types of particles above are mixed at an even ratio

Particle removal performance and influence of flow rate and particle size

Flow rate \ Particle size	10 μm	100 μm
3 m^3/h	7%	99% or higher
10 m^3/h	20%	99% or higher

- Particle removal performance that coincides with the principle of an auto strainer (i.e., particle collection efficiency increases in proportion to the increase of the specific gravity of particles) was confirmed.
- Particles with a size larger than the pore size were confirmed as able to be removed at a removal efficiency of 99% and higher.

VI. Implementation Details (2) Technology Development for Collection/ Removal of Dust Derived from Fuel Debris

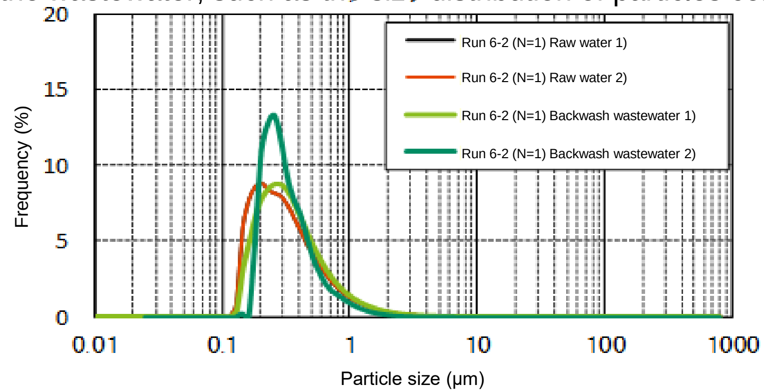
(ii) Liquid-phase particle (insoluble particles) removal technology

(c) Test to evaluate the backwashability of a filter clogged with liquid-phase particles

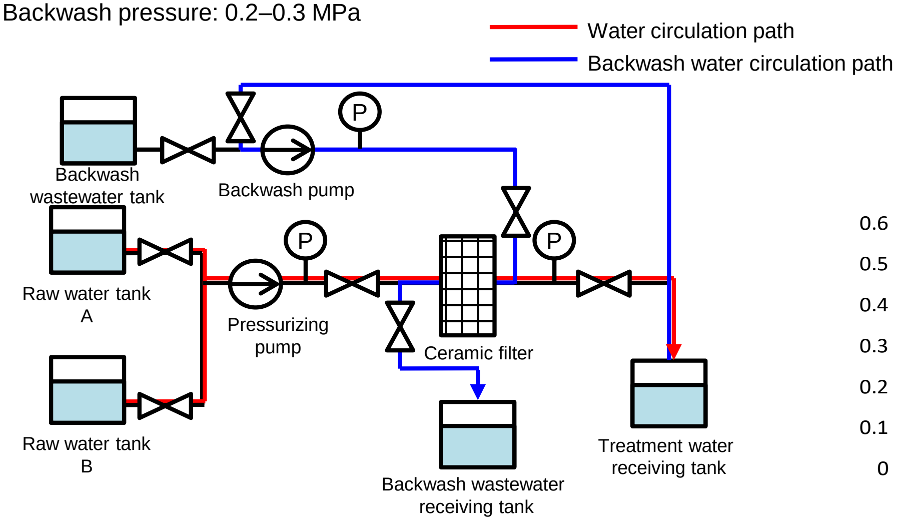
- A filter that was subjected to the liquid-phase particle collection test was backwashed, and changes in the pressure drop of the filter and in backwash pressure are measured to evaluate the backwashability.
- The amount of wastewater generated by backwashing and the characteristics of the wastewater, such as the size distribution of particles contained in the wastewater, are evaluated.

[Test condition]
SS concentration: 300 ppm
Simulated test particles: 0.1 μm SUS316, 50%; 6.7 μm JIS silica sand (mixture of three kinds), 50%
Flow rate: 0.6 m^3/h
Equipment: MF membrane (ceramic filter) with a pore diameter of 0.1 μm

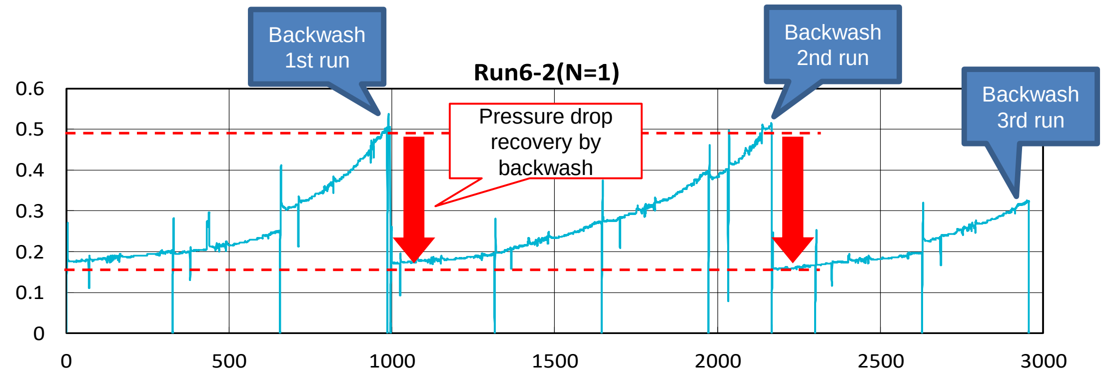
[Backwash condition]
Backwash pressure drop setting: 0.5 MPa
Backwash time: 1 min
Backwash flow rate: 0.6 m^3/h
Backwash pressure: 0.2–0.3 MPa



Size distribution of particles in raw water and in backwash wastewater (test result)



System block diagram



Trend of increase in MF membrane pressure drop with filtering test time

- The recovery of the filter pressure drop to the initial value by backwash was confirmed.
- It was also confirmed that the size distribution of particles is similar between those in raw water and in backwash wastewater.

(ii) Liquid-phase particle (insoluble particles) removal technology

(d) Summary of element test results related to liquid-phase particle collection/removal (1/3)

➢ **Particle collection performance**

Evaluation item	System	Equipment	Result/consideration
Particle collection performance	Large-particle removal	Liquid cyclone collector	✓ Data of removal efficiency for particles with a high specific gravity (SUS, tungsten carbide (WC)) were obtained the first time ever. From these sets of data, the size of particles that can be removed with a removal efficiency of 90% and higher (DF>10) became clear for different materials (such as 60 μm for SUS, 30 μm for WC, and 100 μm for silica). ✓ These results coincide with the basic formula of the cyclone collector, and thus can be used for the design of the system.
		50 μm auto strainer	✓ The test results showed the following: regarding removal efficiency for particles smaller than the pore size of the strainer, it was 45% for tungsten carbide particles (high specific gravity) and only 1% for silica sand particles (low specific gravity). These results coincide with the principle of the strainer: that is, particle removal efficiency increases in proportion to the increase in the specific gravity of the particle. ✓ It was confirmed that the removal efficiency for particles larger than the pore size was 99% or higher. ✓ The large-particle removal equipment was confirmed as effective in reducing the load on the medium-particle removal equipment from the viewpoint of α-nuclide removal.

➢ **Backwashability**

Evaluation item	System	Equipment	Result/consideration
Backwashability	Medium-particle removal	Sintered metal filter	✓ The trend of pressure drop recovery by backwash was obtained. ✓ It was confirmed that the trend of pressure drop increase became stronger with an increase of the ratio of small particles. A reason for this trend is the suggestion that small particles form layers and the particle size cross-section area is reduced. ✓ An optimum pore size needs to be determined for the filter to suppress the pressure drop increase by small particles.
	Final treatment	MF membrane	✓ The following filtering and backwashing test was performed with a sample membrane, and the recovery of the pressure drop of the membrane to near the initial value was confirmed after a second backwash: flow test water with an SS concentration of 300 ppm through the sample membrane at a 10 L/min flow rate until the accumulated test water volume reaches 1,000 L, perform the first backwash, continue to flow the test water (the pressure drop of the membrane at the beginning of this step is approx. 0.2 MPa), and then perform the second backwash. ✓ It was found that the filter provided satisfactory filtering performance for a long time against relatively high SS concentration water. From this result, it is expected that this filter can be used for a long time without backwash or the like when the load on this filter is reduced to an appropriate level by the equipment of the preceding process.
		UF membrane	✓ The trend of recovery was observed in the pressure drop after backwash. ✓ Note that the deterioration trend was observed in backwashability (increase of pressure drop after backwashing) with the increase of the number of backwashes performed.

(ii) Liquid-phase particle (insoluble particles) removal technology

(d) Summary of element test results related to liquid-phase particle collection/removal (2/3)

➢ **Characteristics of filtration drainage water and backwash wastewater**

Evaluation item	System	Equipment	Result/consideration
Characteristics of filtration drainage water and backwash wastewater	Large-particle removal	Liquid cyclone collector	✓ The size distribution of particles (weight based) in filtration drainage water showed an increase of the large-particle ratio and a decrease of the small-particle ratio. From this, the improvement of particle collection efficiency by sedimentation separation or the like is expected. ✓ Filtration drainage water with an SS concentration 20 times higher than that of pre-filtration water is generated at a volume of one-twentieth of pre-filtration water.
		50 μm auto strainer	✓ Although a shift of the size distribution of particles in filtration drainage water toward larger size is indicated compared with that of pre-filtration water, the degree of shift is not significant when viewed from the number of digits. Thus, it can be understood that particle aggregation does not occur. ✓ Particles with a size of 100 μm settle within several minutes, and particles with a size of 10 μm settle within several dozen minutes.
	Medium-particle removal	Sintered metal filter	✓ There is no significant difference in particle size distribution between particles in backwash wastewater and particles in pre-filtration water when viewed from the number of digits. Thus, it can be understood that particle aggregation does not occur.
	Final treatment	MF membrane	✓ There is no significant difference in particle size distribution between particles in backwash wastewater and particles in pre-filtration water when viewed from the number of digits. Thus, it can be understood that particle aggregation does not occur.
		UF membrane	✓ There is no significant difference in particle size distribution between particles in backwash wastewater and particles in pre-filtration water when viewed from the number of digits. Thus, it can be understood that aggregation does not occur.
Addition of boric acid	-	-	✓ The trend of particle size increase and the increase of solvent viscosity were confirmed by the addition of boric acid. ✓ There was no impact on the removal performance and backwashability of the equipment.

VI. Implementation Details (2) Technology Development for Collection/ Removal of Dust Derived from Fuel Debris

(ii) Liquid-phase particle (insoluble particles) removal technology

(d) Summary of element test results related to liquid-phase particle collection/removal (3/3)

- **Waste generation amount**

Evaluation item	System	Equipment	Result/consideration
Waste generation amount	Large-particle removal	Liquid cyclone collector	✓ Filtration drainage water that contains collected suspended solids (SS) is generated at a rate of 0.5 m^3/h from water fed at a rate of 10 m^3/h. ✓ Because all portions of removed SS are concentrated and contained in filtration drainage water (0.5 m^3/h), after treatment of the sludge (such as dewatering and drying) can be performed by compact equipment. ✓ It is expected that part of collected SS is deposited at the bottom of the cyclone collector (near the drainage discharge port). Measures to prevent SS deposits need to be taken on a collector used in the actual 1F site.
		50 µm auto strainer	✓ If drainage sludge discharge is performed every other day, the total annual filtration drainage water generation is estimated to be 2.0E−02 m^3/year. ✓ Assuming the inclusion of particles with sizes of 100 and 10 µm at a concentration of 100 ppm in pre-filtration water, the total annual sludge generation is estimated to be 5.1E+06 g/year.
	Medium-particle removal	Sintered metal filter	✓ With an assumption that the SS concentration of pre-filtration water is 1 ppm, the following values are estimated: 225 L/cycle for the amount of necessary backwashing water per cycle, once a day for the backwashing interval, and 1,000 ppm for the SS concentration of backwash wastewater.
		Bagfilter	✓ The number of waste filters is estimated to be 56 units per year (total volume of waste including sludge: 0.16 m^3).
	Final treatment	UF filter (with backwash)	✓ If backwash is performed every other day, the total annual amount of backwash wastewater generation is estimated to be 1.3E+01 m^3/year. ✓ Assuming the inclusion of particles with sizes of 1 and 0.1 µm at a concentration of 100 ppm in pre-filtration water, the total annual sludge generation is estimated to be 8.8E+06 g/year.
		UF filter (with backwash)	✓ The number of waste filter elements is estimated to be 10 units per year (total volume of waste including sludge: 1.3 m^3).

