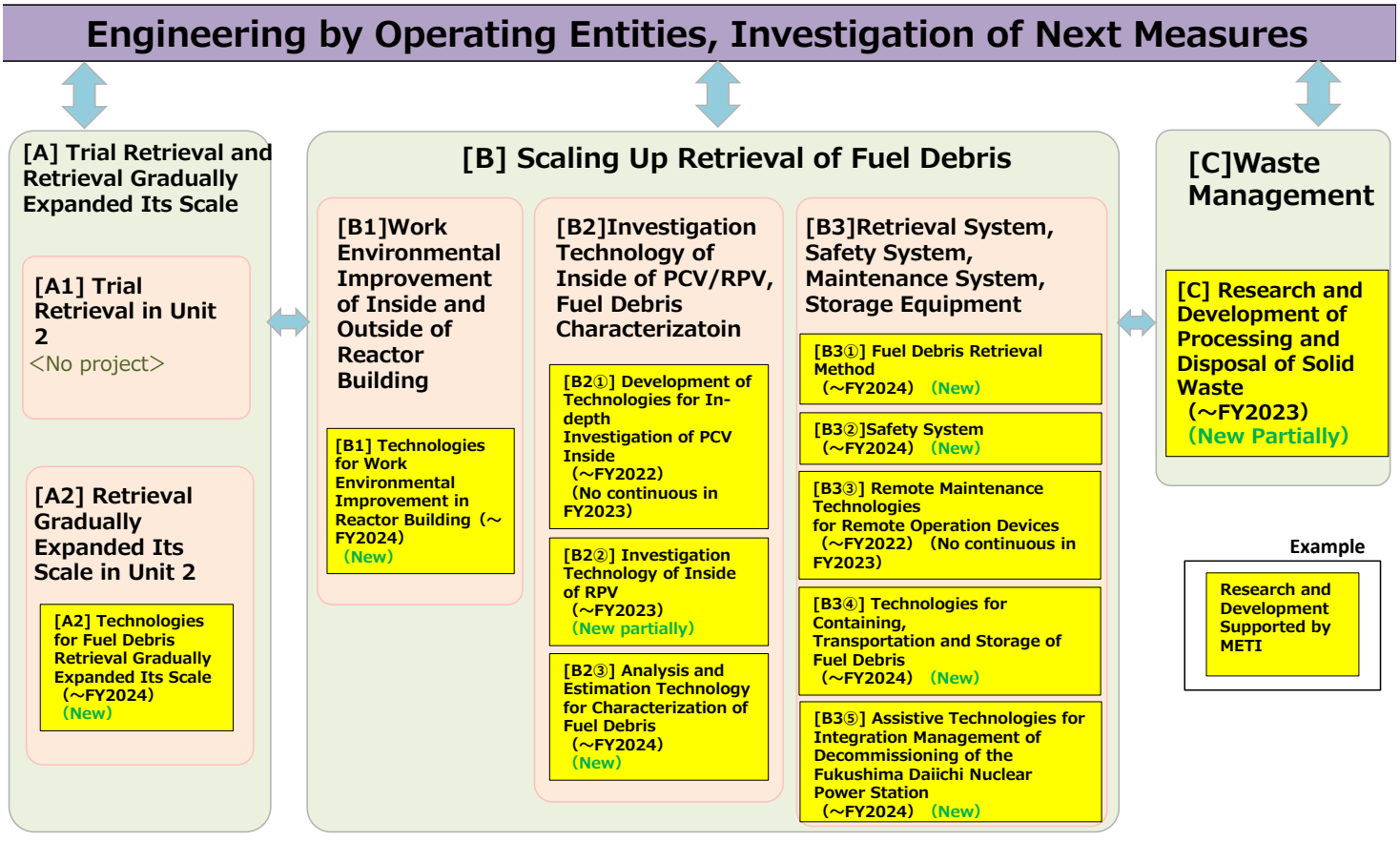
The Decommissioning Research and Development Plan for FY2023



A2： Development of Technologies for Fuel Debris Retrieval Gradually Expanded Its Scale

Purpose

Technologies for Fuel Debris Retrieval Gradually Expanded Its Scale shall be developed for the purpose to contribute to rationalization of criticality control, equipment design and works procedure related to fuel debris retrieval works and risk reduction of fuel debris by its retrieval.

Implementation Content

- ○ The plan of Development of Technologies for Fuel Debris Retrieval Gradually Expanded Its Scale shall be formulated and updated. Also access device for fuel debris retrieval shall be developed and mock-up test simulating actual facility situation shall be conducted for confirming on-site applicability.
- ○ This research and development shall be executed in collaboration with Operating Entity engineering reflecting operators' point of view of Operating Entity and the results shall be used in the engineering conducted by the Operating Entity.

1. Development of Technologies for Fuel Debris Retrieval Gradually Expanded Its Scale

（1） Updating of the Development Plan of Retrieval Technology

As it is assumed that there will be extracted the tasks to be reflected in technologies for fuel debris retrieval gradually expanded its scale (system, equipment for retrieval etc.) which are based on the results of trial retrieval and mock-up test of investigation of inside of PCV and preparation results of on-site investigation, the development plan shall be updated to enable these improvements.

（2）Development of Equipment and System for Retrieval.

① Test for Arm Functions Confirmation

The test for whole arm including arm and arm tip tool (fuel debris cutting and collection device, neutron monitor, etc.) shall be conducted and the existence of necessary functions shall be confirmed. Furthermore, in addition to arm basic functions (elasticity, X-6 penetration passing ability, etc.), knowledge obtained from access device for preceding trial retrieval and investigation inside PCV shall be appropriately reflected and the improvement will be implemented.

② Combination test for Arm and Enclosure

Combination test of enclosure (including dual arm manipulator for maintenance) and arm (including arm tip tool) shall be conducted. And applicability for series of works from collection of fuel debris from inside pedestal up to carry-out from enclosure shall be confirmed.

③ Mock-up test

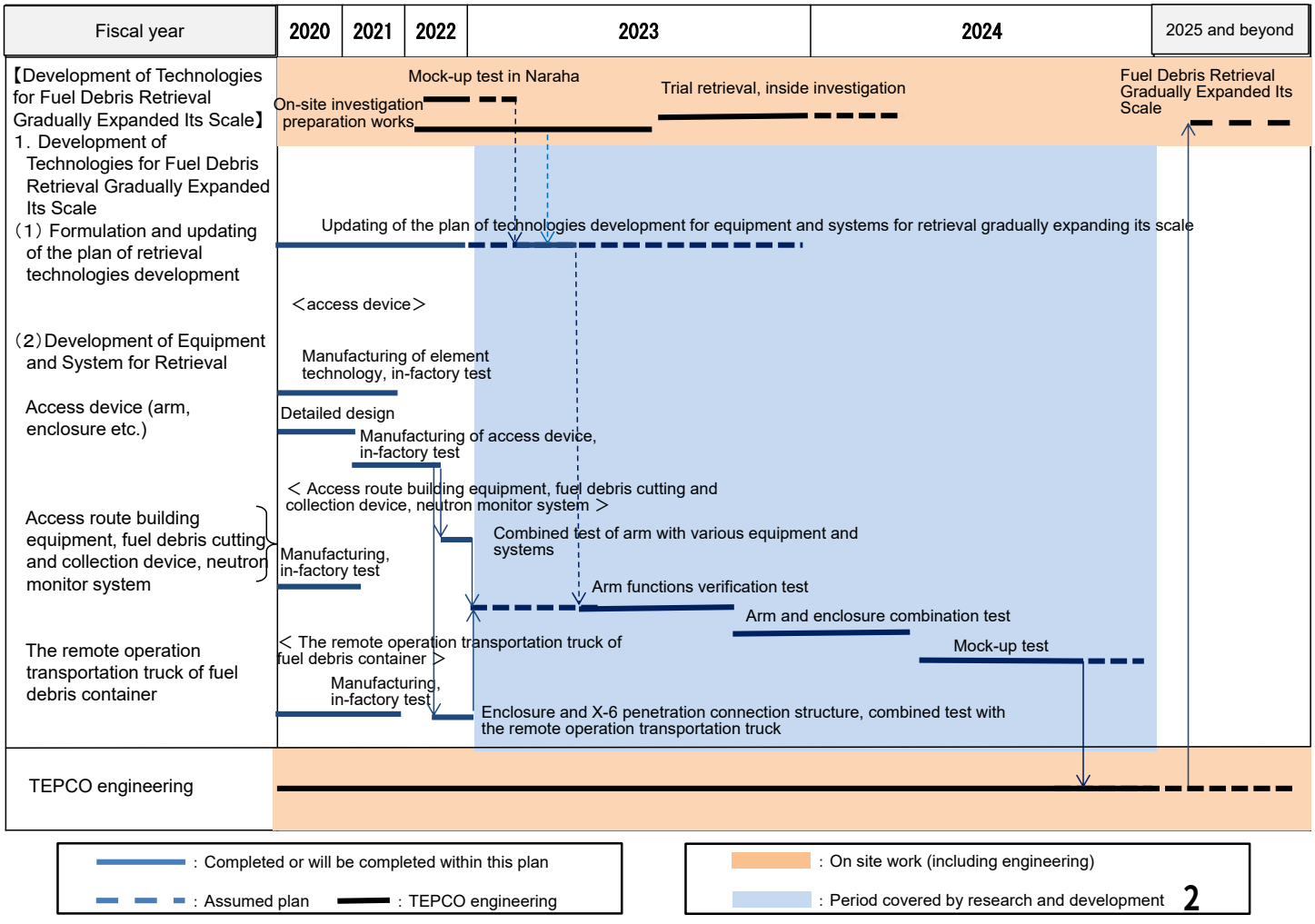
Mock-up test shall be conducted using mock-up facility simulating actual facility and on-site applicability shall be confirmed.

※ The decision about the start period of this project will be taken based on the progress of mock-up test of trial retrieval and investigation inside PCV ,etc.

Definition of criterion for judgment on objective achievement

- ・ Updating of the plan of development technologies for fuel debris retrieval gradually expanded its scale (FY2023～FY2024)
- ・ Test for arm functions confirmation (FY2023～FY2024)
- ・ Combination test of arm and enclosure, and confirmation of on-site applicability by mock-up test (FY2024)

（Implementation schedule）A2： Development of Technologies for Fuel Debris Retrieval Gradually Expanded Its Scale



B1： Development of Technologies for Work Environmental Improvement in Reactor Building

Purpose

Towards the scaling up retrieval of fuel debris and internal structure, technology related environmental improvement shall be developed as it is necessary for safe and efficient work inside the Reactor Building (R/B), where there are still places where the damage status caused by the accident is unknown and the dose rate is still high.

Implementation Content

○Prior to fuel debris retrieval, environmental improvement is necessary for safe and efficient preparatory work for construction of access route in R/B, where there are still places where the damage status caused by the accident is unknown and the dose rate is still high. As an important technical elements for environmental improvement, it is necessary to formulate an exposure dose reduction plan corresponding to recognition of work environment and the dose and the radioactive source distribution, and the changes of the work environment. Regarding technology and devices related to it, taking into consideration the environmental improvement work which is required at any time during the fuel debris retrieval period, survey, investigation and elemental tests shall be implemented to enable on-site application.

