

## B1 Work Environmental Improvement Inside of Reactor Building

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

#### [Purpose]

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

#### <Current issues (Technologies to be necessary)>

A remote monitoring and removal operation system shall be developed for the removal of Primary Containment Vessel (hereinafter referred to as "PCV") penetration pipes etc. as a technological development related to work environmental improvement. Specifically, towards the scaling up of retrieval of fuel debris and internal structures, in order to reduce dose and secure work areas, it is necessary not only to address locations where work difficulty is extremely high such as high places and narrow areas, but also to safely and reliably proceed with countermeasures (e.g. removal, etc.) for high-dose piping at low elevation at an early stage. There are technical challenges in enabling Non-Destructive Investigation inside the PCV Penetration Pipes etc. at low-elevation area which is necessary for evaluating the above measures, and technological development is required to address these challenges.

The main issues to be addressed at present are as follows:

- Systems for Remote Monitoring and Removal Operation for Removal of PCV Penetration Pipes etc.
- Development of Technologies for Non-Destructive Investigation inside the PCV Penetration Pipes etc.

#### <Development in fiscal year 2026>

Evaluation of on-site applicability of the systems for remote monitoring and removal operations for removal of the PCV penetration pipes etc., proposal of specifications, and development of an on-site demonstration plan for low-elevation piping inspection technology.

## B2 Investigation Inside of PCV/RPV, Fuel Debris Characterization

### B2② Development of Investigation Technology of Inside of RPV

#### [Purpose]

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

#### <Current issues (Technologies to be necessary)>

In order to verify the situation inside the RPV and the internal conditions such as radiation dose, ensuring confinement functions by remote operations under the environmental conditions such as high-dose radiation and highly radioactive contamination, a drilling device to construct an access route and a device and system to carry the investigation equipment into the RPV shall be developed.

As the access routes for Access-from-Top Investigation through Small-Diameter Top Opening, the machining technologies required to construct the access routes, and the access/investigation devices required for internal investigations of the RPV, described below, shall be developed.

- Equipment and methods for drilling small-diameter openings in the shield plug
- Equipment and methods for machining the inlet guide vanes of the steam separator, etc.

Regarding the Access-from-Top/Side Investigation Method from the DS pit, an investigation plan shall be formulated for a method that lowers the investigation device to the annulus, accesses the jet-pump interior, and further accesses the RPV bottom interior to investigate the condition of the RPV interior; and a development plan for the access and investigation devices to be used for the investigation shall also be formulated. Regarding the Access-from-Bottom Investigation Method, a development plan for access and investigation devices for RPV interior with improved on-site applicability shall be developed. In addition, requirement specifications shall be formulated for devices equipped with the access and investigation devices, to access the pedestal interior from an existing penetration/CRD opening.

For the investigation technologies for the RPV interior using CS/MS System piping, countermeasures shall be developed to address the following issues and improve the access and investigation devices.

- Remote operability of the devices during passage through piping joints and valves, etc.
- Reliability of methods for moving and retrieving the investigation devices used to access the RPV interior via the N3 nozzle, etc.

The main issues to be addressed at present are as follows:

- Development of Access-from-Top Investigation Method through Small-Diameter Top Opening
- Development of Access-from-Top/Side Investigation Method and Access-from-Bottom Investigation Method
- Development of Investigation Technology of Inside of RPV by using Existing Pipes

<Development in fiscal year 2026>

Design of a device for access-from-top investigation through small-diameter top opening , and formulation of an elemental testing plan.

Design of a device for investigating inside the shroud via access-from-top/side starting from the DS Pit.

Design of a compact, lightweight device for an access-from-bottom investigation.

Improvement of investigation technology of inside of RPV by using existing pipes, and formulation of the plan for the verification tests.

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

### [Purpose]

In order to contribute to the development of fuel debris retrieval method and internal structures and technologies for containing, transportation and storage of fuel debris, technology necessary for quantitative analysis of components and estimation for characterization of fuel debris shall be developed.