(ii) Liquid-phase particle (insoluble particles) removal technology

(e) Issues to be addressed in relation to the development of liquid-phase particle collection and removal technologies and action items

The applicability of various particle removal equipment to the 1F environment and the characteristics of waste generated associated with these pieces of equipment were confirmed as the outcomes of this project. Based on these outcomes and taking advantage of the data obtained in this project, further engineering efforts are required toward the detailed design of the liquid-phase particle collection and removal system. The following technological activities are suggested as development items in the next fiscal year or later in order to proceed to the detailed design of the liquid-phase particle collection and removal system.

- ✓ Development of a collection system taking into account the characteristics of filtration drainage water and backwash wastewater (planned in the next fiscal year or later)

- ✓ Development of a method to separate collected particles from filtration drainage water/sludge and backwash wastewater and tests to evaluate the feasibility of technologies identified as candidates for the separation process

- ✓ Test to collect data related to the timing of discharging filtration drainage water and performing backwash (filter pressure drop) and backwashing conditions (such as water flow rate and pressure) in order to proceed to the design of various particle removal equipment deployed at the actual 1F site

- ✓ Test to collect data required to determine the characteristics of water that each of different particle removal equipment deployed at the actual 1F site needs to handle

VI. Implementation Details (2) Technology Development for Collection/ Removal of Dust Derived from Fuel Debris

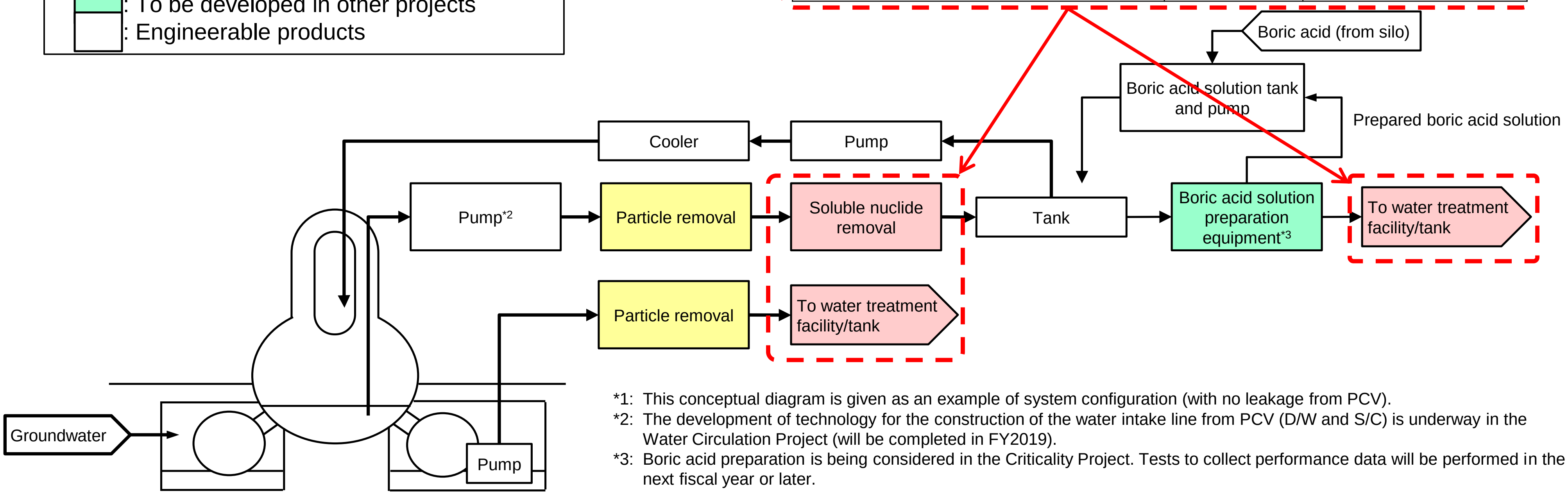
(iii) Liquid-phase substance (soluble substances) removal technology

(a) Objectives of element tests related to liquid-phase soluble nuclide collection/removal and items to be tested

- The conceptual diagram of the PCV liquid circulation system in relation to fuel debris retrieval operation is shown below.
- Regarding components of the system, element tests were performed for technologies that were identified to require tests to obtain removal performance among technologies that were identified as advantageous in last fiscal year's activities.

[Legend]
- : Liquid-phase soluble nuclides under test
- : To be tested in this project
- : To be developed in other projects
- : Engineerable products

Adsorbent or removal method whose removal performance data are needed	Actual use case at 1F	Remarks
Salt of 8-hydroxyquinoline and benzilic acid 2-Methyl-8-hydroxyquinoline (activated charcoal supported)	Yes	Oxine-impregnated activated charcoal is planned to be used.
Zeolite	Yes	
Tannic acid resin	No	
Titanic acid	Yes	
Titanium silicate	Yes	Currently used as Cs and Sr adsorbents



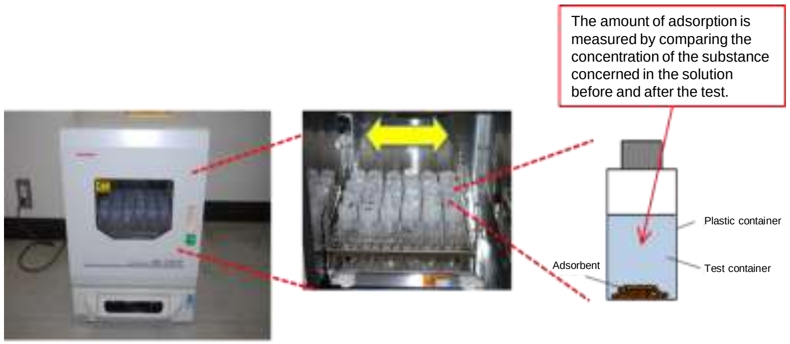
*1: This conceptual diagram is given as an example of system configuration (with no leakage from PCV).
*2: The development of technology for the construction of the water intake line from PCV (D/W and S/C) is underway in the Water Circulation Project (will be completed in FY2019).
*3: Boric acid preparation is being considered in the Criticality Project. Tests to collect performance data will be performed in the next fiscal year or later.

Figure—Conceptual diagram of the PCV liquid circulation system in relation to fuel debris retrieval operation*1 and system components for which element tests are intended

(iii) Liquid-phase substance (soluble substances) removal technology
(b) Results of element tests related to liquid-phase soluble nuclide collection/removal (Examples)

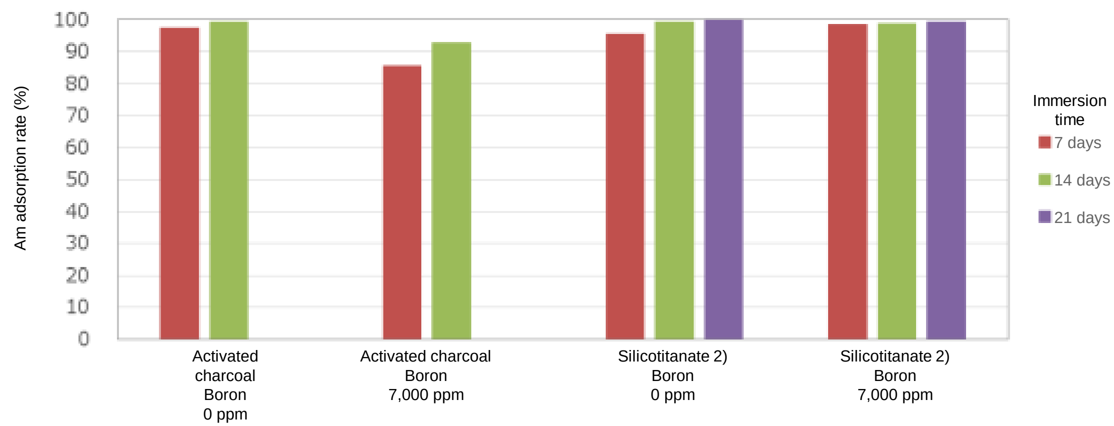
◆ Result of the primary screening by the immersion test

Objective of this test: There are not enough adsorption performance data of promising α-nuclide adsorbents found by research on literature and papers against liquid-phase α-nuclides in the water circulation system at 1F. This test aims to obtain basic data concerning americium (Am) removal performance with different characteristics of water that correspond to each system pattern.



Inside of the shaking machine | Inside of the shaking machine Overnight shaking | Adsorption test container

Collection of Am adsorption performance data in case of leakage from PCV
Test solution: pH 5–9; Cl ion, 200 ppm; sodium pentaborate, 0/7,000 ppm



$$\text{Am adsorption rate (\%)} = \frac{\text{Initial concentration} - \text{Final concentration}}{\text{Initial concentration}} \times 100$$

✓ It was confirmed that activated charcoal and silicotitanate, which showed high Am removal performance under the condition of water that is assumed to occur in case of no leakage from PCV, provided high Am removal performance under the condition of water that is assumed to arise due to the presence of leakage from PCV as well.

(iii) Liquid-phase substance (soluble substances) removal technology

(c) Issues to be addressed in relation to the development of liquid-phase soluble nuclide collection and removal technologies

◆ Achievements of this fiscal year

- Tests to evaluate americium (Am) removal performance were performed on promising α-nuclide adsorbents as a primary screening with respect to their applicability to the adsorption and removal of soluble α-nuclides from the water that circulates in the primary containment vessel (PCV) water system built at 1F for fuel debris retrieval operation.
- As a result of the primary screening by immersion tests, it was confirmed that currently available adsorbents such as activated charcoal and silicotitanate were capable of providing decent Am removal performance.
- Tests in the circulating water that simulates the water flow condition estimated to occur in 1F PCV were performed, and Am removal performance at the early stage of circulation was measured.
- From all the results described above, the adsorption method proved to be promising for collecting and removing Am, one of the soluble α-nuclides, effectively.

◆ Issues that need to be addressed and developed

The applicability of the adsorption method to α-nuclides other than Am needs to be investigated and evaluated. In addition, further tests to collect data necessary to design soluble α-nuclide removal equipment in detail need to be performed. The following development items need to be addressed in the next fiscal year or later:

- Assessment of the applicability of the adsorption method to α-nuclides other than Am (such as Pu and U)
- Long-term water circulation test to collect data such as removal performance, influence of the differential pressure setting for water circulation, and waste generation
- Broader information collection about how α-nuclides, removal target materials, dissolve in the water that circulates in the PCV water system built at 1F
- Development of adsorbent (in the adsorption vessel) replacement technology taking into account worker dose reduction
- Consideration of a method to store and dispose of filters used for α-nuclide collection

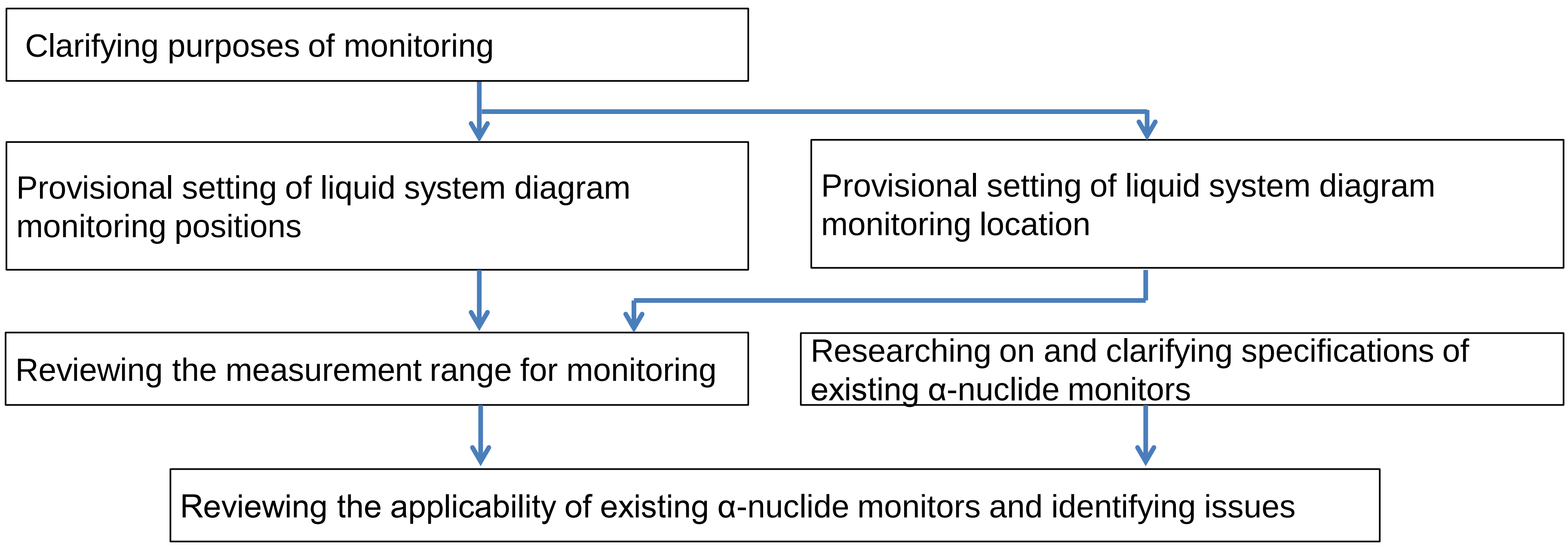
VI. Implementation Details

(3) Study on Alpha-Nuclide Monitoring System Associated with Fuel Debris Retrieval

1. Study method

- Managing and monitoring the concentration of nuclides are important in ensuring the target control of radiation dose (public and workers) specified in in-depth protection.
- The prospect of being able to control βγ with existing technology is achieved, even in the contaminated environment of 1F. However, workers will suffer massive exposure to α-nuclides by inhalation, and monitoring will likely be difficult in an environment high in BG. Therefore, whether it can be managed with existing technology will be examined in this project.