○This research and development shall be executed in collaboration with operator engineering and the results shall be used in the engineering conducted by the operator.

1. Development of Technologies for Work Environmental Improvement in Reactor Building

・Development for higher performance of exposure reduction technologies by digitalization of environment and radioactive source distribution

In order to implement works in the R/B for preparation of the construction of access route for fuel debris retrieval, it is necessary to reduce the exposure of workers as much as possible and to formulate safe and effective works plan. In order to do that, it is necessary to get the proper picture of the damage status of the structures, the equipment and the environment including radiation dose, etc. inside the R/B. In particular, it is important to identify high-dose radioactive sources and formulate a proper plan of response to dose changes ,etc. by removing equipment which are the radioactive source and installing shielding.

Therefore, by converting to a digital model of the environment data from inside of the R/B (position and shape of the equipment and structure, and radiation dose distribution etc.), the estimation system shall be developed which will conduct inverse estimation analysis of radiation dose distribution which should be the target for dose reduction. In addition, the exposure dose estimation and evaluation system shall be developed, and this system will enable to formulate the precise works plan to respond to environment changes caused by works inside the R/B and to consider presence or absence of works by remote devices, workers' moving routes, staying time and others by visualizing in the cyberspace the radiation dose and radioactive source distribution.

So far, elemental technologies like inverse estimation analysis technology and visualizing technology have been developed, and prototype systems of radiation dose and distribution including them have been developed and verified, and their effectiveness have been confirmed. But for on-site applicability, further systems' improvement and rationalization are necessary. Therefore, especially along with improvement of on-site applicability by improving efficiency of digital model creation, rationalization of inverse estimation analysis of radioactive source, labor saving in system operation and others, development shall be conducted based on maintenance and management of the system necessary during the period of environment improvement works.

(notes)

This develpment should be carried out considering operability and maintenance method related to the following:

・The operation basically shall be remote as it will be performed in a high dose area.

・It is necessary to consider contamination and necessary decontamination of devices.

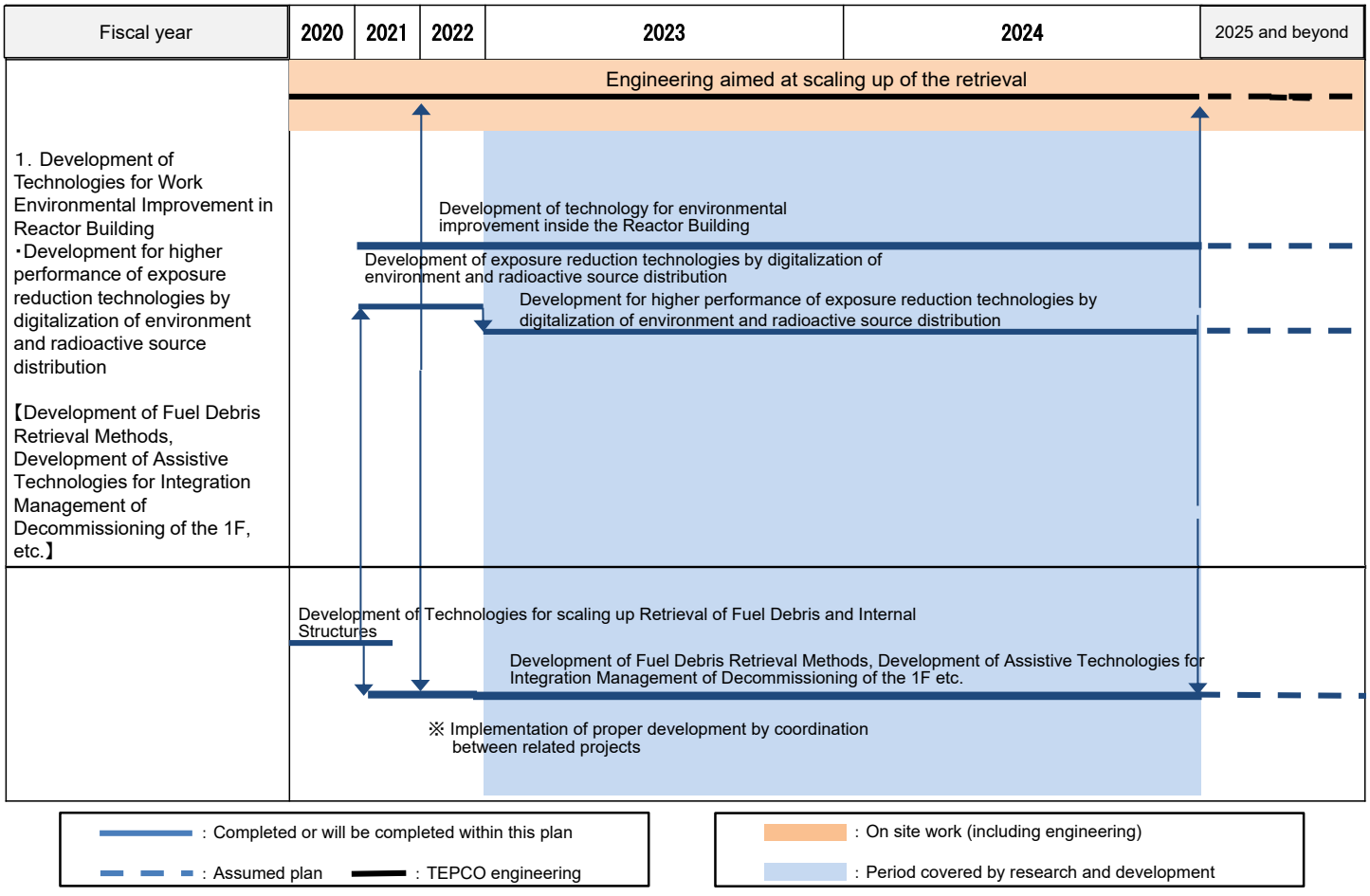
・The area for maintenance works is limited.

・It is necessary to limit the waste generated by the maintenance works as much as possible.

Definition of criterion for judgment on objective achievement

・Conceptual study for higher performance of exposure reduction technologies by digitalization of environment and radioactive source distribution (FY2023), evaluation of on-site applicability (FY2024)

（Implementation schedule）B1： Development of Technologies for Work Environmental Improvement in Reactor Building



B2②: Development of Investigation Technologies of Inside of RPV

Purpose

In order to contribute to consideration concerning fuel debris retrieval inside of the Reactor Pressure Vessel (RPV), the investigation technology for grasping the situation of fuel debris inside RPV etc. shall be developed.

Implementation Content

○To check the situation such as situation and level of radiation inside RPV, devices and systems to carry the drilling devices for constructing an access route (new opening works etc.) and the investigation devices inside RPV etc. shall be developed while ensuring a confinement function by remote operation under high radiation and high contamination condition and carrying the investigation devices into RPV.

○This research and development shall be executed in collaboration with operator engineering and the results shall be used in the engineering conducted by the operator.

1. Development of Access-from-Bottom Investigation Method

① Updating of Access-from-Bottom Investigation plan, and Access and Investigation device development plan.

In case opening is confirmed by investigation from the bottom of RPV and the situation of presence or absence of opening in the bottom of RPV, regarding Access-from-Bottom Investigation Method which investigate the inside of the bottom part of RPV by inserting the investigation devices into the RPV through the opening, the investigation plan formulated until FY2021 and the development plan of Access-from-Bottom Investigation devices shall be updated if necessary.

② Basic design, manufacturing and verification test of Access-from-Bottom Investigation devices

Based on the results of conceptual studies of Access-from-Bottom Investigation devices carried out until FY2021, the basic design and manufacturing shall be conducted and then its necessary functions shall be confirmed by in-factory verification test of a single unit.

In addition, verification test simulating the situation of actual application shall be carried out and on-site applicability shall be confirmed.

2. Upgrading of processing technology in the Access-from-Top Investigation Method

As processing technologies of constructing an access route by cutting and drilling internal structures, regarding the processing technologies (AWJ, laser cutting) selected from the viewpoint of cutting performance and secondary waste etc. until FY2021, the test shall be carried out under the conditions of actual application (remote, dimensional limitations, etc.) and the necessary functions of processing technologies shall be confirmed.

In addition, verification test simulating the situation of actual application shall be carried out and on-site applicability shall be confirmed.

3. Development of Investigation Technology of Inside of RPV by using Existing Pipes

Using high radiation resistant small fiberscope, a development plan shall be formulated for the following technologies which have issues in the process of inside investigation conducting access inside RPV by the existing pipes (core spray(CS) system, main steam (MS) system, etc.).

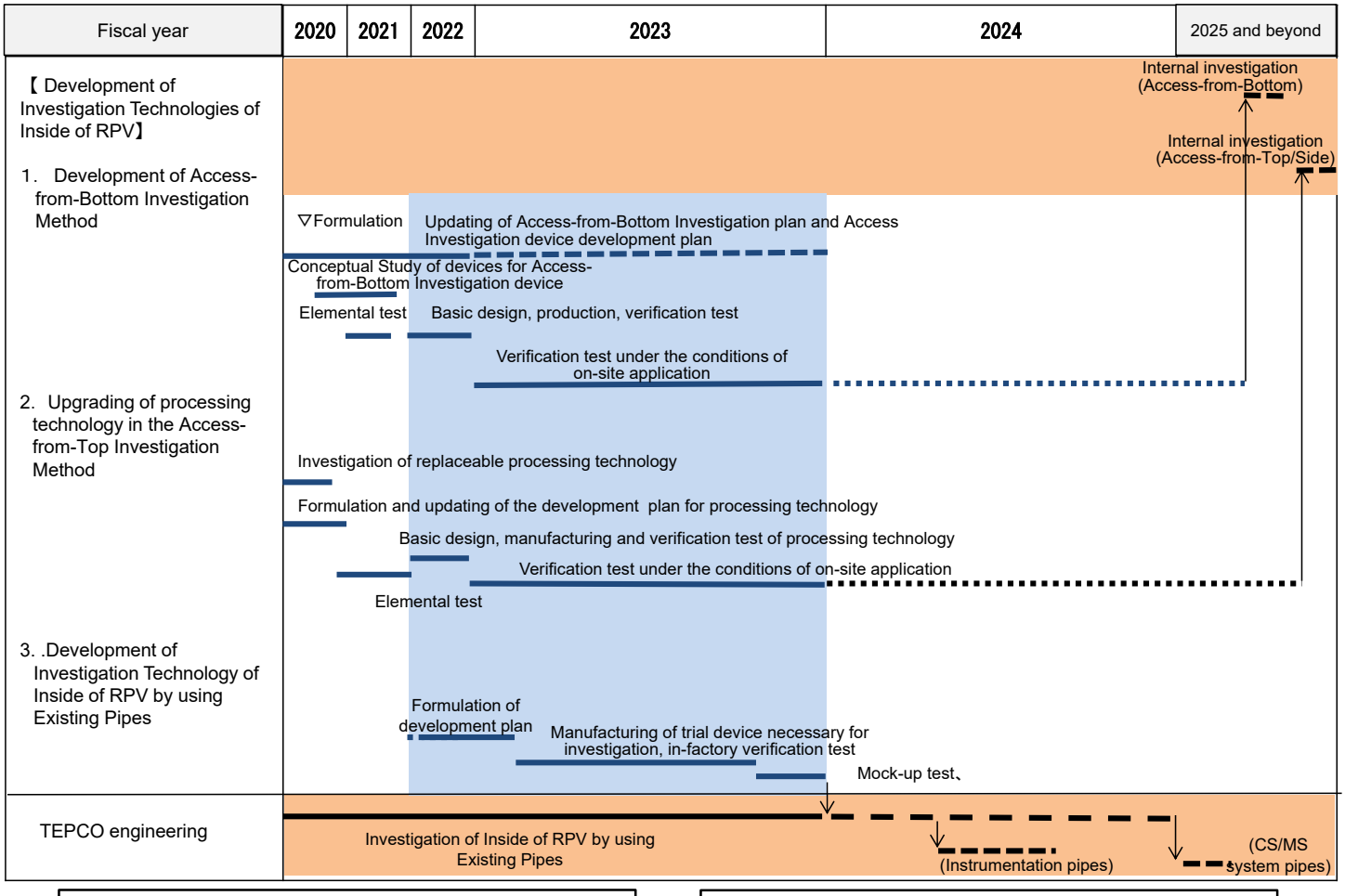
According to the development plan, a trial device shall be developed and then on-site applicability shall be confirmed by mock-up test.