### <Current issues (Technologies to be necessary)>

It is necessary that the data and information on fuel debris and deposits, etc. obtained inside of the PCV, shall contribute to grasp the properties of fuel debris that exist inside the reactor, by way of conducting the investigation of retrieval, containing and storage, and subsequent processing and disposal, etc. of fuel debris. Also, to ensure that the data and information thus acquired is useful for decommissioning, it is necessary to develop technologies for analyzing fuel debris retrieved and samples obtained in the PCV internal investigations, etc. as well as for correctly estimating the fuel debris and surroundings and those conditions expected in the future.

It is presumed that fuel assemblies and the control rods had been melted in the reactor at a temperature higher than normal operation temperature in superheating steam and then they had been flown out from RPV involved surrounding structures. Thus, it is presumed that the chemical composition and structure of the fuel debris are considerably quite complicated and heterogeneous since many substances existed in the area where melting and solidification occurred, and the temperature history was unclear. It is important to determine the properties of fuel debris comprehensively based on the analysis results of not only chemical composition but also chemical form and crystal structure. In addition, since the analysis is performed in parallel with the fuel debris retrieval works, the development of analytical technology for simplified and speed-up detection of fuel components at or near the work site (in-situ) is essential.

The main issues to be addressed at present are as follows:

- Advancement of analytical ability
- Abbreviated (In-situ) analysis of fuel debris
- Non-destructive measurement technology of fuel debris

### <Development in fiscal year 2026>

Analysis and Estimation Technology for Characterization of Fuel Debris

Technology for Abbreviated Analysis and Non-Destructive Measurement of Fuel Debris

## B3 Retrieval Equipment, Ancillary Systems, Maintenance Equipment, Storage Equipment

### B3① Development of Fuel Debris Retrieval Method

#### [Purpose]

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

#### <Current issues (Technologies to be necessary)>

The specific design studies, based on the proposals outlined in the report of the “Sub-Committee for the Evaluation of Fuel Debris Retrieval Methods” presented in March 2024, are currently underway, and the formulation of retrieval scenarios and the technical feasibility of the methods, etc. are being examined.

Given that the retrieval of fuel debris and internal structures are conducted by remote operations under uncertain environmental conditions including high radiation dose and high contamination, technologies are required to efficiently and continuously collect granular fuel debris deposited at the bottom of the PCV, to support long-term, continuous retrieval operations.

In addition, it is known that neutron measurement values and the results of composition analyses attributable to fuel debris vary significantly depending on measurement conditions such as deposits, moisture, shielding materials, and the distance to the target. Uncertainties arising from differences in these conditions may further increase depending on the composition and state, and may affect the selection of countermeasures required for safety assurance. Therefore, with the aim of acquiring information that will lead to uncertainty evaluation tailored to future site conditions, it is necessary to develop a compact and lightweight neutron detector adaptable to diverse methods and environmental conditions.

The main issues to be addressed at present are as follows:

- Component technologies for continuous fuel debris collection
- Component technologies for on-site applications of the compact and lightweight neutron detectors

#### <Development in fiscal year 2026>

Verification through prototyping and testing of component technologies for continuous fuel debris collection.

Identifying the basic requirements for overall measurement system of the compact and lightweight neutron detectors.

## B3②-2 Development of Analytical Technology for Contamination Monitoring

### [Purpose]

Towards scaling up retrieval of fuel debris and internal structures, technology development necessary for efficient contamination monitoring and ensuring safety during operations shall be conducted.