=> A study on the workflow of α-monitoring was conducted as follows.



2. Purpose of α-monitoring and in-depth protection level

In-depth protection levels were specified as follows to monitor parameters that require the monitoring of α-activity concentration.

Legend: A: Parameter used in condition management (control)
B: Parameter used in condition monitoring
C: Parameter used in discharge volume monitoring

System	Monitoring parameter	In-depth protection level		
		1: Normal state	2: Abnormal state	3: Upon accident
Gas-phase	Activity concentration in the primary boundary (gas phase inside PCV)	A*2	B	- (Monitored in the secondary boundary in Level 3)
	Activity concentration of exhaust from the primary boundary (Filtered)	C*1	C*1	C*1
	Activity concentration in the secondary boundary	B	A (Leakage detection)	A*1 (When the function of the primary boundary is lost)
	Activity concentration of exhaust from the secondary boundary (Filtered)	C*1	C*1	C*1
Liquid-phase	Underwater activity concentration in PCV	B*3	B	- (Monitored in the torus room in Level 3)
	Activity concentration of water inside the torus room	B*3	B	- (Water level inversion is prevented by the system)
	Activity concentration in drain water (After water processing)	C*1, 4	B	- (Discharge into the environment during leakage is prevented by dikes)

Note *1: Monitor amount of emission/discharge into the environment
*2: Used for target management for reduction of potential risks
*3: Under review to assess whether it can be used for target management for reduction of potential risks
*4: Intends to conduct analysis while stored in the tank before being discharged into the environment

3. Summary of applicability of the existing gas-phase α-monitor

Below are the study results of the applicability of a primary gas-phase α-nuclide monitor with consideration of the measurement range and time requirements.

<Criteria for performance of existing technology>

1) iCAM/MF [compact, small flow rate] detectable α-activity concentration 1.6×10^{-7} [Bq/cm^3]: 5-min measurement
2) BAI9100D [large, large flow rate] detectable α-activity concentration 1.43×10^{-7} [Bq/cm^3]: 10-min measurement

*BG level of γ-rays at the location of installation: 0.1 [mSv/h] or lower

Measurement location	Measurement range and time requirement	Specification of the commercial monitor	Applicability
1) Location where the atmosphere inside PCV can be monitored	8.8×10^{-5} to 8.8×10^{0} [Bq/cm^3] (current concentration estimate [the total discharge of dust inside PCV (5 mSv) is included in the public dose]) 1–10 min	iCAM/MF 1.6×10^{-7} or more 5-min measurement BAI9100D 1.43×10^{-7} or more 10-min measurement BG0.1 mSv/h or less	C (BG measures required)
2) Location where amount of emission from the exhaust end can be monitored	2×10^{-10} to 8.8×10^{-5} [Bq/cm^3] (current concentration estimate [public dose up to 8.4 μSv/year]) 1 day to 1 week		B
3) Location where leakage from the primary boundary can be detected	3.5E−06 [Bq/cm^3] (50 times the announcement density [taking a full-face mask into account] × 1/10) 1–10 min		C (BG measures required)

- 2) The dust monitor installed at the downstream filters that control discharge is applicable as no issues arose in long measurements.
- Regarding α-monitors for 1) measurement of the atmosphere inside PCV and 3) location where leakage from the primary boundary can be detected, the reduction of γ-ray background in areas where α-nuclide dust monitors are installed is an issue.

4. Functional requirement for monitoring liquid-phase contaminants

- The functional requirement for monitoring liquid-phase contaminants is to **reduce the concentration of liquid-phase radioactive materials to the control standard value (during draining) or less**.

- The policy is to prevent the discharge of contaminated water that contains dust produced in fuel debris processing into the environment (no direct discharge into the environment) in assumed events that will be included in the design basis.

- The policy intends to protect the public, workers, and the environment by preventing the discharge of liquids. Therefore, although the control standard value of circulating cooling water after purification will be specified, **no direct limit will be established for the circulating cooling water of PCV and the torus room in terms of protecting the public and workers.**

=>The measurement range for α-monitoring on liquid-phase contaminants was examined by considering the functional requirements and the design policy for liquid-phase contaminants.

5. Study result summary

- The measurement range requirements of gas-phase and liquid-phase contaminants were specified, and the applicability of existing technology (commercial α-monitors) was studied.

- The monitoring of gas-phase contaminants will be presumed, in “the location where the amount of emission from the exhaust end can be monitored” (mandatory), which can be conducted using existing α-monitoring technology.

- Monitoring of gas-phase contaminants in “location where atmosphere inside PCV can be monitored” and “location where leakage from the primary boundary can be detected” will likely satisfy the measurement range and time, but will need to take into account the decrease of background dose in the installed location. (Decrease of background dose will be studied in engineering.)

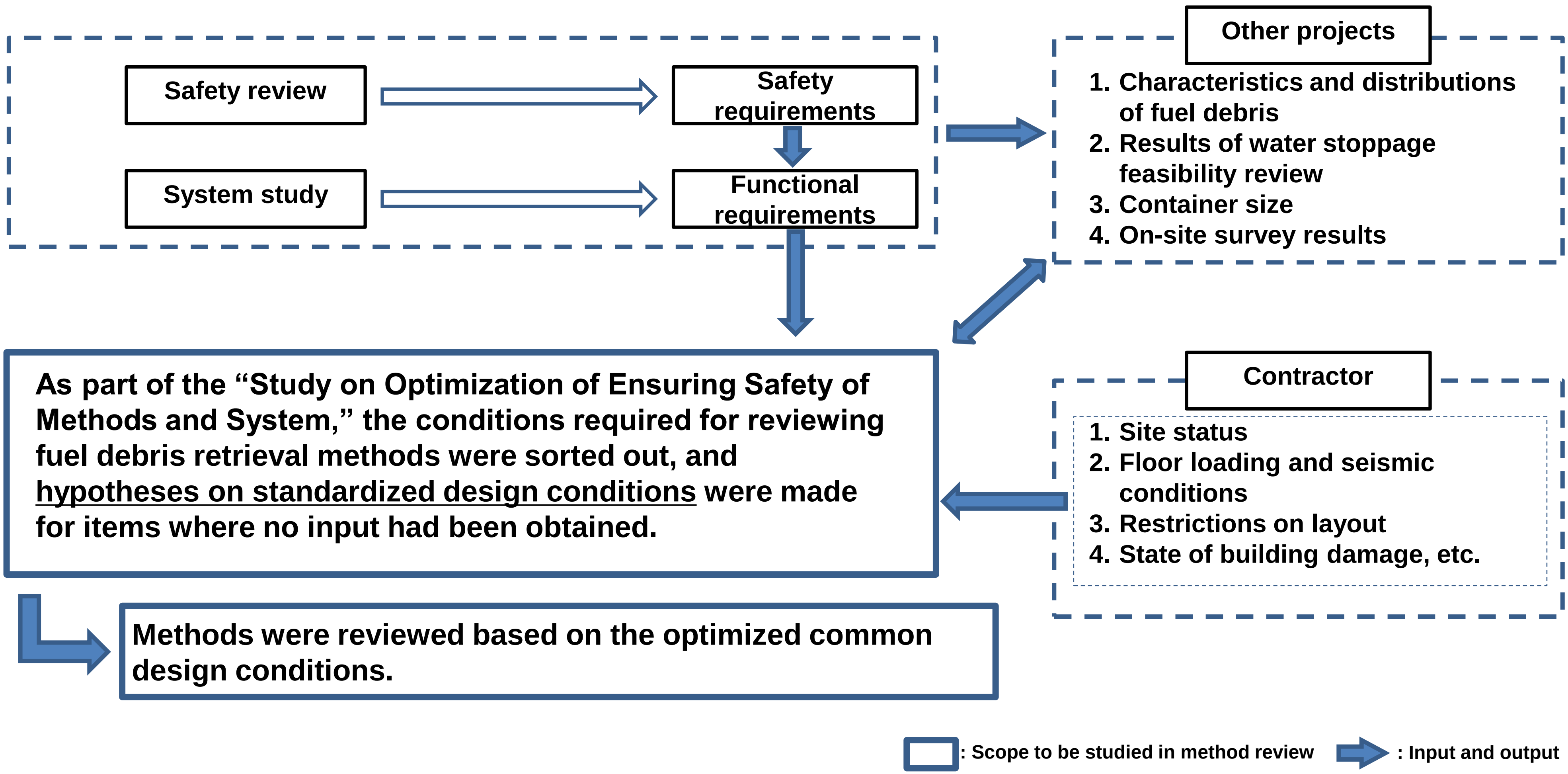
- It is presumed that continuous monitoring of liquid-phase contaminants with existing α-monitoring technology will be difficult. However, as there is no target in terms of worker and public exposure up to Level 3 regarding concentration within the liquid, it can be analyzed manually if there is a long measurement time request.

VI. Implementation Details (4) Optimization Study on Ensuring Safety of Methods and Systems

(i) Optimization of methods for ensuring safety

1) Review of method design conditions

The design conditions required to review fuel debris retrieval methods were sorted out and optimized.



VI. Implementation Details (4) Optimization Study on Ensuring Safety of Methods and Systems

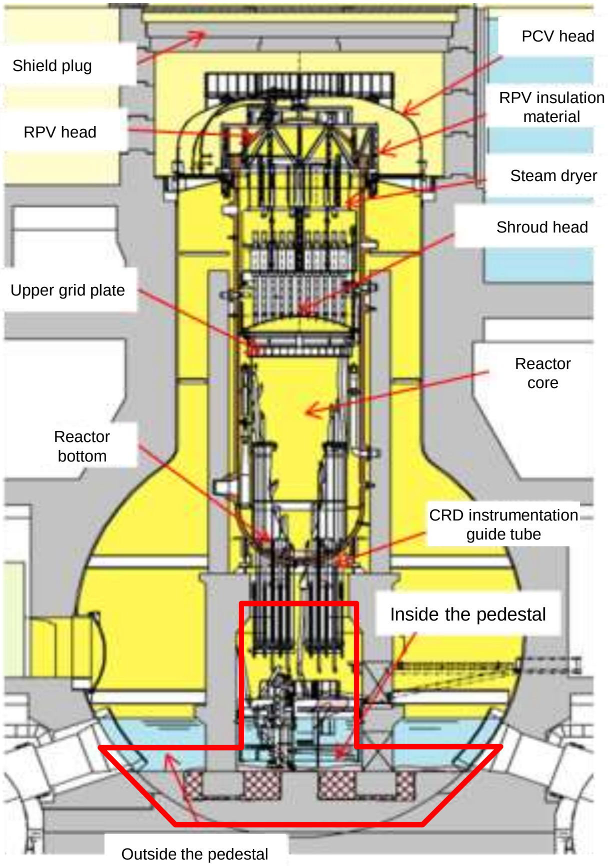
(i) Optimization of methods for ensuring safety

2) Analysis concerning throughput

Example of fuel debris retrieval throughput study (interfering objects removal throughput was studied similarly)

The throughput was analyzed to identify future issues.
For the analysis, the amount of fuel debris that needs processing was estimated for each of the debris characteristics based on the analyzed value.