- Technology for passing through the equipment (valves, orifice, tees etc.) that blocks the access to RPV.
- Technology for passing through pipes (vertical part, elbow part etc.) and reaching RPV

Definition of criterion for judgment on objective achievement

- Confirmation of on-site applicability of the Access-from-Bottom Investigation device by trial devices and tests (FY2023)
- Confirmation of on-site applicability by tests of processing technology for internal structures in the Access-from-Top Investigation (FY2023)
- Confirmation of on-site applicability by mock-up test of the device for internal investigation using existing pipes (FY2023)

（Implementation schedule）B2②: Development of Investigation Technologies of Inside of RPV



B2③: Development of Analysis and Estimation Technology for Characterization of Fuel Debris

Purpose

In order to contribute the development of methods for scaling up retrieval of fuel debris and internal structures and technologies for containing, transportation and storage of fuel debris etc., it has been implemented the development of necessary technologies etc. to analyze and estimate fuel debris properties.

Implementation Content

○Fuel debris produced by the first core meltdown accident at BWRs in the world have uneven compositions affected by a reaction with concrete and effect of the seawater injection, etc. and then include many poor solubility isobars and fission products. Therefore, it shall be implemented that development of analysis and estimation technology for characterization of fuel debris which include many uncertainties such as the formation process.
○The estimation technology for fuel debris characterization shall be developed by utilizing analysis and evaluation of on-site samples, then the methods for estimation on properties of fuel debris and display of PCV internal damaged condition shall be improved and also the analysis accuracy shall be improved..
○In order to realize safe and efficient retrieval and storage of fuel debris, the development of technologies for abbreviated analysis the existence of fuel components and for grasping non-destructively fuel amount in fuel debris shall be implemented.
○This research and development shall be executed in collaboration with operator engineering and the results shall be used in the engineering conducted by the operator.

1. Technology Development necessary for Analysis and Estimation of Fuel Debris Characteristics

① In order to implement safety assessment such as criticality control and storage management etc. for fuel debris retrieval, it is necessary to grasp fuel debris properties. However, it has unprecedented the fuel debris produced by BWR accident. It is difficult to analyze fuel debris properties because it includes insolubility and many isobars and fission product, in addition to the unknown of a reaction with concrete, effect of the seawater injection and temperature history during the formation process. For the development of analysis technologies of fuel debris, fuel debris and deposits etc. obtained from inside PCV shall be analyzed at research institutes which have hot lab facilities. Furthermore, based on the analysis results of fuel debris and deposits etc. and the formation mechanism of fuel debris in each Unit, “estimation of fuel debris properties” shall be advanced and the information shall be provided for various processes related to fuel debris retrieval.

② Though internal investigations of the PCV have been implemented, it is unknown which visual confirmed parts contain the nuclear fuel because it has obtained mainly images and the air dose rate data.

In order to lead to efficient fuel debris retrieval, in reference to the results of the deposits and adhesive materials analysis and on-site investigation obtained so far, it shall be implemented that melting and damaging tests among materials, accident progression analysis and evaluation for migration behavior of molten materials, then it shall be grasped the series of processes such as melting the nuclear fuel, damaging the RPV and downward flow of molten fuel into the pedestal etc. and also the distribution situation of fuel shall be estimated. Furthermore, main events occurred the damages of pedestal confirmed by internal investigations of PCV and such progression process and the analytical methods shall be studied. In order to present and understand the obtained results efficiently, it prepares the estimation figure of inside PCV by 3 dimensions CG shall be prepared.

③ Fuel debris have uneven compositions and include insolubility and many isobars and fission products. In addition, due to the effect from pretreatment and device at each hot lab facility, etc. when the analysis, distribution degrees of analysis results tend to be large. Previously, investigation related to the improvement of the reliability of analysis result and analysis accuracy have been implemented by conducting analyses of chemical compositions and structure etc. for fuel debris simulants that has same chemical compositions.

B2③: Development of Analysis and Estimation Technology for Characterization of Fuel Debris

However, it has not progressed the investigations for fuel debris properties affected the fuel after fission such as the content ratio of fission products, isotopic compositions of fuel etc. Using the fuel debris formed in Three Mile Nuclear Power Plant Unit 2 (TMI-2) accident as a sample, at each hot lab facility, it shall be confirmed the effectiveness for fuel debris of the analysis processes and pretreatment methods cultivated through analysis of fuel debris simulant so far, and then it shall be reflected into the efficiency of the analysis processes. Furthermore, the comparison data with TMI-2 sample and the fuel debris that will be obtained in the future at 1F on-site shall be obtained, while referring to common and different points of those fuel debris, it shall be reflected into the estimation for the formation process of fuel debris and accident progression, and investigation of safety measures and storage management. By attending global round robin tests for analysis of fuel debris, it shall be confirmed that Japan has sufficient capability of analysis abilities for fuel debris and acquired the findings of analysis evaluation by overseas research institutes.

- The considerations of above ①-③ shall be progressed with the discussion among experts in Japan and abroad and obtained finding by such discussion.

2, Development of abbreviated analysis and non-destructive technology of fuel debris

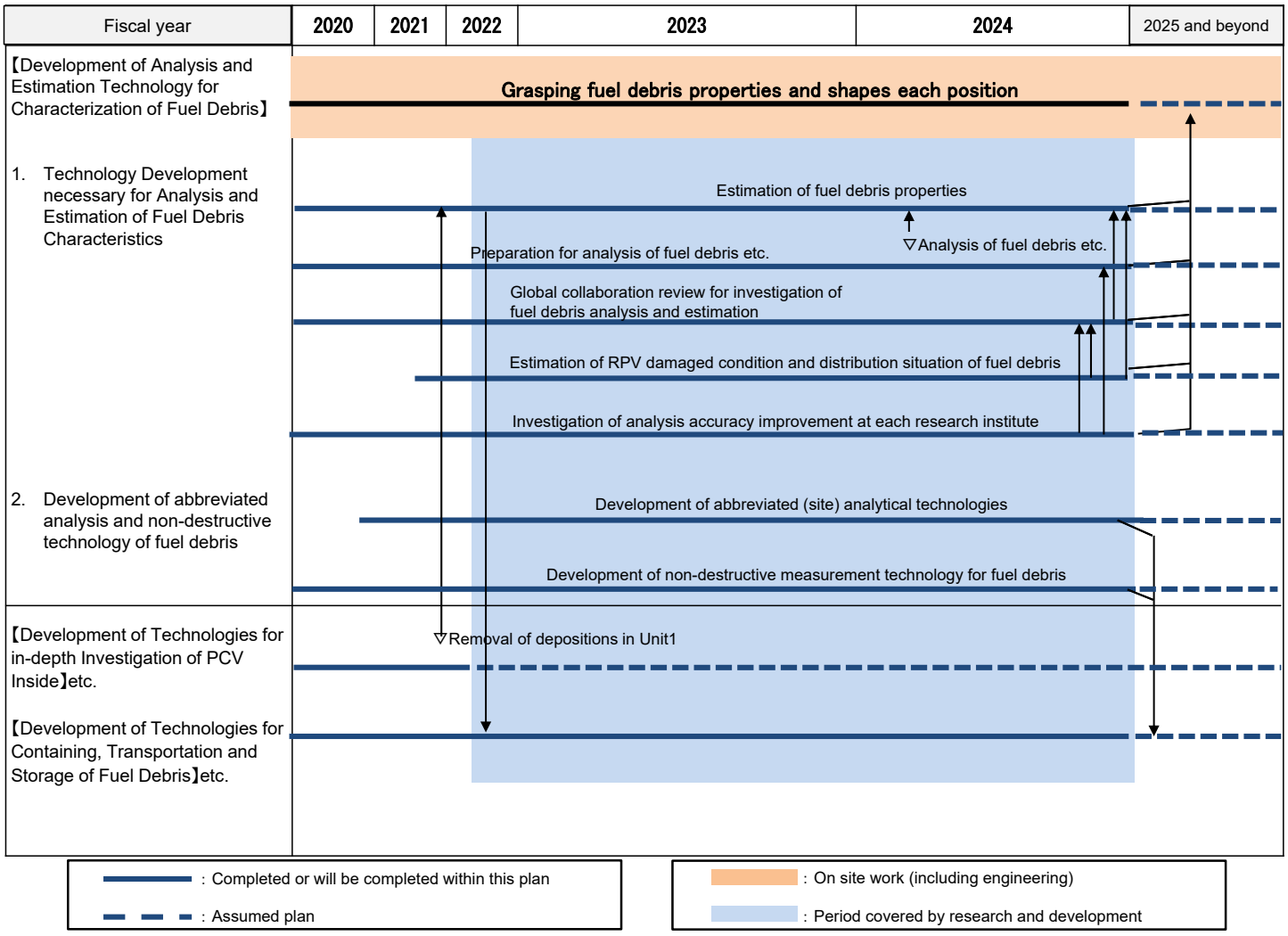
① Due to the results of previous internal investigation, adhesion of molten materials have been identified in the structural materials inside PCV. In order to identify the existence of fuel components in the molten materials when the fuel debris retrieval works, it is necessary to transport to hot lab facilities each time to analyze them. Time and resource will be necessary for the transportation fuel debris to hot lab facilities and it may interfere prompt fuel debris retrieval works. In order to reduce the transportation burdens to hot lab facilities, abbreviated(in-situ) analysis technologies to identify promptly the existence of fuel components adhered and invaded in the structural materials inside PCV shall be developed. Specifically, by utilized spent fuel etc., it shall be accumulated results and findings of the analysis against high level radiation samples and then advancements for fuel components detection such as improvement of detection efficiency and contamination counter measurement when measuring shall be conducted. In addition, it shall be conducted the advancement for long time stable operations under the on-site environment affected from humidity and dusts, etc.