### <Current issues (Technologies to be necessary)>

During the fuel debris retrieval, to suppress radioactive dust dispersion, remove heat generated by processing, and cool the fuel debris etc., it is necessary to conduct spraying and blowing cooling water onto fuel debris. Due to the contact of fuel debris, nuclear fuel materials and radioactive elements are dissolved into the circulating cooling water in the liquid processing system. Additionally, gaseous radioactive materials are also precipitated as fine particles due to decay or chemical changes. Nuclear fuel materials and radioactive elements in fluids such as water and gases migrate and adhered to walls and floors, or mixed with existing stagnant water and circulating cooling water. Because of that, the contamination is distributed over a wide area in the building. Although the concentrations of these nuclear fuel materials and radioactive elements are lower compared, large number of samples need to be collected for monitoring the contamination levels. Therefore, in the analysis targeting the samples which include nuclear fuel materials and radioactive elements, etc. for contamination monitoring in the reactor building, technology development for acceleration, efficiency, automation and laborsaving of the pretreatment etc. shall be conducted.

The main issues to be addressed at present are as follows:

- Analysis of nuclear fuel materials and elements etc. with difficulty
- Acceleration and improvement of efficiency in analysis
- Technology for accelerated pretreatment of low-energy radioisotopes

### <Development in fiscal year 2026>

Technology of accelerated and efficient analysis for  $\alpha$  radioactive elements

Technology of accelerated and efficient analysis for  $\beta$  radioactive elements

Evaluation of the adsorption performance of solid-phase adsorbents

### B3②-3 Development of Technologies for Impact Assessment due to Dust Dispersion

#### [Purpose]

Towards scaling up retrieval of fuel debris, necessary for ensuring safety of retrieval works technology shall be developed for assessment of dust dispersion impact.

#### <Current issues (Technologies to be necessary)>

For scaling up retrieval of fuel debris and internal structures, it is necessary to develop safety assessment techniques for the retrieval methods under consideration for normal operations and an event of accident. It has been in progress the acquisition of fundamental data on dust dispersion under both dry and wet conditions to understand the impact due to dust dispersion generated during fuel debris retrieval. Furthermore, it is necessary to estimate the actual impact of dust dispersion from data obtained during the processing of fuel debris and optimize safety assessments of the next stage.

The main issues to be addressed at present are as follows:

- Tests under PCV internal conditions (wet, water, flowing water)
- Acquisition of dust dispersion and migration data during processing of fuel debris
- Safety assessments using dust dispersion data

#### <Development in fiscal year 2026>

Acquisition of Dust Dispersion Rate Data using simulated debris (cold materials, uranium-containing simulated debris, etc.) in assumed environments (wet conditions, etc.)

Test of dust migration behavior into the environment using large-scale test equipment

## B3②-4 Technology Development of Analytical Method for Exposure Dose Evaluation

### [Purpose]

Towards scaling up retrieval of fuel debris and internal structures, the elemental technologies to ensure safety during these operations shall be developed and conducted the tests.

### <Current issues (Technologies to be necessary)>

In scaling up retrieval of fuel debris and internal structures, it is essential to ensure the safety of workers by checking regularly that there is no intake of  $\alpha$ -nuclides and other nuclides into the body. In the unlikely event of radiation intake, it is necessary to know quickly the amount of the radioactive materials taken in and evaluate the exposure dose to take appropriate actions in an early stage. In case of an intake of  $\alpha$ -nuclides and other nuclides, due to the situations from a difficulty of  $\alpha$ -ray measurement, and the excessively high internal exposure dose conversion factor, etc., an evaluation by bioassay etc. is essential. Therefore, the response frameworks established at nuclear power plants for normal operations (including periodic inspections and maintenance) and for the decommissioning stage cannot be applied. The Fukushima Daiichi NPS differs significantly from existing facilities in Japan and overseas in terms of the nuclide composition and concentration of radioactive materials to be handled, the status of work and the number of workers to be managed and other factors of the working environment related to decommissioning. Considering these situations technically and comprehensively, it is required to develop a new protocol used for analysis and measurement including the development of hardware.

The main issues to be addressed at present are as follows:

- Protection technology of internal exposure
- Measurement technology of internal exposure
- Evaluation of internal exposure

### <Development in fiscal year 2026>

Technology for Measuring and Evaluating Internal Exposure

Technology for Measuring and Evaluating Body Contamination

### 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 to its storage, the system shall be developed for safe, secure and reasonable containment, transportation and storage of retrieved fuel debris.