[red box] : Range of estimated mass per fuel debris characteristic



Example of Unit 3

No.	Position of distribution	Characteristics	General state	Features	Amount of fuel debris		Fuel debris properties	
					Analysis value [t]	Assumed value [t]	Dimensions	Necessity of processing
1	Reactor core	Fuel rod stubs	Almost all the fuel melted down, and some undamaged fuel assemblies remained in the reactor core periphery (MAAP).	The top part of the fuel assemblies in the reactor core periphery melted down; few fuel pellets remained.	0–31	15	Up to 4 m	Processing is needed
		Powder, pebble size	Adhered to or stacked on residual structures	Molten core materials rapidly cooled down into small pieces.		16	Few µm to few cm	Collection only
2	Reactor bottom	Powder, pebble size	Both the MAAP and SAMPSON code indicate small amounts of fuel debris in the lower plenum.	Molten core materials rapidly cooled down into small pieces.	21–79	24	Few µm to few cm	Collection only
		Block		Slowly cooled down into a block		24	Thickness: several dozen cm	Processing is needed
		Crust (bedrock)		Molten metals and oxide fuel mixed and solidified into fuel debris		25	Thickness: 0.1–1 m	Processing is needed
3	Control rod drive (CRD)/instrumentation guide tube	Piping	Fuel debris adhered in gaps inside and on the outer surface of tubes.	Fuel debris clogged the duct in the lower SUS piping from the bottom end of RPV.		6	Penetration depth: 10 plus cm	Processing is needed
4	Inside the pedestal	Powder, pebble size	Most of the molten fuel debris solidified without forming molten core concrete interaction (MCCI) because the timing of water injection was too early. There may be MCCI in the sump pit.	Molten reactor core materials leaked out of RPV, quenched, and dispersed, Concrete barely reacted.	92–222	111	Few µm to few cm	Collection only
		Block		Solidified block fuel debris is distributed uniformly, and there may be MCCI in the sump pit.		111	Thickness: 15 cm	Processing is needed
5	Outside the pedestal	Powder, pebble size	Solidified fuel debris leaked from the pedestal; most were powder and pebble-size debris.	Pebble-size debris leaked from the pedestal.	0–146	73	50 µm to 20 cm	Collection only
		Block		Corium that leaked from the pedestal reacted with the concrete and solidified; the debris had a slightly rich metal content.		73	Penetration depth: up to 0.20 m	Processing is needed

VI. Implementation Details (4) Optimization Study on Ensuring Safety of Methods and Systems

(i) Optimization of methods for ensuring safety

2) Analysis concerning throughput

Example of fuel debris retrieval throughput study
(interfering objects removal throughput was studied similarly)

Analysis conditions for fuel debris retrieval using the side entry method were specified.

No.	Item	Condition	Remarks
1	Target time period for fuel debris retrieval	Unit 1: 10 years; Unit 2, 10 years; Unit 3: 10 years	
2	Number of work days for fuel debris retrieval per year	200 days (remaining days are for maintenance)	
3	Daily work hours for fuel debris processing	10 h or less	
4	Amount of fuel debris	Assumed for Unit 3, which has the largest amount (Attached to CRD and instrumentation guide tubes: 6 tons*, inside pedestal: max. 222 tons, outside pedestal: max. 146 tons, total 374 tons)	When the side entry method is used
5	Fuel debris processing tool	1. MCCI: chisel processing, ultrasonic core boring, etc. 2. Attached to CRD and instrumentation guide tubes: disc cutter, AWJ, laser, etc. 3. Attached to metallic structures: disc cutter, AWJ, laser, etc.	
6	Fuel debris processing speed	1. Chisel processing, ultrasonic core boring : determined based on the element test results of the Fundamental Technology PJ 2. Disc cutter, AWJ, laser: processing speed similar to that of interfering objects removal 3. Core boring: 3.25 kg/h (FY2016 test result) 4. Laser gouging: 4.76 kg/h (FY2016 test result)	
7	Method of collecting fuel debris	A collection method with a track record of grabbing and scooping will be applied as review conditions and results of element tests will also be considered.	
8	Fuel debris handling speed	A handling method with a track record will be applied as review conditions and results of element tests will also be considered.	

*Study results are from the FY2015 Identification of Conditions inside the Reactor Project.

VI. Implementation Details (4) Optimization Study on Ensuring Safety of Methods and Systems

(i) Optimization of methods for ensuring safety

2) Analysis concerning throughput

Example of fuel debris retrieval throughput study (interfering objects removal throughput was studied similarly)

[red box] : **fuel debris processing test conducted in the Fundamental Technology PJ**

Below is a rough plan of the fuel debris retrieval throughput using the side entry method.

No.	Equipment name	Time elapsed	Remarks
1	Fuel debris retrieval equipment (processing tool)	Process fuel debris / Process fuel debris	10 h or less per day
2	Fuel debris retrieval equipment (collection tool)	Replace with collection tool / Fuel debris collection / Replace with processing tool	
3	Transport system 1 (red area)	Transport	
4	Confinement equipment 1 (red and yellow area)	UC to canister	
5	Transport system 2 (yellow area)	Transport	
6	Confinement equipment 2 (yellow and green area)	Canister to cask	
7	Transport system 3 (green area)	Transport	
8	Transfer inspection system (e.g., surface contamination)	Inspection	
9	Transfer truck	Transfer / Transfer / Transfer	

VI. Implementation Details (4) Optimization Study on Ensuring Safety of Methods and Systems

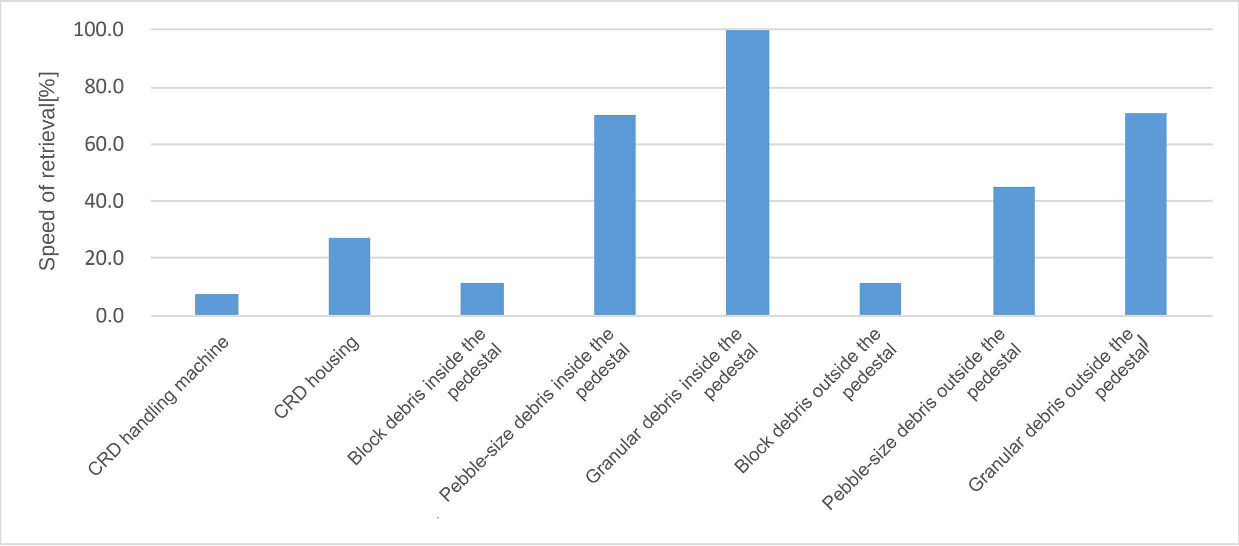
(i) Optimization of methods for ensuring safety

2) Analysis concerning throughput

Example of analysis on fuel debris retrieval using the side entry method (PLAN-A*)

<u>Analysis results of throughput regarding fuel debris retrieval (1/3)</u>

	Weight [ton]	Work hours for processing [%]	Work hours for collection [%]	Work hours for transfer [%]	Total time [%]
CRD exchanger	9.2	4.71	0.62	0.01	5.33
CRD housing	71.8	10.18	1.34	0.01	11.52
Block debris inside the pedestal	111.0	34.35	4.63	3.99	42.97
Pebble-size debris inside the pedestal	55.5	0.00	1.43	2.00	3.43
Granular debris inside the pedestal	55.5	0.00	0.18	2.23	2.41
Block debris outside the pedestal	73.0	21.01	4.92	2.64	28.56
Pebble-size debris outside the pedestal	36.5	0.00	2.23	1.32	3.55
Granular debris outside the pedestal	36.5	0.00	0.12	2.11	2.22
<u>Total</u>	449.0	70.25	15.45	14.30	100.00



- Collection of granular fuel debris by vacuum collection is efficient and time saving.
- Collection of pebble-size fuel debris using a collection tool is also relatively efficient.
- However, collection of a CRD handling machine, CRD housing, and block fuel debris that entail fuel debris processing is time consuming and extremely inefficient.

- To improve the throughput, **it is necessary to establish a processing method** in the future that can process and cut fuel debris **efficiently**.
- The realizability of efficient fuel debris collection methods such as vacuum collection shall be studied by element tests, and **collection technology needs to be established.**
- As the composition ratio of bulk, pebble size, and granular fuel debris were of estimated value, the results of internal investigation shall be reflected and revised.

*For details of PLAN-A, refer to “FY2014 Supplementary Budget Subsidies for Government-Led R&D Program on Decommissioning and Contaminated Water Management (Upgrading of Approach and Systems for Retrieval of Fuel Debris and Internal Structures),” “FY2016 Final Report and FY2016 Supplementary Budget Subsidies for Government-Led R&D Program on Decommissioning and Contaminated Water Management (Upgrading of Approach and Systems for Retrieval of Fuel Debris and Internal Structures),” and FY2017 Progress Report.

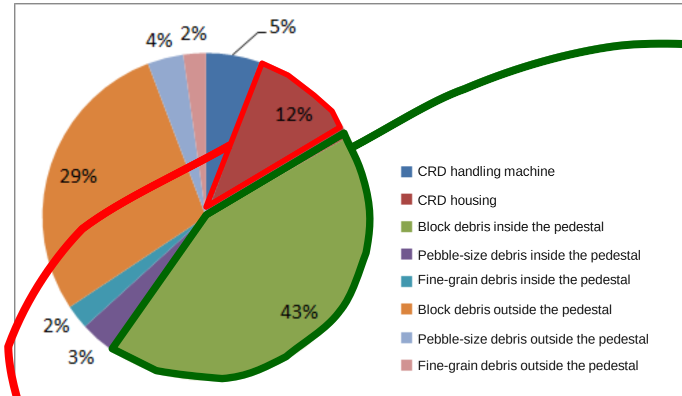
VI. Implementation Details (4) Optimization Study on Ensuring Safety of Methods and Systems

(i) Optimization of methods for ensuring safety

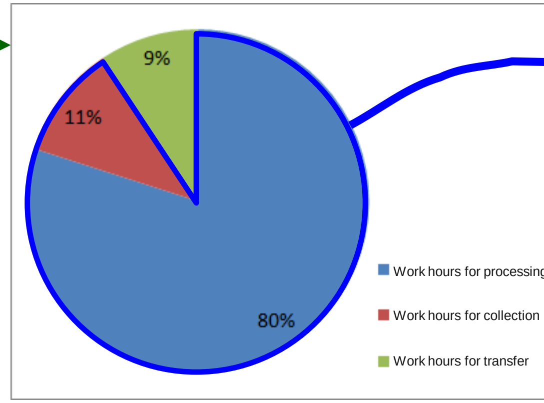
2) Analysis concerning throughput

Example of analysis on fuel debris retrieval using the side entry method (PLAN-A)

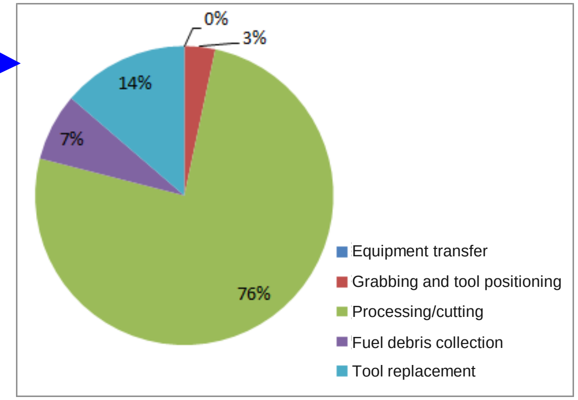
Analysis results of throughput regarding fuel debris retrieval (2/3)



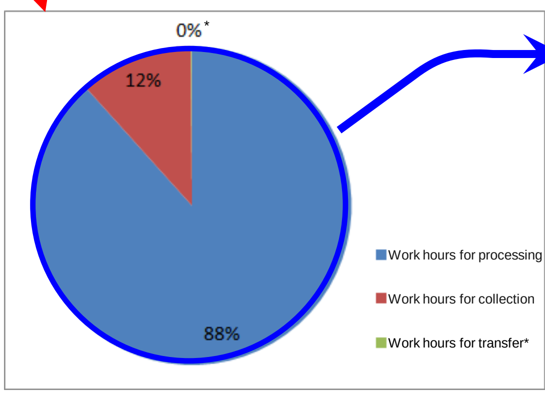
Ratio of work hours for fuel debris retrieval



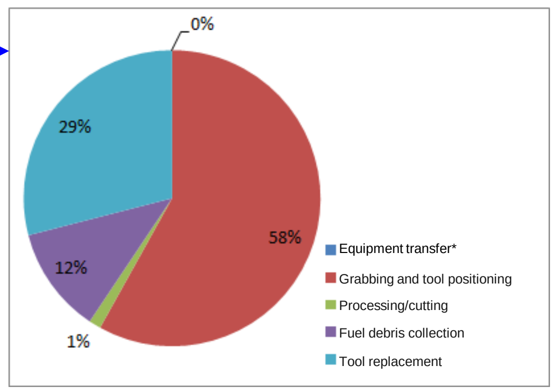
Breakdown of work hours for retrieval of block fuel debris inside the pedestal



Breakdown of work hours for processing and collecting block fuel debris inside the pedestal



Breakdown of work hours for retrieval of CRD housing



Breakdown of work hours for processing and collection of CRD housing

- Retrieval of block fuel debris from inside and outside the pedestal takes a longer time.
- Processing and cutting block fuel debris are time consuming.