③ Fuel debris contains neutron absorbers when melting. Therefore, it has possibility not to generate sufficient nuclear fission reactions because incident neutrons are absorbed by neutron absorbers if it is used the method to measure the releasing radiation induced by nuclear fission reaction due to incident neutrons from outside. Furthermore, it is difficult to apply the methods which estimate the fuel burn-up based on the gamma-ray from cesium because cesium was released when melting. Due to these individual characteristics of fuel debris, it has concerns to apply originally non-destructive measurement methods used at nuclear fuel reprocessing facility etc. Accordingly, in order to obtain the data contributed to criticality control and storage management of fuel debris and then conduct the prompt sorting depending on the fuel amounts of materials removed from PCV, research and development shall be conducted for aiming at on-site application of technology that can non-destructive measurement of fuel mass. Specifically, it shall be investigated the evaluation methods and conceptual structures of the sorting scenario and measuring system for the case to apply the non-destructive measurement technology to the fuel debris. Furthermore, the calculation models to simulate of fuel debris measurement shall be prepared and then, in order to confirm the applicability to the fuel debris, the measurement tests for fuel debris simulant which has the factors which interfere the existing or small equipment and measurements shall be conducted.

Definition of criterion for judgment on objective achievement

- Preparation for fuel debris analysis and analytical evaluation (FY2024)
- Advancement of “estimation of PCV inside damaged condition” and “estimation of fuel debris properties” based on the latest information (FY2024)
- Analytical evaluation of fuel debris in TMI-2 (FY2024)
- Evaluation for feasibility and expansion of measurement results by abbreviated analytical methods (FY2024)
- Summary of simulation results of technology development of non-destructive measurement, results of measurements tests and results of conceptual study of measurement devices (FY2024)

(Implementation Schedule) B2③： Development of Analysis and Estimation Technology for Characterization of Fuel Debris



B3①： Development of Fuel Debris Retrieval Method

Purpose

Towards scaling up retrieval of fuel debris and internal structures, development and test shall be conducted for elemental technology required for feasibility of works regarding retrieval method, and on-site applicability shall be evaluated.

Implementation Content

〇In the partial submersion method, in order to verify important technological elemental issues for work continuity of long-term fuel debris retrieval on the premise that fuel debris retrieval will be remotely operated under high dose, high contamination, and environmental conditions including uncertainties, equipment for upper part of operation floor like large transportation devices, filling stabilization technology, technology for protection from falling during processing and other technologies shall be developed.

〇In the examination of fuel debris retrieval methods, regarding other methods including submersion method (shell method) which is on the discussion table, issues shall be examined and resolution of necessary technical issues shall be conducted.

〇This research and development shall be executed in collaboration with operator engineering and the results shall be used in the engineering conducted by the operator.

1. Development of Top-Access Partial Submersion Retrieval Method

(1) Large Transportation Device

For transportation of large internal structures from inside the reactor, it is necessary to shield and transport heavy structures with high radiation dose and high contamination to prevent the spread of contamination. So far, research and study, such as previous transportation technologies, choice of the method of transportation, devices structural examination were conducted. From now on, regarding large transport mechanism focused on confinement, connecting passage gate which will act as isolation boundary, conceptual study shall be conducted, verification by trial manufacturing shall be conducted and on-site applicability shall be evaluated.

(2) Filling Stabilization Technology

Method to improve safety and efficiency during dismantling works by filling stabilization of damaged internal structures shall be examined. So far, characteristics of filling material and others were evaluated by the basic tests. From now on, regarding damage condition, effective method of filling stabilization of the opening in the bottom part of reactor, device configuration, filling procedure and others, conceptual study shall be conducted, element test using simulants shall be conducted, and on-site applicability shall be evaluated.

(3) Technology for Fall Prevention Measures

Because of the possibility of falling to pedestal bottom of fragments during fuel debris processing and/or heavy objects due to vibration and others, it is necessary to take fall prevention measures in order to prevent re-criticality situation because of falling, suppress dust dispersion, prevent equipment damage and others. The concept of fall prevention measures shall be examined, the feasibility by the elemental test shall be verified and on-site applicability shall be evaluated.

(notes)

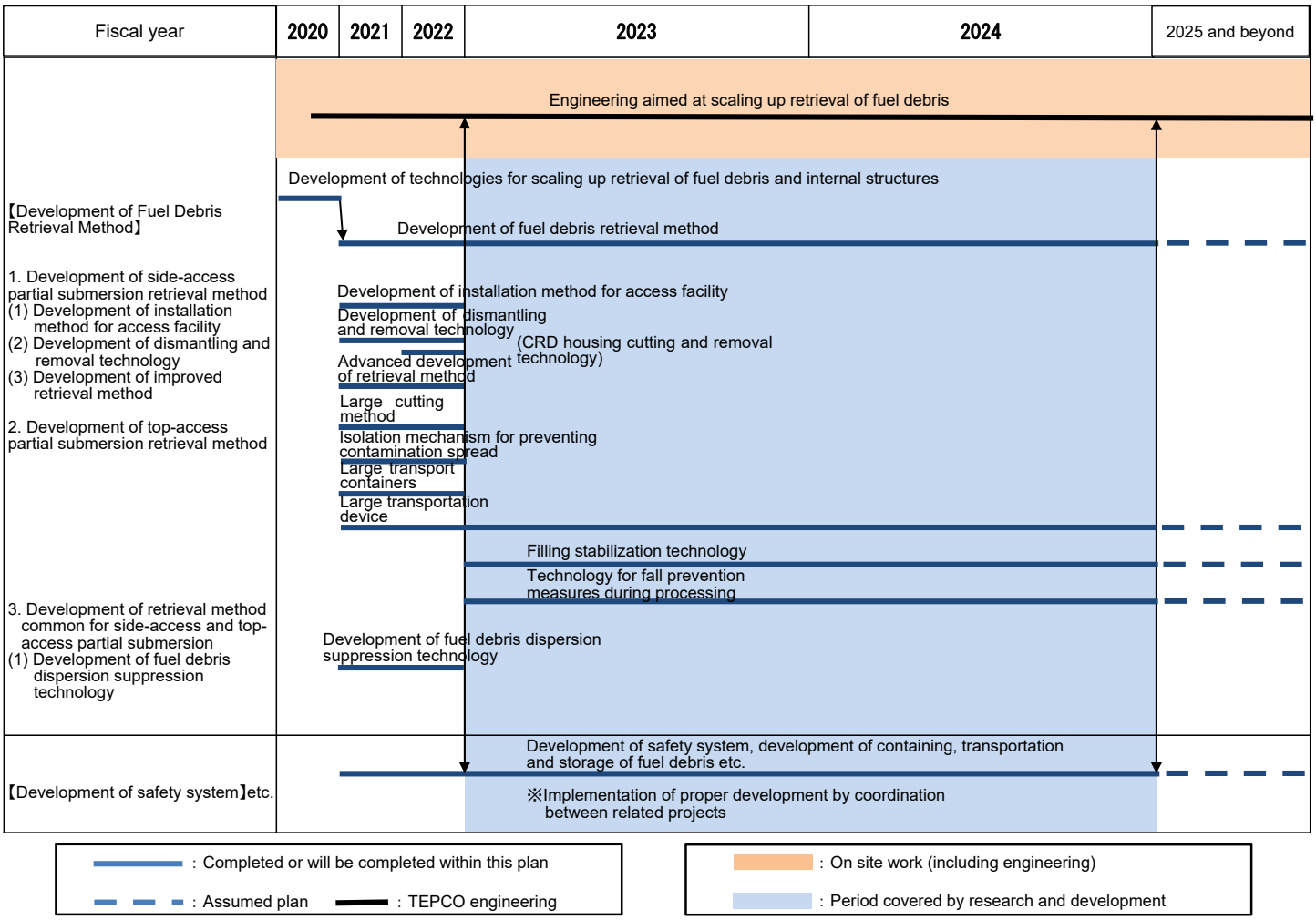
In the partial submersion method, development shall be conducted focusing on handleability and maintenance method regarding the following matters.

・As the installation will be made in high radiation area, remote maintenance is the rule.
・It is necessary to consider device contamination and necessary decontamination.
・Work area for maintenance is limited.
・It is necessary to curb waste generated by maintenance works as much as possible.
・It is necessary to consider setting up and handling of criticality monitor.

Definition of criterion for judgment on objective achievement

・Design of the concept of large transportation device(FY2023), verification by test manufacturing and on-site applicability evaluation (FY2024)
・Examination of the concept of filling stabilization technology, test plan (FY2023) verification by test execution and on-site applicability evaluation (FY2024)
・Examination of the concept of technology for fall prevension measures (FY2023), verification by test execution and on-site applicability evaluation (FY2024)

(Implementation schedule) B3①：Development of Fuel Debris Retrieval Method



B3②： Safety System (1/2)

Purpose

For the scaling up retrieval of fuel debris and internal structures, it shall be implemented the development and tests of essential technologies which will be necessary for ensuring the safety during on-site works.

Implementation Content

○ Fuel debris retrieval works have uncertain elements of environmental conditions in addition to the conditions under high radiation and high contamination. For the scaling up retrieval of fuel debris, it shall be implemented the acquisition of data necessary for safety system, safety monitoring and assessment and the technology development of analytical methods.

○ This research and development shall be executed in collaboration with Operating Entity engineering reflecting operators' point of view of Operating Entity and the results shall be used in the engineering conducted by the Operating Entity.

1. Development of Safety System (Liquid Processing System)

1.1 Development of α-nuclides Removal Technology

With regard to removal technologies of soluble α-nuclides assumed to be leached from fuel debris to the circulating cooling water, elemental tests using simulated liquid have been conducted and then the applicability to actual facilities have been evaluated so far. From now on, it shall be developed more reasonable processing methods which can respond to colloidal state α-nuclides in addition to soluble α-nuclides through elemental tests etc.

Furthermore, the tests using the actual liquid (stagnant water in the reactor buildings) for reducing the risk related to the applicability to actual facilities of liquid processing systems shall be prepared.

1.2 Development of Secondary Waste Processing Technology

Based on the assumed properties and measures of secondary wastes (sludge etc.) generated by liquid treatment systems, in cooperation with the project of containing, transportation and storage of fuel debris and the project of processing and disposal of solid waste, pretreatment methods considering actual management and storage canisters have been investigated. From now on, more reasonable processing methods which can respond to sludges generated by liquid treatment system through elemental tests and others shall be developed.

2. Acquisition of Dust Dispersion Rate Data

For the works of fuel debris retrieval, in order to develop safety assessment technologies related to dust dispersion rate data during fuel debris cutting, the dust dispersion rate data under drying conditions by several cutting methods have been acquired so far. Based on the results of the data acquisition, further acquisition and organization of data focused on dust generation and transfer under the assumed environment during fuel debris cutting shall be implemented, and then the findings of those behaviors shall be expanded.