A method to efficiently process block fuel debris needs to be developed.

- Similar to the retrieval of interfering objects, in the retrieval of CRD handling machines and CRD housing, more time is required to position processing tools, grab onto the target object, and replace tools than the actual processing and cutting process.

An operation-support tool that assists workers in operating manipulators will be necessary.

Note: The analysis results above are based on a hypothesis, and revision will be made taking into account future studies and the results of element tests.

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*The work hours for CRD housing transfer were approx. 0.09%; hence, it was rounded down to 0% in this graph. The work hours for equipment transfer were also rounded down to 0% for the same reason.

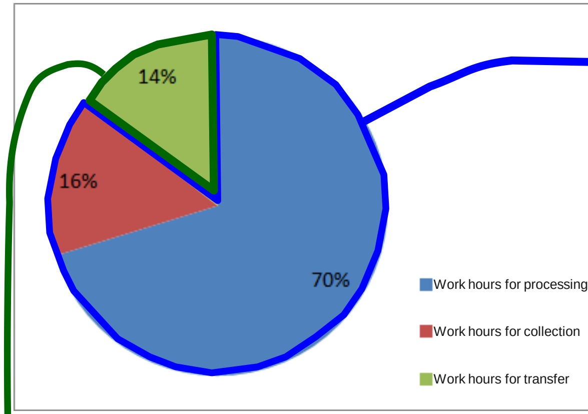
VI. Implementation Details (4) Optimization Study on Ensuring Safety of Methods and Systems

(i) Optimization of methods for ensuring safety

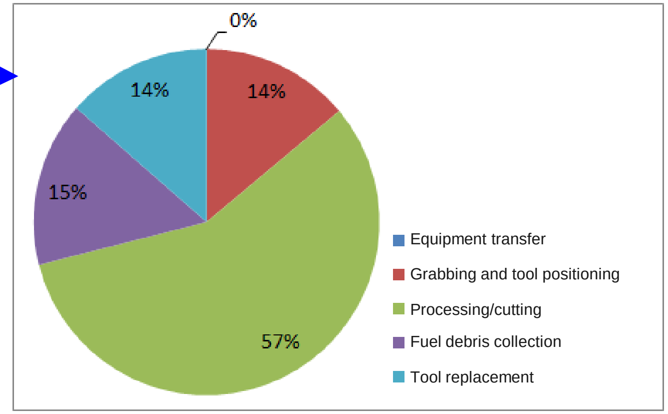
2) Analysis concerning throughput

Analysis results of throughput regarding fuel debris retrieval (3/3)

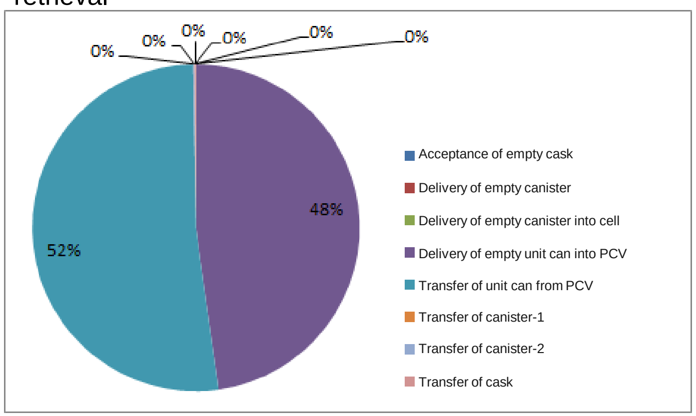
Example of analysis on fuel debris retrieval using the side entry method (PLAN-A)



Breakdown of work hours for fuel debris retrieval



Breakdown of work hours for processing and collecting fuel debris



Transfer of canister-1: transfer of canister in the mini cask cell
Transfer of canister-2: transfer of canister in the canister cell

Breakdown of work hours for fuel debris transfer

Replacement of the tip tool is also relatively time consuming → **Study and develop efficient methods to replace the tip tool**

Note: The analysis results above are based on a hypothesis, and revision will be made taking into account future studies and the results of element tests.

Inquiries based on the results of throughput analysis

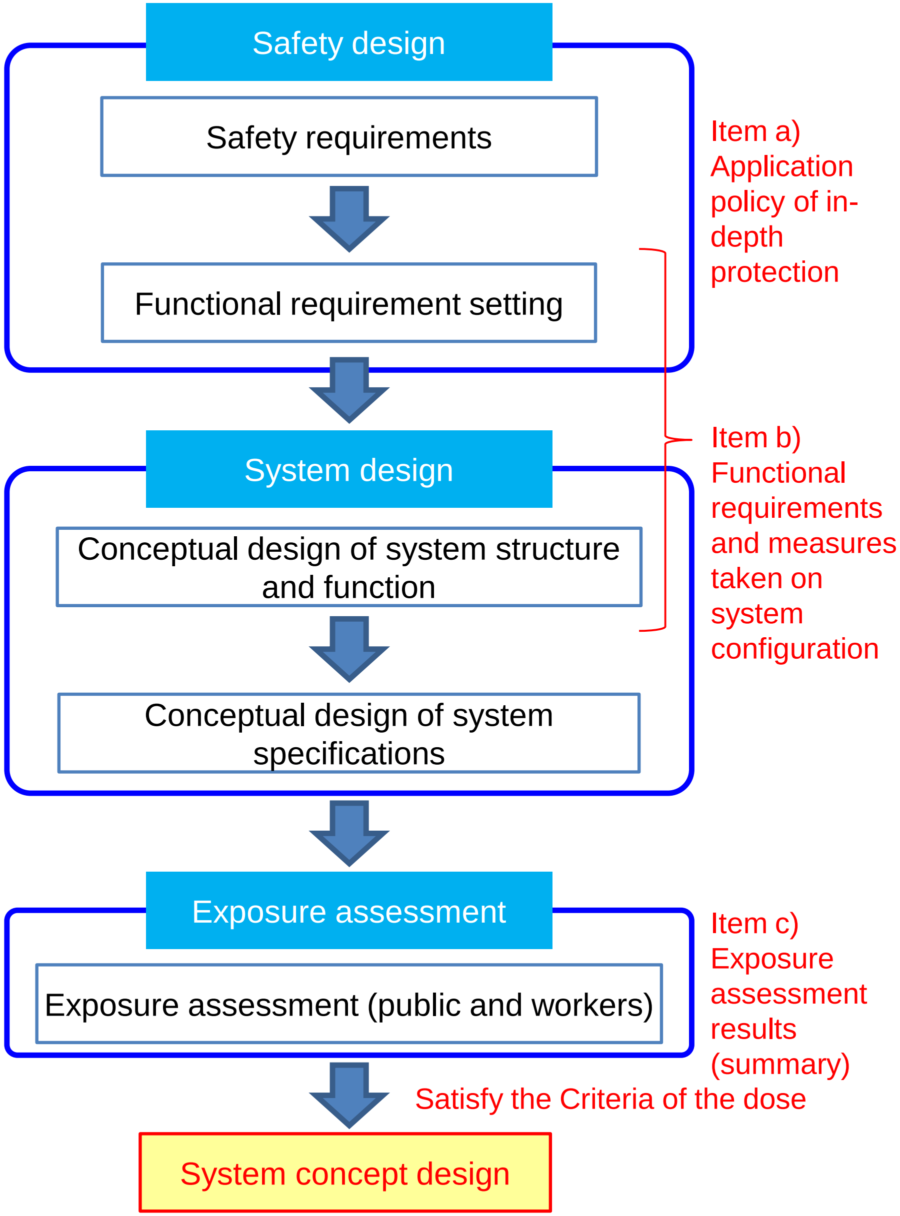
Inquiry into the analysis results

- Processing occupied most of the throughput time.
- In the scope of the throughput analysis conducted this time, it was found out that it will be difficult to achieve the target time period of 10 years.
- It is necessary to develop technology that will reduce the time taken in processing, which makes up most of the operation time. It is planed to classify fuel debris into more detailed groups, study different processing methods that reflect the classification results, develop operation-support tools to reduce the time required for processing, and study retrieval methods with reduced processing time.
- The impact of the size of collection containers was analyzed separately. The results showed that larger UC containers will reduce the number of transfers and will shorten the operation time.

Inquiry into the inputs that impact throughput

- In this analysis, interfering objects are simplified and deformation is ignored. A highly accurate analysis is achieved by checking for deformations in the internal investigation results and reflecting them in the analysis.
- The physical and mechanical characteristics of fuel debris affect the method of processing and measures for sub-criticality. Therefore, it is necessary to reflect future studies and sampling results.
- In this analysis, inspection involved in the transfer is included in the analysis conditions. If additional requirements (e.g., sorting, drying, inspection) arise before the transfer process, the transfer speed may become slower than the processing and collection speed, which would cause a bottleneck.
- In this analysis, the mass per fuel debris characteristic is estimated for each of the characteristics. A greater ratio of block fuel debris may lengthen the operation period. Therefore, it is important to develop processing methods that correspond to the fuel debris classification results.

VI. Implementation Details (4) Optimization Study on Ensuring Safety of Methods and Systems
(ii) Optimization of systems for ensuring safety



- To optimize the system, the project concept of the previous term was reviewed from the upper stream conditions to the lower stream. (The diagram on the left is a study flow in which system-related items are simplified.)
- From the next page onward, the following are summarized as important items of the system study.
  - a) Application policy of in-depth protection
  - b) Functional requirements and measures taken on system configuration
  - c) Exposure assessment results (summary)
- The goal of the system studied in this project (conceptual study) will be achieved when the exposure assessment results fall under the Criteria.

a) Application policy of in-depth protection

Application of in-depth protection in 1F fuel debris retrieval is effective in reducing the risk of events with high impact. In-depth protection shall be designed for random equipment failure, abnormal transition resulting from human error, and accidents in the light-water reactor.

<u>Definition of each protection level during 1F fuel debris retrieval operation</u>

Protection level	Definition	Level of frequency
Level 1	Prevent deviation from normal operation Prevent failure of a safety-significant facility	Create a layer that will maintain the normal state as much as possible to reduce the risk of Level 2 events
Level 2	Detect and control deviation from normal operation	Create a layer that will suppress the impact to an adequate level even when in an abnormal state in order to reduce the risk of Level 3 events
Level 3	Prevent events assumed in the design basis	Create a layer that will suppress the impact to a level allowable in terms of design Reduce the risk of events that occur in this layer (Level 3) to a level in which accidents are improbable

a) Application policy of in-depth protection

Criteria of each in-depth protection level during 1F fuel debris retrieval operation

Protection level	Criteria[*1] (public dose)	Criteria[*2] (worker dose)
Level 1	0.1 mSv/year	100 mSv/5 years, 50 mSv/year
Level 2	0.1 mSv/event	10 mSv/event
Level 3	5 mSv/event	100 mSv/event

*1. Criteria are specified with reference to the allowable dose for the in-depth protection level of the light-water reactor
Level 1: 1/10 of the public dose limit at normal times
Level 2: allowable dose that prevents a significant rise in the risk of possible events in this level
3: Criteria dose during an accident specified in the safety assessment policy

*2. Specified based on the dose limit provided in the law

b) Reflect safety design progress on system design

- **A proposal for the environment control system configuration that complies with the safety requirements of each level (1–4) is shown in the table below.**
- **Those in red will be the fundamental configuration, and others will be listed as options.**
- **The basic conditions of the gas phase system regarding the studied system configuration will be shown as an example from the next page onward.**

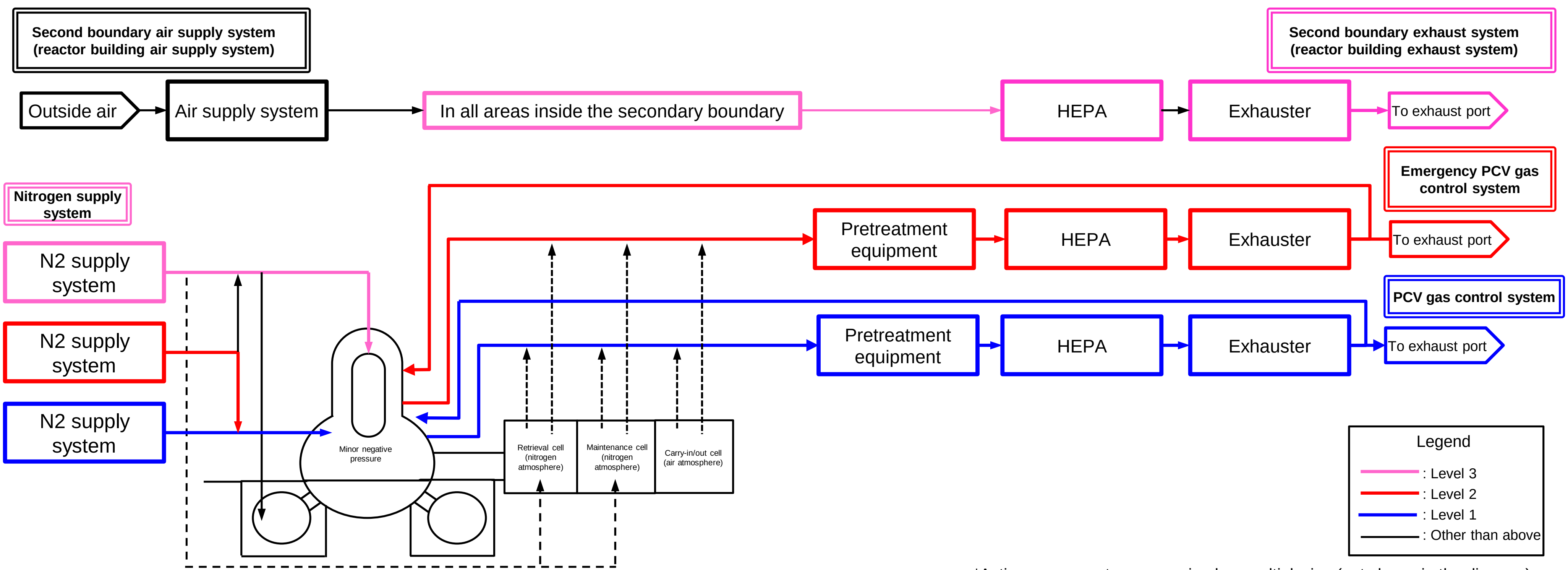
		Level 1	Level 2	Level 3	Level 4 (reference)
Definition of state		Normal state	Abnormal state	During an accident	Disaster prevention
Aim of protection		Prevent deviation from normal operation Prevent failure of a safety-significant facility	Detect and control deviation from normal operation	Prevent events assumed in the design basis	Mitigate impact of exposure
System configuration	1) Gas phase leakage prevention	PCV gas control system	Emergency PCV gas control system	Second boundary gas exhaust system*1	Adaptive response and disaster prevention
	2) Liquid phase leakage prevention (no leakage from PCV)	Cooling water circulation system (D/W)	Cooling water circulation system (S/C)	Emergency torus room drainage system*1	
	2) Liquid phase leakage prevention (with leakage from PCV)	Cooling water circulation system (D/W)	Cooling water circulation system (S/C)		
		Torus room drainage system	Monitoring system Auxiliary equipment for Level 1 measures (equipment for response to equipment abnormality)		
	3) Criticality prevention*2 (Reactor reactivity margin: **Small**)	Neutron absorption material (soluble)	Monitoring system Auxiliary equipment for Level 1 measures (equipment for response to equipment abnormality)	Emergency standby liquid control system*1	
		Neutron absorption material (insoluble)			
	3) Criticality prevention*2 (Reactor reactivity margin: **Large**)	Water level control system *No neutron absorption material	Neutron absorption material (soluble or insoluble) Water level control system		
	4) Decay heat removal	Cooling water circulation system (circulation cooling)	Emergency cooldown system (circulation cooling)	Emergency cooldown*1	

*1 Independent system for Level 3 Review use of transportable systems as necessary (Determined by considering the maximum amount of materials that can be installed in the building and measures against uncertainties)
*2 In criticality approach monitoring, monitoring systems (neutron monitoring system or FP gas monitoring system) are selected for every level of each unit.

Reflect safety design progress on system design

- The overall structure of the gas phase system (Levels 1–3 of in-depth protection) studied based on the safety requirements is shown in the schematic below.
- Functional requirements that crystallize and fractionalize the safety requirements of each level and the measures taken on the system configuration will be shown on the next page.

Conceptual diagram of the gas phase system (overall) [pressure control: recirculation method]



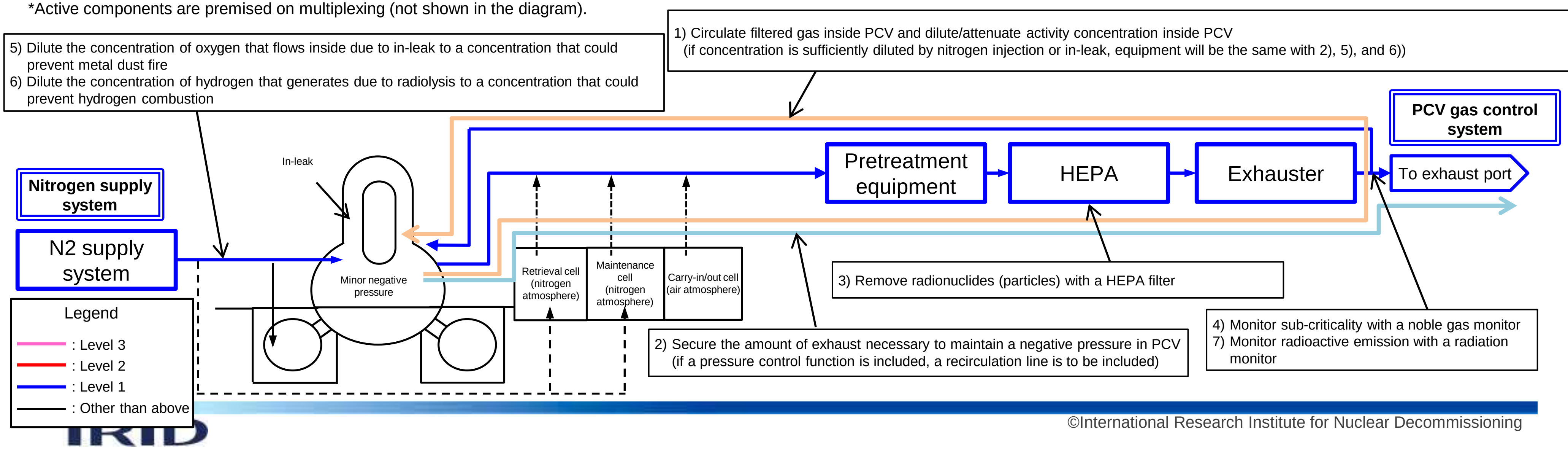
*Active components are premised on multiplexing (not shown in the diagram).

Reflect safety design progress on system design

Functional requirements of Level 1 protection against gas-phase contaminants and the measures taken (system-related expert)

Safety requirements	Protection level	Functional requirements	ID
Prevent leakage that exceeds the allowable level specified in the safety standards for gas-phase radioactive materials	Level 1	Reduce the concentration of radioactive materials within the primary boundary (PCV, cell) to a value equal to or less than the control standard value	1)
		Prevent the leakage of gas-phase radioactive materials that exceed the allowable level specified in the safety standards from the primary boundary using a dynamic boundary	2)
		Regarding exhaust to maintain a dynamic boundary, prevent the emission of gas-phase radioactive materials that exceed the allowable level specified in the safety standards into the environment	3)
Prevent the abnormal generation of radioactive materials caused by nuclear reaction	Level 1	Reduce reactivity to a level equal to or below the control standard value	4)
Maintain conditions under which a fire will not break out by the reaction of metal dust and oxygen	Level 1	(PLAN-A) Maintain an oxygen concentration equal to or below the control standard value and suppress a rise in the concentration of metal dust (PLAN-B) Suppress a rise in the concentration of metal dust =>The structure of PLAN-A is adopted in this document.	5)
Maintain the concentration of flammable gas equal to or below the flammability limit to prevent fire and explosions	Level 1	Reduce the hydrogen concentration within the primary boundary by nitrogen replacement to a value equal to or less than the control standard value	6)
Monitor the plant to keep track of its state	Level 1	Equip a monitoring function to control radioactive release into the environment	7)

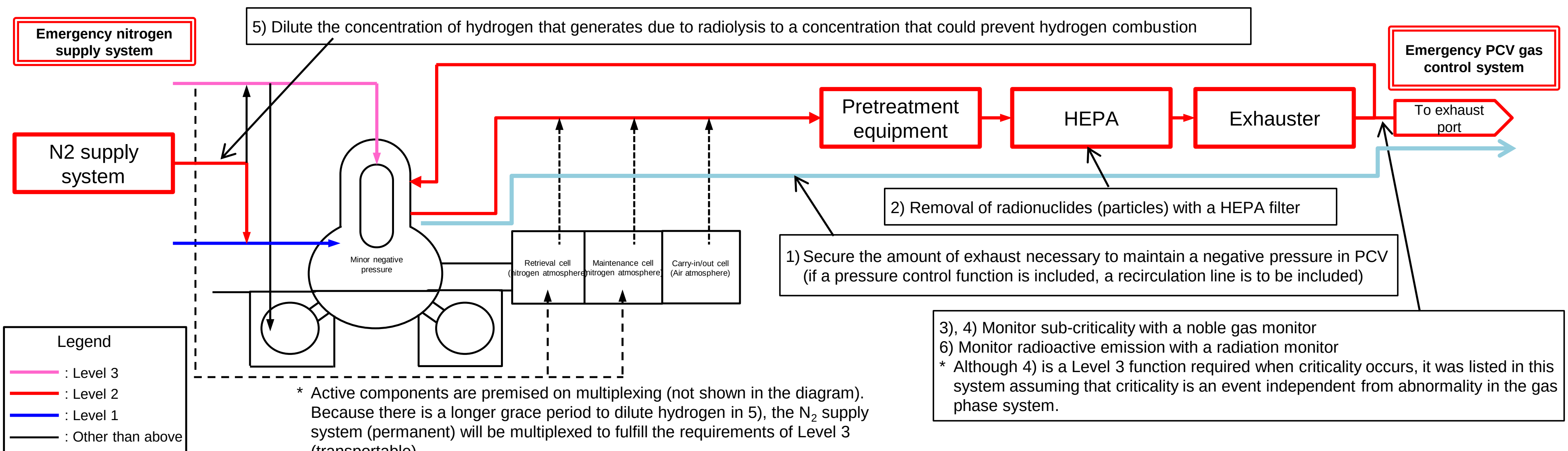
*Active components are premised on multiplexing (not shown in the diagram).