In order to contribute the safety assessment at the normal and accident, tests for the acquisition of dust dispersion rate data which is applicable to estimated environment (moisture condition etc.) by several cutting methods shall be conducted and the behaviors of dust dispersion shall be grasped. The tests shall be implemented by adding the assessment conditions and using test specimen simulating fuel debris (cold materials* or MCCI debris simulant including uranium). The obtained data shall be organized systematically for the technical basis of safety assessment during fuel debris cutting in the future.

*Cold materials: test specimen not including uranium. The materials which have similar physical properties to those of fuel debris have been selected and they are used to implement the test under the various ranges of cutting conditions.

B3②： Safety System (2/2)

3. Technology Development of Analytical Method for Exposure Dose Evaluation

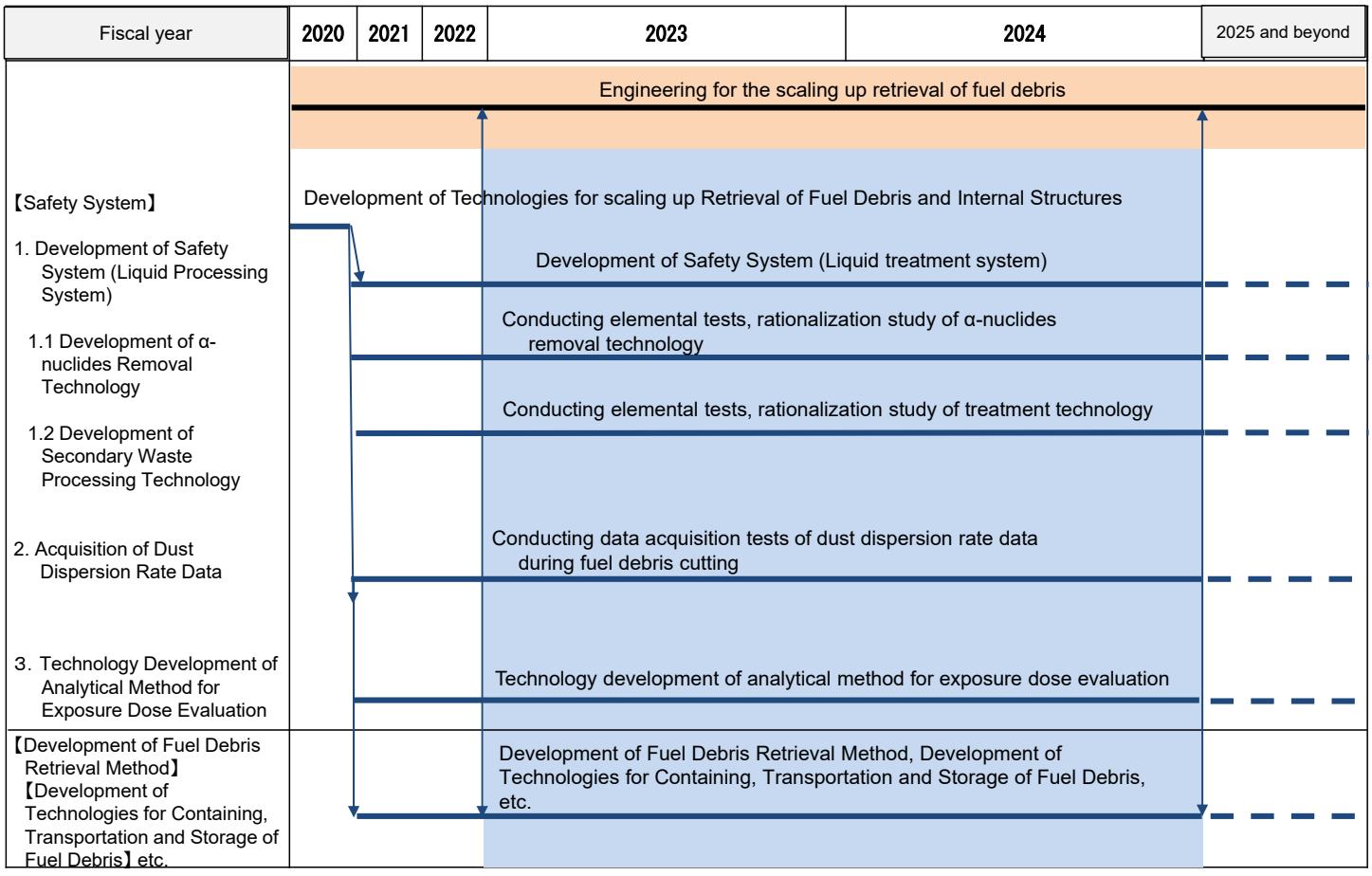
In order to the necessity of monitoring of various nuclides by many operators at the decommissioning works, as the accurate and prompt method for internal exposure dose evaluation, the conceptual study of the program for internal exposure dose evaluation and the technology development such as speed-up of bioassay and accuracy improvement of paper filter samples measurement have been proceeded so far.

Preparing for the radiation intake risk of α・β nuclides during decommissioning woks such as fuel debris retrieval, both the development of program for internal exposure dose evaluation by the organization and standard development of comprehensive evaluation system for internal exposure dose using in vitro measurement (lungs monitoring etc.) and bioassay and the continuous technology development related to internal exposure dose measurement and evaluation shall be proceeded.

Definition of criterion for judgment on objective achievement

- Conducting elemental tests etc. and evaluating actual applicability for rationalization of α-nuclides including colloidal state removal technology, and preparing the tests using the actual liquid (FY2024)
- Conducting tests and studies such as elemental tests and evaluating actual applicability for rationalization of secondary waste (sludge, etc.) treatment system (FY2024)
- Conducting the test for acquisition of dust dispersion data including the moisture conditions during fuel debris cutting and developing the evaluation technology (FY2024)
- Developing the program for internal exposure dose evaluation considering the decommissioning process. (FY2024)

（Implementation schedule）B3②： Safety System



B3④: Development of technology for containing, transportation and storage of fuel debris

Purpose

In order to establish a scenario for the process from fuel debris retrieval up to its storage, system shall be developed for safe, reliable and rational containing, transportation and storage of retrieved fuel debris.

Implementation Content

○Technology shall be developed for construction of the system which can handle various forms of collection (from lump to powdery, slurry/sludge state) of fuel debris with heterogeneous composition and make possible long-term storage after safe, reliable and rational containing and transportation, considering the hydrogen that may be generated by radiolysis and the criticality of nuclear fuel materials. Furthermore ,the development shall be conducted in coordination with related projects.

○This research and development shall be executed in collaboration with operator engineering and the results shall be used in the engineering conducted by the operator.

1. Development of Technology for Handling of Powdery and Slurry/Sludge State Fuel Debris

① Improvement of the hydrogen gas generation prediction method

・Verification test shall be executed for verification of the influence evaluation results of the factors affecting hydrogen generation from powdery and slurry/sludge-like fuel debris (hereinafter referred to as “powdery fuel debris”), and for verification of the method to predict the hydrogen gas generation speed, which were obtained from desk study executed in FY2022. Based on these results, the prediction method of hydrogen gas generation shall be improved.

・Regarding the results of FY2022 desk study concerning generation behavior of hydrogen gas accumulation and its release characteristics such as effects at the time of release, verification experiment shall be conducted based also on the effects of various mixtures in fuel debris.

② Life Span Evaluation of Storage Canister Filter

・Based on the selection results of failure scenarios that may affect filter performance and investigation of test methods necessary for assessment, which were conducted in FY2020/2021, and investigation of powdery debris amount accumulated in the storage canister filter conducted in FY2022, detailed assessment shall be conducted regarding the possibility of storage canister filter deterioration in the process before the storage and during the storage and occurrence of its failure scenario, and impact on safety function.

In addition, test simulating cases of filters' deterioration and failure shall be conducted, and together with validation of the impact of filter deterioration and failure to the safety functions (for example, hydrogen release and confinement function etc.) ,methods to mitigate/avoid deterioration and failure shall be investigated.

③ Reevaluation of storage method and storage container

・Based on the results of mentioned above ①, ② ,the investigation results of storage method and storage container for powdery fuel debris, which was conducted in 2021, shall be reevaluated.

※ Projects for development of related technology

“Development of Analysis and Estimation Technology for Characterization of Fuel Debris”, “Development of Technologies for Retrieving Fuel Debris and Internal Structures” and “Research and Development of Processing and Disposal of Solid Waste”.

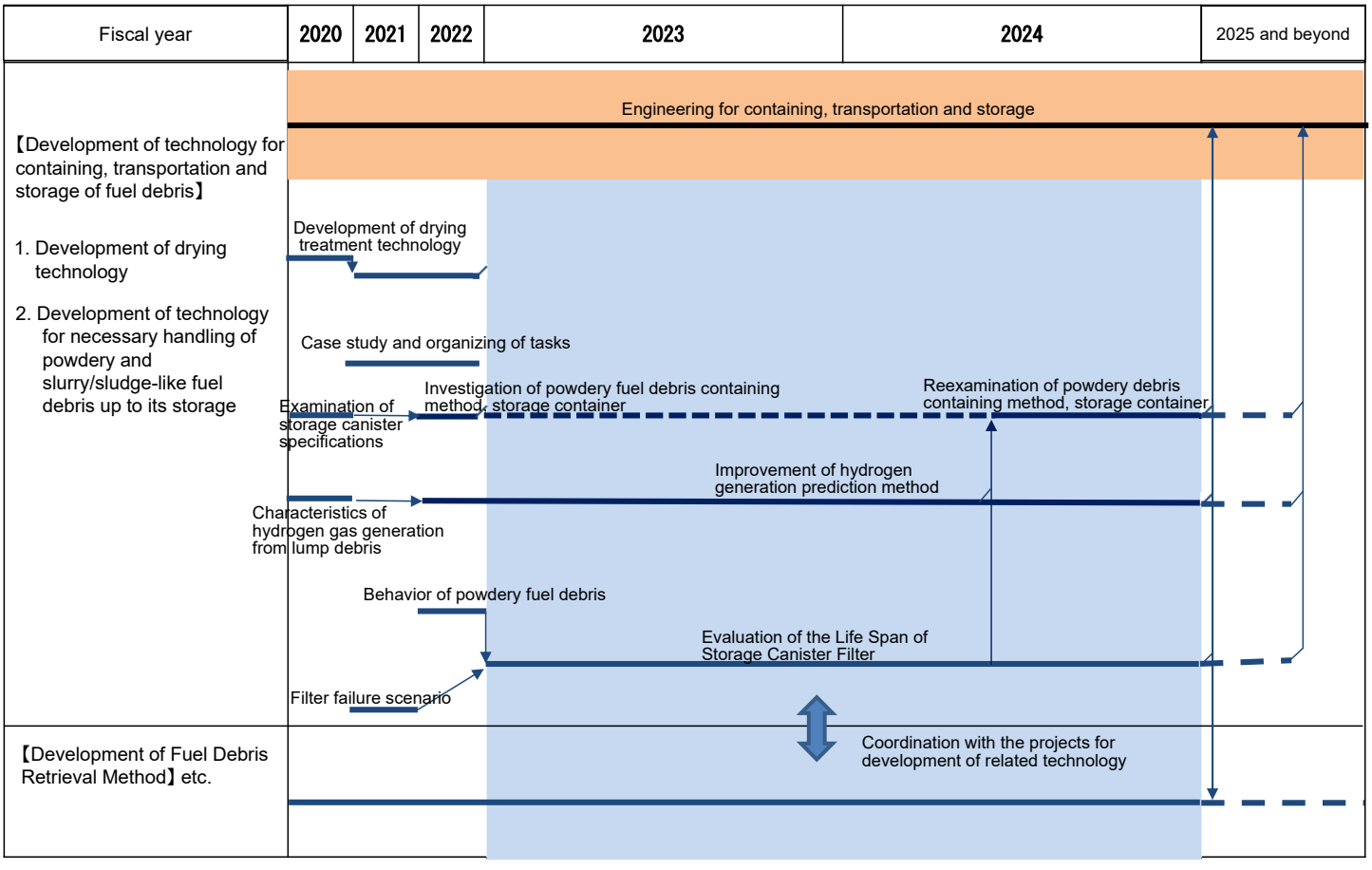
Definition of criterion for judgment on objective achievement