Reflect safety design progress on system design

Functional requirements of Level 2 protection against gas-phase contaminants and the measures taken (system-related expert)

Safety requirements	Protection level	Functional requirements	ID
Prevent leakage that exceeds the allowable level specified in the safety standards for gas-phase radioactive materials	Level 2	Prevent the leakage of gas-phase radioactive materials that exceed the allowable level specified in the safety standards from the primary boundary using a dynamic boundary	1)
		Regarding exhaust to maintain a dynamic boundary, prevent the emission of gas-phase radioactive materials that exceed the allowable level specified in the safety standards into the environment	2)
Prevent the abnormal generation of radioactive materials caused by nuclear reaction	Level 2	Prevent criticality during gas phase and liquid phase leakages so that the emission of radioactive materials does not exceed the dose standards required in Level 2	3)
	Level 3	Be able to stop the nuclear reaction immediately when criticality occurs	4)
Maintain the concentration of flammable gas equal to or below the flammability limit to prevent fire and explosions	Level 2	Be able to reduce the hydrogen concentration by replacing with nitrogen using alternative equipment in case the hydrogen concentration inside the primary boundary exceeds the Level 1 management guideline value	5)
Monitor the plant to keep track of its state	Level 2	Equip a monitoring function to control radioactive release into the environment	6)



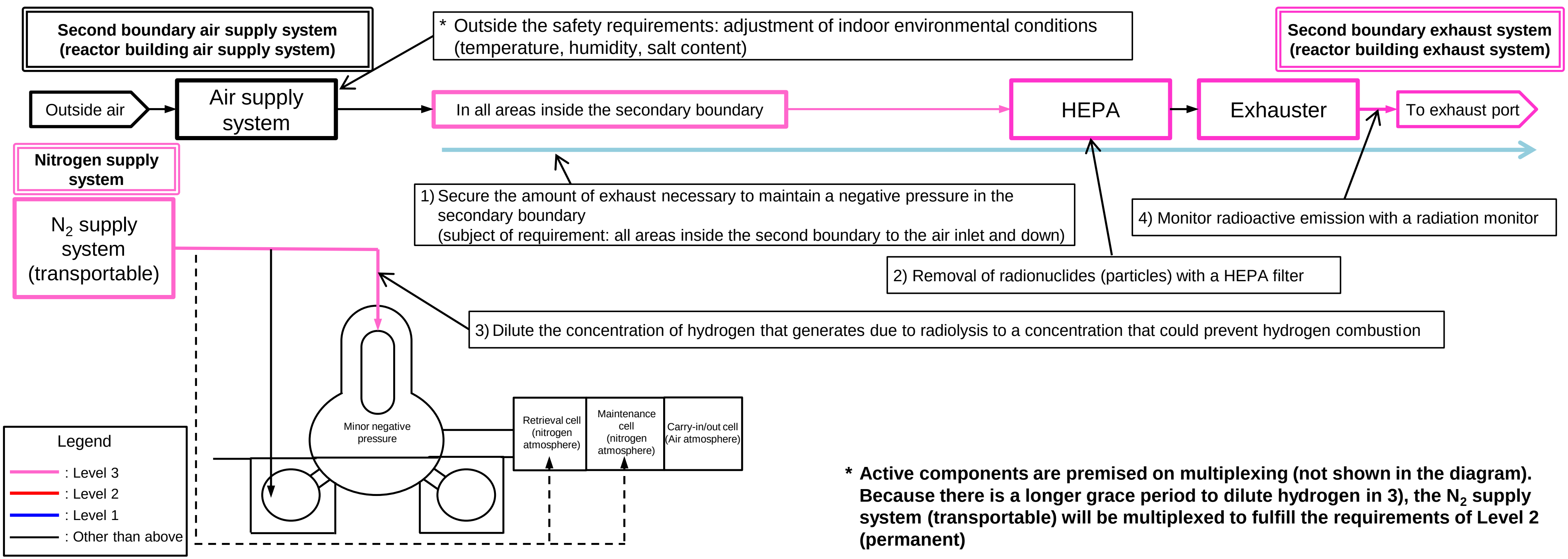
* Active components are premised on multiplexing (not shown in the diagram). Because there is a longer grace period to dilute hydrogen in 5), the N_2 supply system (permanent) will be multiplexed to fulfill the requirements of Level 3 (transportable).

(ii) Optimization of systems for ensuring safety

Reflect safety design progress on system design

Functional requirements of Level 3 protection against gas-phase contaminants and the measures taken (system-related expert)

Safety requirements	Protection level	Functional requirements	ID
Prevent leakage that exceeds the allowable level specified in the safety standards for gas-phase radioactive materials	Level 3	Prevent the leakage of gas-phase radioactive materials that exceed the allowable amount specified in the safety standards from the secondary boundary with a dynamic boundary	1)
		Regarding exhaust to maintain a dynamic boundary, prevent the emission of gas-phase radioactive materials that exceed the allowable level specified in the safety standards into the environment	2)
Maintain the concentration of flammable gas equal to or below the flammability limit to prevent fire and explosions	Level 3	Be able to reduce the hydrogen concentration by replacing with nitrogen using alternative equipment in case the hydrogen concentration inside the primary boundary exceeds the Level 1 management guideline value	3)
Monitor the plant to keep track of its state	Level 3	Equip a monitoring function to control radioactive release into the environment	4)



*** Active components are premised on multiplexing (not shown in the diagram). Because there is a longer grace period to dilute hydrogen in 3), the N_2 supply system (transportable) will be multiplexed to fulfill the requirements of Level 2 (permanent)**

c) Identification of abnormal events and results of exposure assessment

Identification of abnormal events (1/3)

[Assumed conditions of the normal state (Level 1) for the identification of abnormal events]

- It was premised that the boundary function is maintained in the normal state and there will be no leakages from the boundary. In addition, abnormal events were identified on the understanding that leakage and shielding measures are taken as part of the facility measures even in cases where there is transfer of the radiation source (e.g., contaminant) in the piping duct due to the continuation of normal operation.

[Study on exposure assessment for the abnormal state (Level 2) and during an accident (Level 3)]

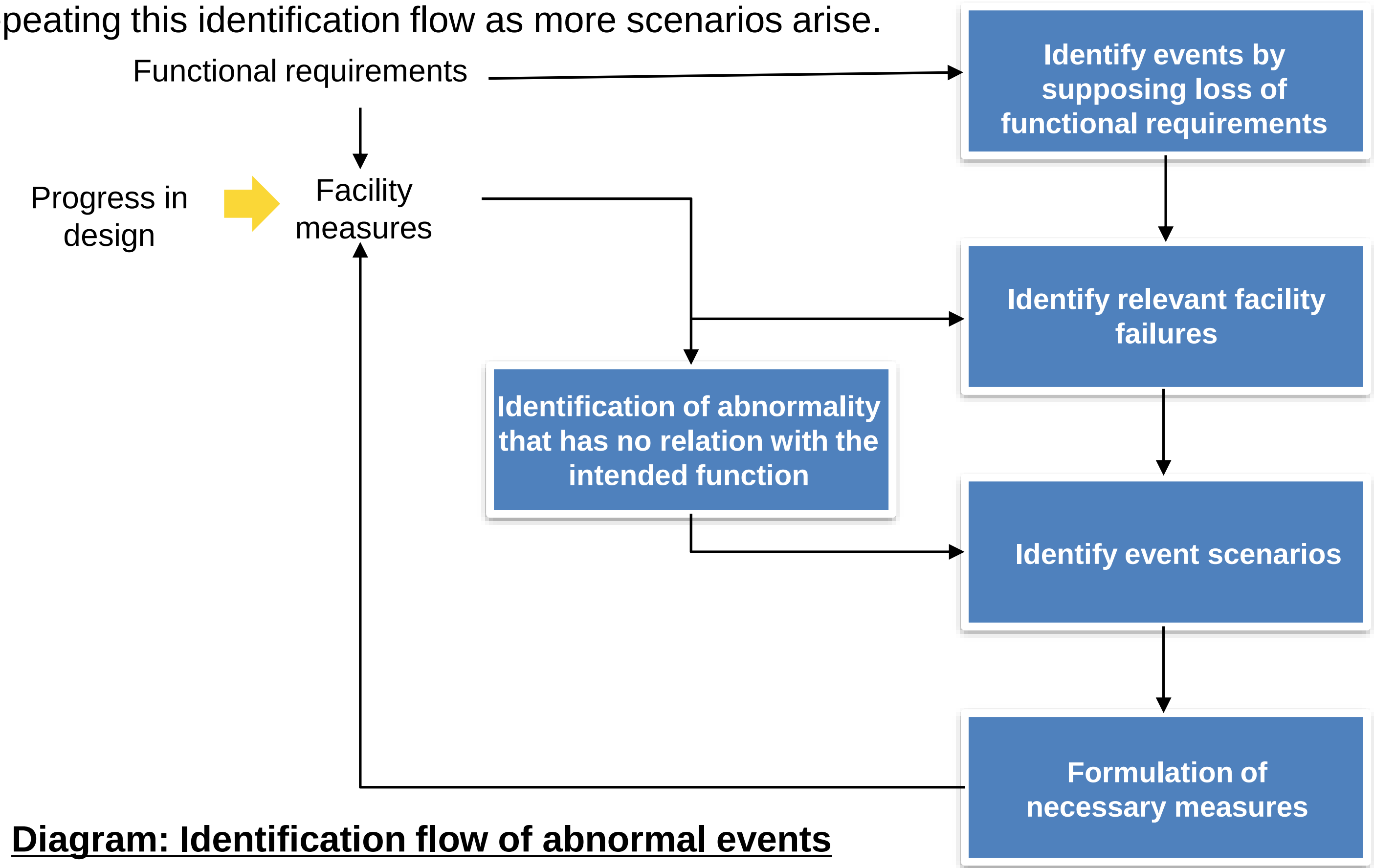
- The intention was to use measures that would fulfill the functional requirements specified for each of the safety requirements. Level 2 events are cases in which the in-depth protection Level 1 function is lost, and Level 3 events are cases in which the Level 2 functions are lost. Based on this, specific events (event scenarios) that may cause abnormal events were identified.

- The leakage ratio of each emission route (e.g., ratio of leakage from the primary boundary to the secondary boundary) in relation to the abnormal state (e.g., air conditioner shutdown) was specified. The emission ratio was calculated taking into account the route of emission into the environment for each of the event scenarios, and exposure assessment was conducted.

c) Identification of abnormal events and results of exposure assessment

Identification of abnormal events (2/3)

- Abnormal events (loss of function) were identified based on the functional requirements specified for each safety requirement.
- Abnormal events refer to events other than the intentional loss of function (e.g., dropping the equipment). (Requires further identification in the future)
- There will be more event scenarios as progress is made on facility design. Event identification is aimed to be improved by repeating this identification flow as more scenarios arise.



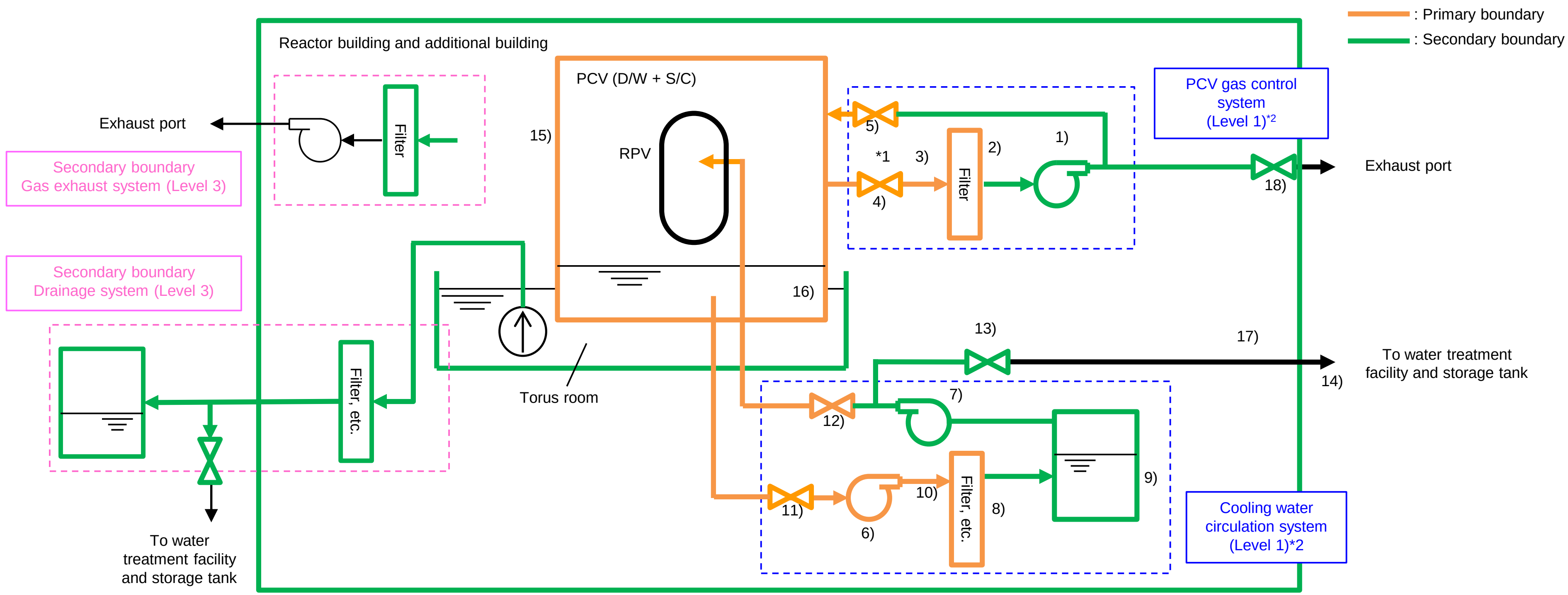
<u>Diagram: Identification flow of abnormal events</u>

c) Identification of abnormal events and results of exposure assessment

Identification of abnormal events (3/3)

Schematic of boundary structure and locations of assumed failure

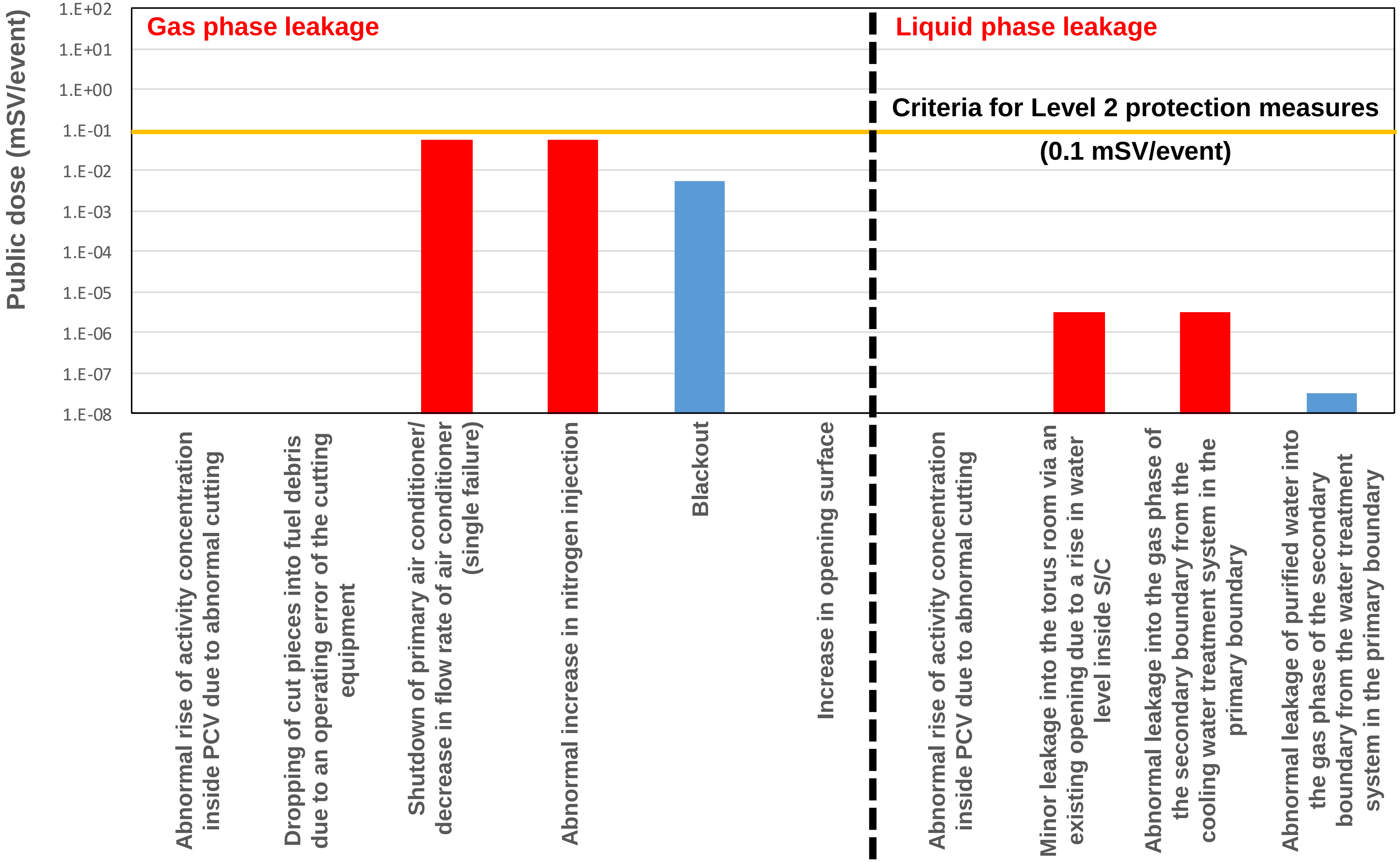
- Verify the consistency of facility design and event identification on the confinement function and check for any oversight in the identified abnormal events.
- Exposure assessment on the supposition of abnormalities (leakage, performance decrement) was conducted on 1)–18) in the figure below.



*1: Under the condition that exceeds Level 1, a boundary is provided in the Level 1 facility up until the isolation valve concerned.
*2: The structure of Level 1 is shown as a representative example because the structure of Level 2 is similar.

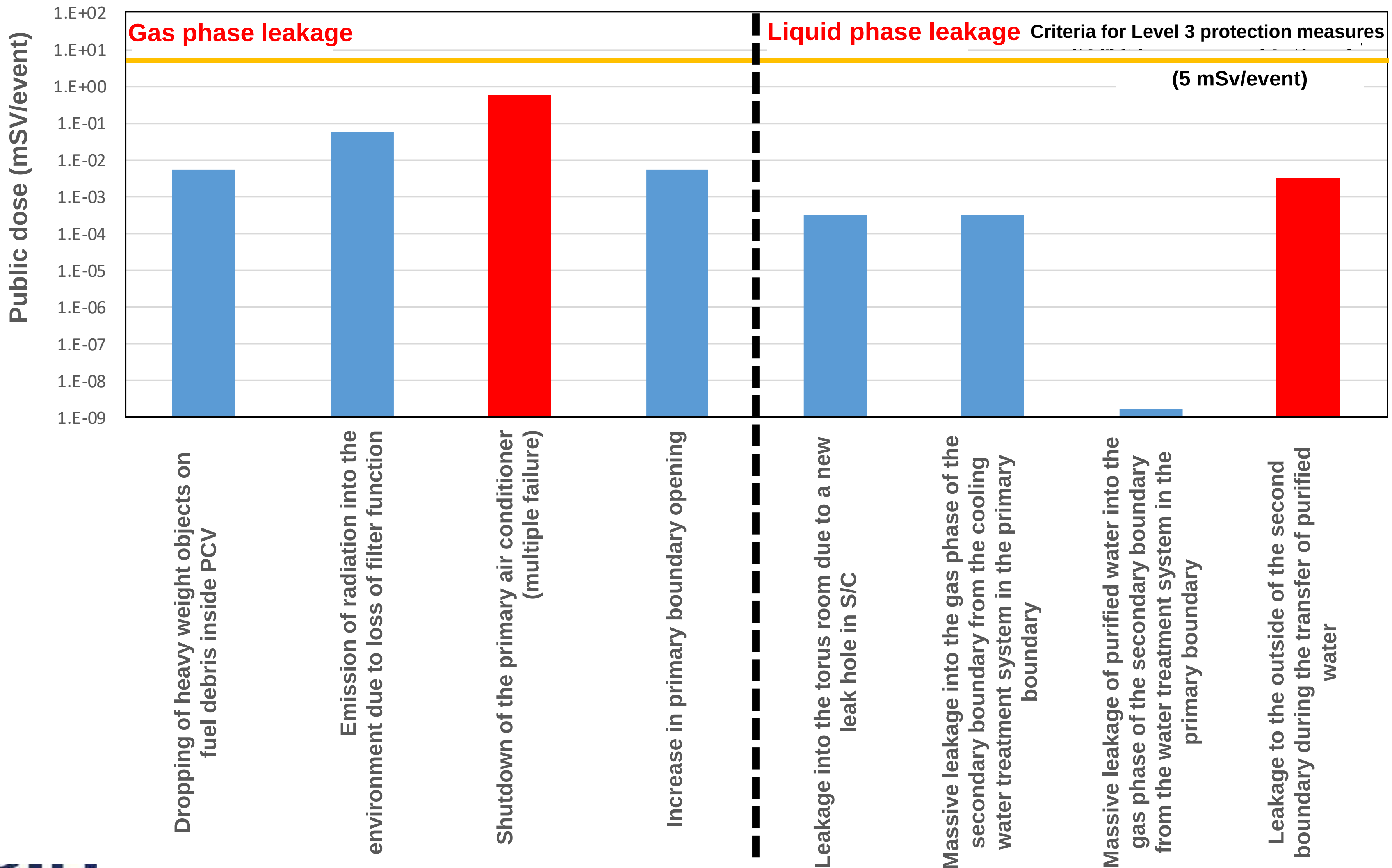
c) Identification of abnormal events and results of exposure assessment

Exposure assessment results (Level 2)



c) Identification of abnormal events and results of exposure assessment

Exposure assessment results (Level 3)



c) Identification of abnormal events and results of exposure assessment

Summary of exposure assessment results (gas phase)

- **Criteria of each in-depth protection level and results of exposure assessment (gas phase)**

	Public dose		Worker dose	
Protection level	Criteria[*1]	Evaluation result	Criteria[*2]	Evaluation result
Level 1	0.1 mSv/year	Up to 8.4 μSv/y (exposure due to exhaust during fuel debris retrieval operation)	100 mSv/5 years, 50 mSv/year	- (Trial calculation for the thickness of the required shielding)
Level 2	0.1 mSv/event	Up to 56 μSv/event	10 mSv/event	Up to 0.39 mSv/event[*3, 4] (Exposure during evacuation)
Level 3	5 mSv/event	0.56 mSv/event[*5] (Leakage from the primary boundary)	100 mSv/event	

*1. Criteria are specified with reference to the allowable dose for the in-depth protection level of the light-water reactor
*2. Specified based on the dose limit provided in the law
*3. Assumed scenario: basis case, with a full-face mask, 1 m^3/h leakage from PCV
*4. 390 mSv/event in a basis case with a full-face mask and no measures for massive leakage (assumed leakage from PCV: 1,000 m^3/h)
*5. 56 mSv/event if there is no secondary boundary

c) Identification of abnormal events and results of exposure assessment

Summary of exposure assessment results (liquid phase)

- **Criteria of each in-depth protection level and results of exposure assessment (liquid phase)**

	Public dose		Worker dose	
Protection level	**Criteria*1**	**Evaluation result**	**Criteria*2**	**Evaluation result**
Level 1	**0.1 mSv/year**	**- (No leakage in the normal state. The target of the water treatment facility is the value equal to or less than the emission concentration limit notified.)**	**100 mSv/5 years, 50 mSv/year**	**- (Trial calculation for the thickness of the required shielding)**
Level 2	**0.1 mSv/event**	**Up to 3.2 × 10^{-3} μSv/event**	**10 mSv/event**	**- (As it takes time for radioactive materials to transfer from the leaked water to the gas phase, it is assumed that evacuation is possible.)**
Level 3	**5 mSv/event**	**3.2 μSv/event (during leakage to the outside of the secondary boundary)**	**100 mSv/event**	

*1. Criteria are specified with reference to the allowable dose for the in-depth protection level of the light-water reactor
*2. Specified based on the dose limit provided in the law

d) Summary

(1) Based on the functional requirements specified for each of the safety requirements, exposure assessment was conducted on a scenario that assumes a loss of function or any other unintended abnormality (dropping of components, requires further identification of possible abnormalities in the future).

(2) An exposure assessment method that takes the specific conditions of 1F into account was also studied (exposure to radiation attendant on worker evacuation during a gas leak, exposure with consideration given to gas phase transfer during a liquid leak). From this, the concentration conditions necessary to achieve the safety goal during leakage were verified.

(3) The environment control system during fuel debris retrieval operation holds out the prospect of achieving the target of the conceptual study because the results of the exposure assessment (final step of the verification process) were lower than the Criteria. [Summary of the current situation]

(4) Various parameters used in event scenarios and exposure assessment have a certain level of uncertainty that results from the estimation of actual conditions. Therefore, it is necessary to reflect detailed facility designs and the know-how obtained up until large-scale retrieval (including the dispersion factor during processing) and revise the parameters. [Future issues]

Terminology

No.	Terms	Definition
1	1F	Fukushima Daiichi Nuclear Power Station
2	PCV	Primary containment vessel
3	RPV	Reactor pressure vessel
4	CRD	Control rod drive
5	D/W	Drywell
6	S/C	Suppression chamber
7	BSW	Biological shielding wall
8	MCCI	Molten core concrete interaction
9	GOTHIC code	One of the general-purpose thermal-hydraulic analysis codes (developed by EPRI and ZACHRY)
10	Am	Americium (of all the radionuclides contained in fuel debris, americium has an exposure impact equivalent to that of plutonium and requires caution)