・Investigation aiming improvement of hydrogen gas generation prediction method and hydrogen gas generation behavior, and planning of the verification test and preparation for the test (FY2023), Conducting the test and improvement of the prediction method based on it (FY2024)

・Detailed assessment of scenarios of deterioration and failure of storage canister filter and its impact, and planning and preparation for verification test (FY2023), verification of the impact by conducting the test and investigation of the methods to mitigate/avoid deterioration and failure (FY2024)

・Reevaluation of storage method / storage container based on above results (FY2024)

(Implementation schedule) B3④: Development of technology for containing, transportation and storage of fuel debris



B3⑤: Development of Assistive Technologies for Integration Management of Decommissioning of the Fukushima Daiichi Nuclear Power Station

Purpose

Technologies related to the assistive system necessary for smooth integration management of decommissioning of the Fukushima Daiichi NPS shall be developed, including scaling up retrieval of fuel debris and internal structures.

Implementation Content

○In the decommissioning of the Fukushima Daiichi NPS including scaling up retrieval of fuel debris and internal structure, it is necessary to ensure throughput by remote operation under high-dose radiation and highly radioactive contaminated environment with uncertain conditions. For this reason, regarding information management system which enables accurate and quick on-site response by long-term and continuous monitoring of environmental changes during the fuel debris retrieval operation period, and also by integrating and sharing the monitored data and operation data including trouble data obtained in the actual operation of the remote devices, it would be highly useful to develop technology using digital technologies. Based on the results of "Development of Technologies for scaling up Retrieval of Fuel Debris and Internal Structures", technology for integration management using digital technology shall be developed as an elemental technology to support safe, efficient, and sustainable integrated management for long-term Fukushima Daiichi NPS decommissioning.

○This research and development shall be executed in collaboration with operator engineering and the results shall be used in the engineering conducted by the operator.

1. Examination of overall concept of assistive system for integration management

It is important to proceed with fuel debris retrieval putting safety first under unified understanding and sharing various information obtained at each stages of retrieval as "Trial retrieval, investigation inside PCV", "Retrieval gradually expanded its scale", and "scaling up retrieval of fuel debris". For that purpose, it is necessary to maintain the system which will integrate the information in an easy-to-recognize way and support data management and operation.

So far, organizing of monitoring items by risk evaluation focusing on safety requirements and retrieval work continuity, conceptual study of the concept for monitoring method focusing on on-site applicability and tasks organizing have been carried out. In proceeding with efficient decommissioning of the Fukushima Daiichi NPS, it is considered effective to introduce digital technology which will integrate and share information at every stage of design, development, installation, operation and others, in addition to monitoring information.

Therefore, regarding increasing efficiency effect caused by introduction of digital technology, the examination shall be conducted based on on-site needs and case studies and others, requirements to the system shall be organized and the tasks towards introduction of integration management technology shall be organized upon examination of the overall concept of assistive integration management system.

2. Development of technology for integrated management using digital technology

In proceeding with efficient decommissioning of the Fukushima Daiichi NPS, it is considered effective to introduce digital technology which will integrate and share information.

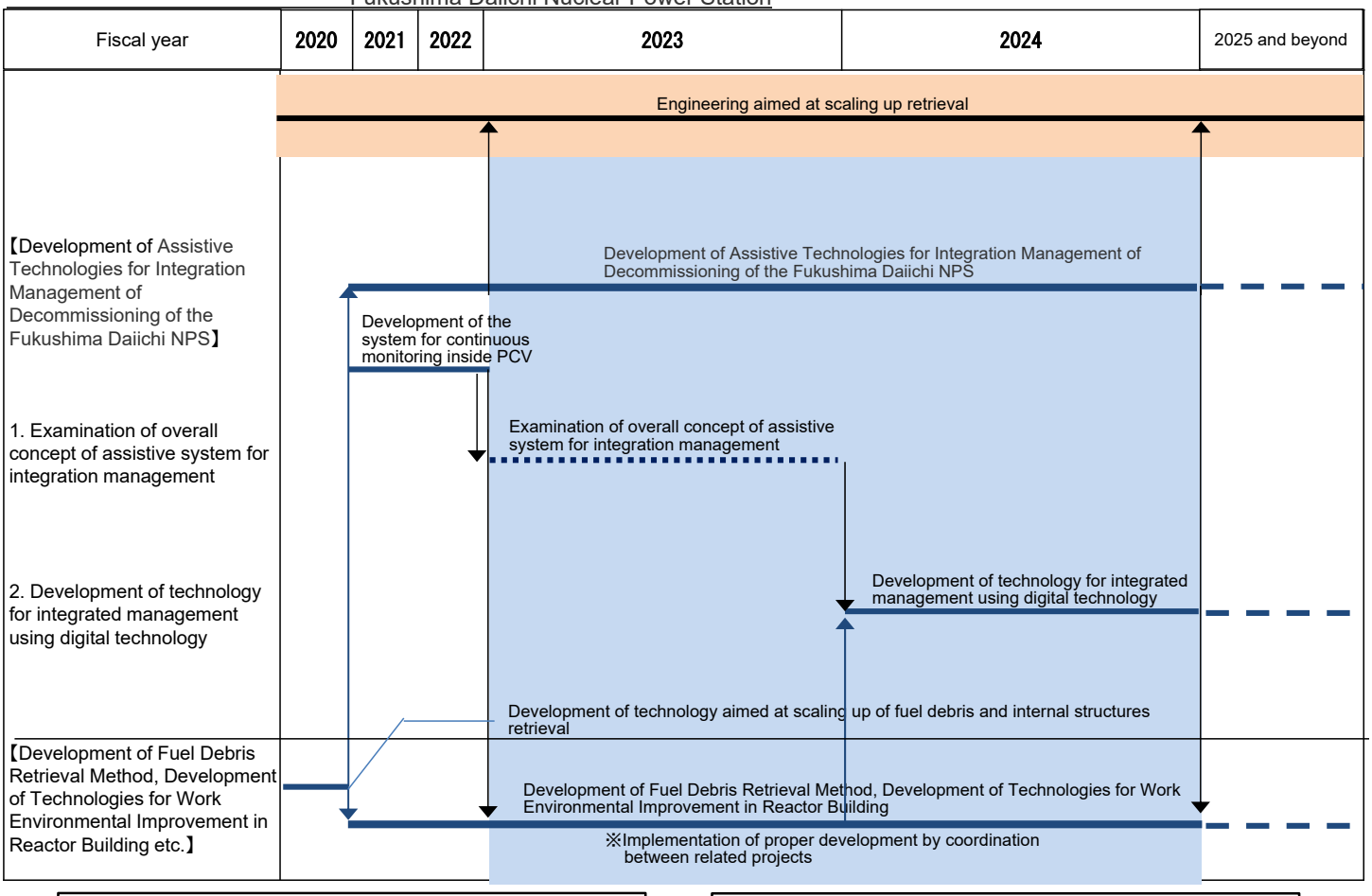
Development of assistive system is necessary for various tasks like works plan, remote operation, status monitoring, equipment maintenance and others which are necessary for decommissioning of the Fukushima Daiichi NPS. Also, it is important to develop a platform which will have scalability to handle new kinds of data and system necessary during long-term operation and react to flexible updates. In addition, it is important to develop data management system which will process and transform huge amount on obtained information and data for use in various assistive systems to be connected to the platform.

Firstly, the assistive system for the tasks of the on-site needs priority shall be developed. Then, specific examination and trial production shall be conducted for the construction of integrated management assistive system including platform and data management system related to mentioned above assistive system , and ,due to this the applicability for targeted tasks shall be evaluated and tasks for construction of the whole system shall be organized.

Definition of criterion for judgment on objective achievement

・The indicators shall be set up in FY2024 based on the examination of overall concept of assistive system for integration management.

(Implementation schedule) B3⑤: Development of Assistive Technologies for Integration Management of Decommissioning of the Fukushima Daiichi Nuclear Power Station



C: Research and Development of Processing and Disposal of Solid Waste（1/2）

Purpose

Based on the prospects of processing/disposal method of solid waste and technology related to its safety presented in FY 2021, further possibilities for more waste volume reduction shall be examined, and creation of options for processing/disposal measures and their comparison and evaluation should be conducted with promoting characterization to establish a waste stream that are suitable for features of solid waste (*1). Proceed study on specific management of the solid waste to present appropriate measures as a whole.

Implementation Content（Overview）

Ⅰ. In order to reflect in overall solid waste management, acquisition and management of analysis data shall be conducted and activities for enhancement of efficiency of waste characterization shall be proceeded.

Ⅱ. For safe and reasonable storage and management, the technology for reduction and recycling in order to reduce the amount of waste shall be developed.

Ⅲ. In order to obtain technical knowledge necessary for establishing of waste streams suitable for features of solid waste, the technology for waste processing/disposal shall be developed. Regarding the processing technology, the following issues shall be investigated: the applicability of low-temperature processing, the stability of the solidified waste manufactured by various processing methods, the interim treatment technology for the expansion of the range of application of the low-temperature processing technology. Regarding the disposal technology, along with the survey of the information and knowledge necessary for creation of the disposal concept, the construction of the storyboard of critical event progression in disposal facility and improvement of the safety assessment method shall be started.

This research and development shall be executed in collaboration with operator engineering and the results shall be used in the engineering conducted by the operator.

Ⅰ. Characterization

1. Acquisition and Management of Analysis Data, etc.

The analytical nuclides and the required analytical accuracy shall be investigated according to the classification of waste. Taking into account TEPCO's plan for analysis of solid waste aimed at optimization of storage and management, mid/long-term analysis plan shall be reviewed, annual analysis plan shall be prepared and according to these consideration, acquisition, evaluation and management of analysis data shall be conducted.

Simplified evaluation technology of radioactivity of the waste generated from fuel debris retrieval, and difficult to analyze and important nuclides for safety assessment of disposal like C-14 and I-129 shall be developed.

Upon the evaluation of analytical method based on the simple and quick technology achieved by optimization and automatization of samples preprocessing and its applicability for waste generated at Fukushima Daiichi NPS, its standardization shall be investigated.

Regarding the adsorbent collected from actual cesium adsorption tower its analytical method shall be examined taking into consideration the limitations caused by high radioactivity.

Maintenance and operation of the database for obtained analytical data and samples information shall be carried out.

2. Enhancement of Efficiency of Characterization

The trial of analytical planning methods that combines Data Quality Objectives (DQO) process(*2) with the statistical method shall be continued, the application examples shall be accumulated and the work on technical improvement shall be conducted.

Regarding the statistical inventory estimation method, transition model shall be improved and efforts will be made for the reduction of the uncertainty of the radionuclide transfer parameters reflecting newly obtained analytical data. In addition, the examination will be conducted regarding the changes which were caused by the accident in the waste generated before the earthquake. Using this method, the waste inventory database necessary for disposal safety assessment shall be maintained by waste categories. Also, the waste inventory estimation method shall be examined regarding the waste from fuel debris retrieval.

Regarding the most typical waste, the assumed parameters for verification of the waste form and its uncertainty will be investigated.

Ⅱ. Storage and Management

For the purpose of volume reduction and recycling, the radionuclide distribution behavior during the melting and decontamination of contaminated metals and verification method after the melting processing shall be investigated.

C: Research and Development of Processing and Disposal of Solid Waste（2/2）

Ⅲ. Processing/Disposal

1. Processing Technology

Regarding the applicability of low-temperature processing technology for each solid waste, all the tasks shall be evaluated and organized and its solution shall be investigated including safety during the processing. Regarding screening method to determine the possibility of solidification, the extension of its scope of application shall be examined on the basis of results up to FY2021 for the purpose of generalization of a variety of solid waste. In addition, regarding solid waste including ferrocyanides, the applicability of low-temperature processing technology shall be investigated. The applicability of low-temperature processing for carbonate slurry shall be evaluated by actual processing of about 200 liters.

The possibility of flexible and rational processing technologies such as technology of bulk solidification of highly radioactive rubble and dehydrated slurry processing technology in each storage container shall be examined.

Regarding the solidified wastes produced by the various processing technologies their stability (leaching characteristics, long-term stability, radiation effects, etc.) shall be investigated and evaluated.

Regarding slag generated from melting processing of contaminated metals, data about nuclides leaching rate, etc. necessary for examination of its disposal shall be collected.

In order to contribute to the expansion of the range of application of low-temperature processing technologies, regarding interim treatment technologies such as pyrolysis processing, applicable technologies shall be investigated.

2. Disposal Technology

① Survey of the information and knowledge required for presentation of a disposal concept

In order to develop measures to meet the needs of disposal concept, it shall be investigated the necessary information and knowledge about waste, for which waste streams are being studied.

② Trial of development of safety assessment method of solid waste disposal

In order to extract important scenarios for solid waste disposal, a storyboard of critical events evolution relevant to a disposal facility shall be developed based on the characteristics of solid waste. Also evaluation policy will be improved to apply to the disposal concept to be constructed in ①.

*1 Solid waste: Include rubbles and water treatment secondary waste after the accident and radioactive solid waste stored at Fukushima Daiichi Nuclear Power Plant before the accident.

*2 A method to plan analytical samples for decision makings developed by U.S. Environmental Protection Agency.

Definition of criterion for judgment on objective achievement

Ⅰ. Characterization

- Preparation of annual analysis plan and accumulation of obtained analytical data and sample information in the database (2023FY)
- Presentation of the results of development of non-destructive measurement technology for the waste generated from fuel debris retrieval, and analytical technology for nuclides that are difficult to analyze and important for safety assessment of disposal (2023FY)
- Presentation of the results of investigation about the standartization of analytical method based on simplified and speeding up technology (2023FY)
- Presentation of the results of examination of analysis method for the adsorbent collected from actual cesium adsorption tower (2023FY)
- Presentation of the results of trial use of analysis planning method based on the DQO process and the issues to be improved (2023FY)
- Presentation of the results of investigation about the statistical inventory estimation method (results of the reduction of the uncertainty, inventory estimate for all types of waste including changes in the waste generated before the earthquake which were caused by the accident, etc.) (2023FY)
- Presentation of the uncertainty of the assumed parameters before verification of the waste form for most typical waste (2023FY)

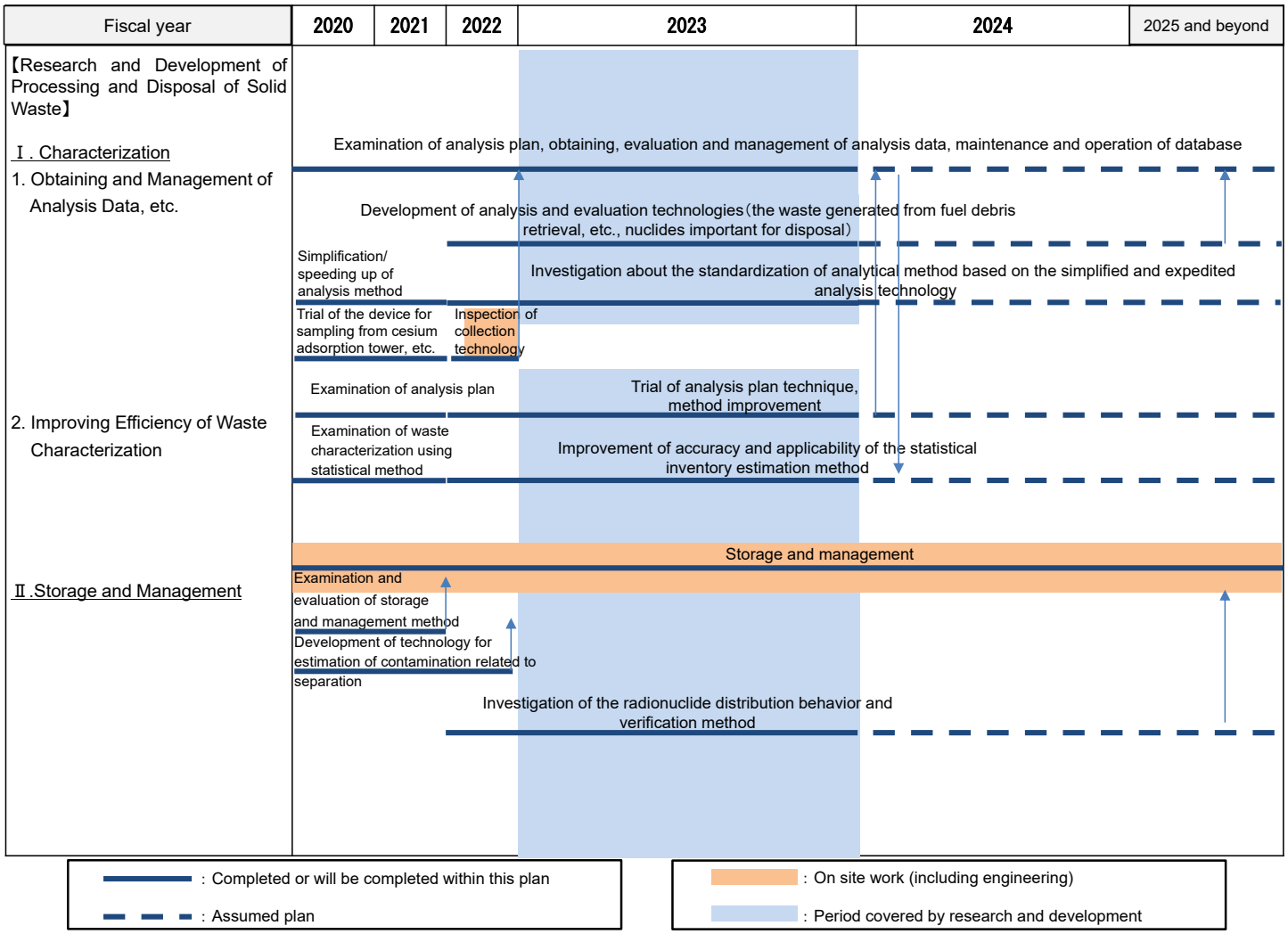
Ⅱ. Storage and Management

- Presentation of issues related to verification method and knowledge about the radionuclide distribution behavior during the melting of contaminated metals (2023FY)

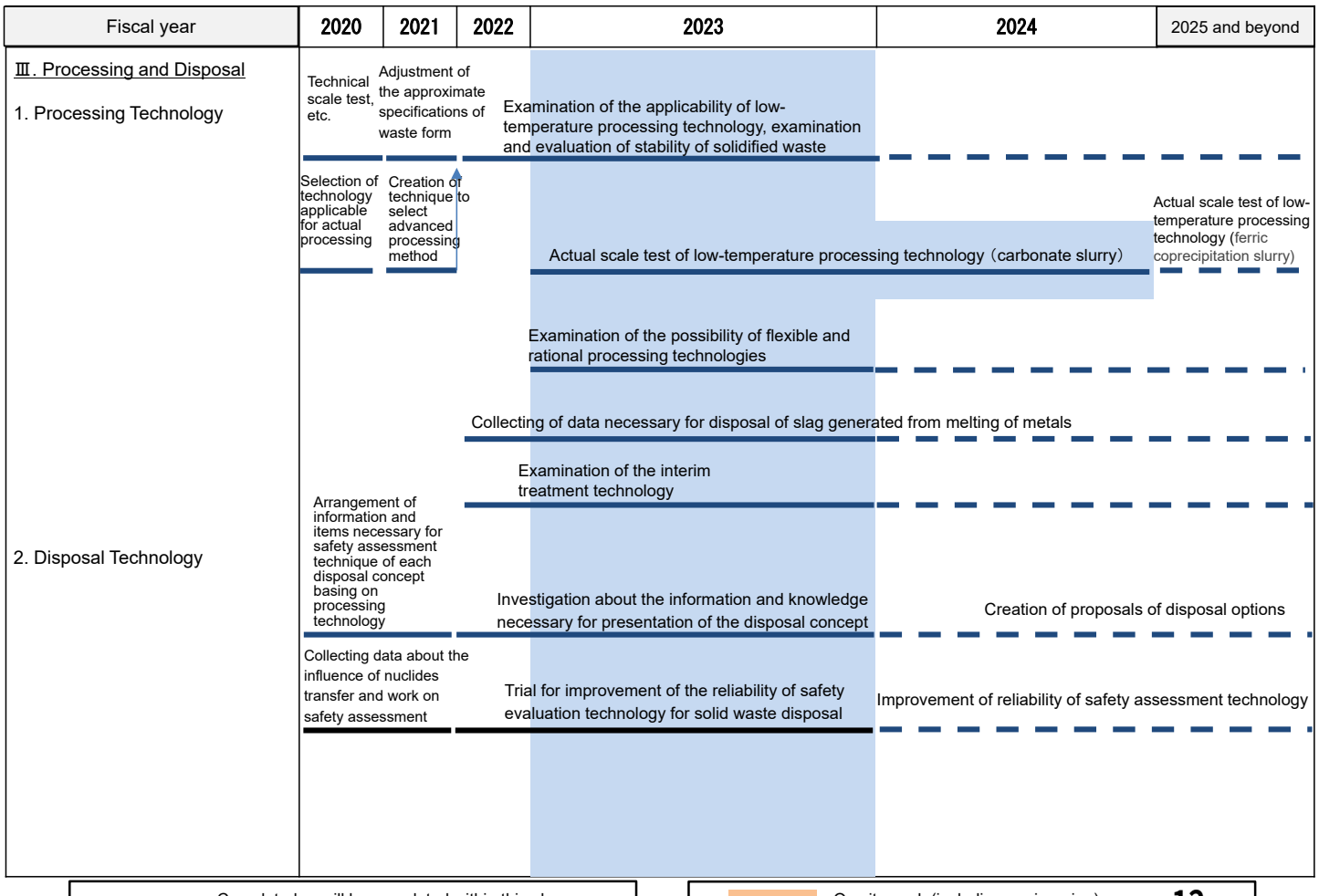
Ⅲ. Processing/Disposal

- Presentation of the examination results applicability of low-temperature processing (2023FY)
- Results of evaluation of the applicability of low-temperature processing for carbonate slurry (2024FY)
- Presentation of the results of examination and evaluation of solidified waste stability (2023FY)
- Presentation of the results of examination of the possibility of flexible and rational processing technologies (2023FY)
- Presentation of the results of data collection necessary for disposal of slag generated during melting processing (2023FY)
- Presentation of candidates of interim treatment technologies (2023FY)
- Presentation according to priority of knowledge and information necessary for proposed requirements of appropriate disposal concept and meeting of these requirements, in order to prepare measures required for the disposal concept (2023FY)
- Building a prototype of a storyboard of critical events evolution in a solid waste disposal facility, preparation of the plan for evaluation of mentioned above disposal concept suitable for solid waste, creating a evaluation model according to this plan and trial of evaluation parameters setting (2023FY)

(Implementation Schedule) C: Research and Development of Processing and Disposal of Solid Waste (1/2)



(Implementation schedule) C: Research and Development of Processing and Disposal of Solid Waste (2/2)



Reafference 1

Mid-and-Long-Term R&D Plan

- Major Processes and Approach to Major R&D Activities for Decommissioning [Fuel Debris Retrieval] of the Fukushima Daiichi NPS of TEPCO -

FY: 2021 | 2022 | 2023 | 2024 | 2027 | 2033～

Key Milestones

Phase 2 | Phase 3-(1) | (Next phase)

- **Start of debris retrieval at the first implementing unit**
- **Retrieval Gradually Expanded Its Scale**
- **Scaling Up Retrieval of Fuel Debris**

[A] Trial Retrieval and Retrieval Gradually Expanded Its Scale

［1］Trial retrieval in Unit 2

- Improvement of the environment inside the buildings
- Trial retrieval (internal investigations and fuel debris sampling), Characterization of fuel
- Manufacturing, testing and installation of retrieval devices, etc. *1, Operational change of the safety systems, Removal of obstacles in openings, etc.
- Development of Technologies for In-depth Investigation of PCV Inside

*1: Reveraging Naraha Center for Remote Control Technology Development

Legends :
- Main Processes — Described based on TEPCO DAP 2022
- Practical application development and Applied research
- Basic/fundamental research — Major studies on debris retrieval
- Key Technical issues ( )
- → : Where R&D results are applied
- → : Linkage between main processes

［2］Retrieval Gradually Expanded Its Scale in Unit 2

- Improvement of the environment inside the buildings
- Fuel debris retrieval facility/Safety system/Fuel debris temporary storage facility/Maintenance facility
- Design, manufacturing and testing (Reveraging of the Naraha Remote Technology Development Center)
- Installation
- **Development of Technologies for Fuel Debris Retrieval Gradually Expanded Its Scale**
  - Technical issues for gradual expansion of fuel debris retrieval
    - ① Providing retrieval system (improving device durability, verifying passing with transport truck)
    - ② Manufacturing equipment for gradual expansion of fuel debris retrieval
    - ③ Preparing storage facilities for fuel debris/waste
- Fuel debris retrieval (Gradual expansion of scale)
  Operation of temporary storage facility for fuel debris
  Operation of maintenance equipment
  → To fuel debris characterization

[B] Scaling Up Retrieval of Fuel Debris

［1］Work Environmental Improvement of Inside and Outside of Reactor

- Environmental improvement inside and outside the Unit 1 buildings — Inside the buildings: Radiation dose reduction/Removal of obstacles, etc. Outside the buildings: Removal of SGTS piping/lower part of exhaust stacks at Units 1/2, and transformers, etc. => Securing space *2
- Environmental improvement inside and outside the Unit 3 buildings — Inside the buildings: PCV water level lowering/Radiation dose reduction, etc. Outside the buildings: Removal of exhaust stacks and transformers at Units 3/4, Improvement of the basement floor, etc. => Securing space *2

*2: Added buildings, maintenance buildings, storage buildings

- Development of technology for environmental improvement inside/outside reactor buildings
  Development of assessment methods for deterioration status, etc., of building frames and equipment
- To achieve lowering the PCV water level
- Research to visualize the distribution of radioactive materials and contribute to the reduction of radiation exposure
  Research on the relationship between radiation and corrosion and material degradation
  → Target : - Improvement of a system for work planning to reduce radiation exposure
  - Establishment of measures and evaluation methods considering the effects of corrosion on long-term integrity

［2］Investigation Technology of Inside of PCV/RPV, Fuel Debris Characterizatoin

- Technologies for Fuel Debris Retrieval Gradually Expanded Its Scale in Unit 1
- PCV internal investigations at Unit 3
- Development of Investigation Technology of Inside of RPV/Advancement of Processing Technologies in Investigation Method → To RPV internal investigation design
- RPV internal investigations at Unit 2
- Development of technology for RPV quick internal investigation
- Characterization of fuel debris
- Development of Analysis and Estimation Technology for Characterization of Fuel Debris
- Demonstration of analytical technology (Radioactive material analysis/Utilization of research facilities)
- Research on analytical evaluation methods for retrieved fuel debris, including non-destructive measurement
  Research on the advancement of analytical techniques for radioactive material and nuclear fuel material
  → Target : - Establishment of analytical evaluation method including non-destructive measurement, and methods for radioactive waste sorting and inventory evaluation
  - Establishment of remote/in-situ/rapid analysis technique
- Development of Estimation Technologies of the situation in the PCV
- Estimation of in-core conditions and research on accident events by analyzing and evaluating fuel debris
  → Target : - Grasping of in-core situation and refinement of understanding of FP behavior in the PCV based on on-site knowledge and actual debris data

［3］Retrieval System, Safety System, Maintenance System, Storage Equipment *3

*3: Main processes for proceeding with the study on Unit 3 as a preceding case

- **Reflecting the results of Trial retrieval (Internal investigation / fuel debris sampling)**
- **Reflecting findings obtained after the start of a gradual scale expansion**

*4: Process for side-access retrieval installation

- Conceptual study → Verification of the actual site applicability → Study of safety systems/maintenance methods
- Design of retrieval installations *4 → Design of safety system / maintenance installations
- Manufacturing, installation and testing of retrieval equipment *4/ training facility and fuel debris retrieval → Manufacturing, installation and testing of safety systems/ maintenance installations
- Top-access retrieval installation/ retrieval
- Retrieval in other units
- Backcast
- Forecast
- Sharing issues to strengthen cooperation among TEPCO, JAEA and NDF *5
  - An examples of issue -
  Issues for conceptual study/scenario development of fuel debris retrieval

＊5：Being considered to build a basis for analyzing and sharing, including long-term issues beyond 10 years

- **Development of Technologies for scaling up Retrieval of Fuel Debris and Internal Structures**
  Side-access retrieval method: Examination and enhancement of elemental technologies, Verification of the actual site applicability
- Top access method: Conceptual study, examination and enhancement of elemental technologies
- Research on safety assurance during fuel debris retrieval and storage
  Research to visualize the distribution of radioactive materials and contribute to the reduction of radiation exposure
  → Target : - Eestablishment of effective evaluation methods for ensuring safety during long-term in-core residency and after retrieval
  - Improvement of a system for work planning to reduce radiation exposure
- Technical issues toward further expansion of fuel debris retrieval
  - ① Development of fuel debris retrieval method (side-access/top-access/of common)
    Development of access facility installation method, dismantling technology, technology for realizing a removal concept for large structure, and crashing and collection technology
  - ② Development of safety systems (liquid-phase system/gas-phase system and criticality control)
    Strengthening of function to remove radioactive material, development of boric acid management technology such as boric acid recovery, evaluation/collection of dust behavior, and establishment of containment function of radioactive material
  - ③ Development of safety assessment technology　Data acquisition of debris dispersion rate and analytical method for evaluating radiation exposure
  - ④ Development of technologies for maintaining remote equipment　Development of decontamination and maintenance technology for contaminated remote equipment
- Basic design of fuel debris storage facilities → Equipment design, Equipment manufacturing → Trial operation, Start of operation
- Development of Technologies for Containing, Transportation and Storage of Fuel Debris
- Resarch onsafety assurance during fuel debris retrievaland storage
  → Target : - Establish safety and risk assessment for fuel debris storage
- Development of Assistive Technologies for Integration Management of Decommissioning of 1F

Mid-and-Long-Term R&D Plan

- Major Processes and Approach to Major R&D Activities for Decommissioning [Fuel Debris Retrieval] of the Fukushima Daiichi NPS of TEPCO -

Reafference 1

FY	2021	2022	2023	2024	2027	2033～
Key Milestones	Phase 2			Phase 3-(1)		(Next phase)
			Start of debris retrieval at the first implementing unit		**Retrieval Gradually Expanded Its Scale**	**Scaling Up Retrieval of Fuel Debris**

[C] Research and Development of Processing and Disposal of Solid Wast

［1］Characterization

- Characterization
- Acquisition and maagement of analysis data, etc.
- Improvement of efficiency in characterization

Technical issues for characterization
① Development of non-destructive measurement technology ② Development of analytical techniques for important nuclides for disposal ③ Refinement and operation of analytical and material database
④ Study of applicability of statistical inbentory estimation methods ⑤ Examination of rational waste confirmation

The rerated issues and needs are taken up in the processing/disposal fields of tghe over all map of basic and fundamental research, and implemented as basic fundamental research.

［2］Storage

- Storage
- Development of alpha surface contamination measurement technology
- Research on waste reduction through reuse

［3］Processing/disposal

- Development of processing/disposal concept and safety asessment methods
- Development of processing technology
  Development of disposal technology
  Study on waste stream

Technical issues for processing/disposal
① Development of low-temperature processing technology ② Evaluation of stability of solidified products
③ Study of slab processing, disposal, reuse, etc. ④ Development of intermediate processing technology
⑤ Trial to improve reliability of safety assessment technology for solid waste disposal
The rerated issues and needs are taken up in the processing/disposal fields of tghe over all map of basic and fundamental research, and implemented as basic fundamental research.

In reviewing the R&D Mid-and-Long-term plan, TEPCO, MEXT, METI and NDF have discussed the required results, timing needed and implementing structures through the R&D planning meetings. From this time onward, the plan is being prepared by incorporating basic/fundamental research into practical application development and applied research, such as the Decommissioning and Contaminated water/Treated water Project, as an integral part.