#### <Current issues (Technologies to be necessary)>

To ensure the containment, transportation and storage of retrieved fuel debris to be done safely, securely and reasonably, it is necessary to have storage containers including canisters (hereinafter referred to as "storage containers"), equipment/facilities for transportation and storage, as well as treatment and handling methods and procedures that are appropriate for the characteristics and conditions of retrieved fuel debris. Particularly, some of the powdery fuel debris generated during the fuel debris cutting or crushing process in the retrieval process is planned to be collected in the cooling water circulation system etc., which is expected to result in slurry/sludge-like fuel debris. In cooperation with related research and development projects, investigations on measures against hydrogen gas generation (advancement of hydrogen gas generation prediction method and establishment of measures for hydrogen gas accumulation) shall be conducted.

To safely, reliably, and reasonably store fuel debris, it is important to maintain the integrity of the containment boundaries of the storage containers. To examine the necessity of monitoring corrosion of the storage containers that could affect the integrity of the containment boundaries, it is necessary to develop and verify a corrosion progression models based on the materials of the storage containers and other factors affecting corrosion such as. storage conditions of the storage containers.

The main issues to be addressed at present are as follows:

- Safety ensuring of handling slurry/sludge state fuel debris
- Transportation technology of slurry/sludge state fuel debris
- Storage technology of slurry/sludge state fuel debris

#### <Development in fiscal year 2026>

Technology for handling of powdery and slurry/sludge state fuel debris

Technology for maintaining the stable storage of fuel debris

## B4 Development of Utilization Technology for Robots Equipped with Physical AI in Remote Operations under Severe Environments

### [Purpose]

Technology development shall be conducted to evaluate the feasibility of utilizing robots equipped with Physical AI to perform tasks in place of skilled operators and workers involved in preparation activities.

### <Current issues (Technologies to be necessary)>

Inside the reactor building, it is essential to safely and reliably carry out investigations and operations in areas with extremely high difficulty, such as confined spaces, high-radiation areas, or areas with poor visibility, and locations lacking power supply and communication infrastructure to reduce radiation dose and secure workspaces.

Therefore, it is necessary to develop technologies to equip quadruped walking robots and other systems with physical AI to enable autonomous investigations and operations, so that the robots can perform, in place of humans, investigations and preparation activities, etc., in the severe environments described above.

Especially for investigations and operations on the first floor of the reactor building, it is anticipated that robots will autonomously navigate from the area outside the reactor building entrance to high-radiation areas (such as the vicinity of the HCU), perform tasks including radiation measurement and other investigations and operations, etc., and return to outside the reactor building entrance.

In light of the above, the operational requirements necessary for motions shall be identified, including functions such as posture control for quadruped walking robots, etc., and the optimization of investigation paths. In addition, the requirements for sensing capabilities shall be identified, covering functionalities such as general sensing technologies, etc., as well as radiation dose sensors for detecting high-radiation areas. These requirements shall then be organized, etc., as operational technology requirements for quadruped walking robots equipped with physical AI, taking into account the work inside reactor building.

The main issues to be addressed at present are as follows:

- Construction of a virtual environment (digital twin) based on point cloud data for machine learning
- Verification of the autonomous navigation and operational capabilities for quadruped walking robots, etc., equipped with physical AI

### <Development in fiscal year 2026>

Identifying and organizing the operational technology requirements for quadruped walking robots, etc. equipped with physical AI.

Acquisition of autonomous robot functions necessary for work inside the reactor building.

## C Research and Development of Processing and Disposal of Solid Waste

### [Purpose]

Considering the prospects of processing and disposal method and technology related to its safety, as provided in FY2021, in order to form waste streams suitable for the characteristics of solid wastes, proceeding the progress of waste characterization, it shall be conducted to develop, compare, and evaluate storage/management, processing, recycling and disposal options and planned to investigate towards presenting the appropriate measures for the practical solid waste overall management (management from solid waste generation up to its recycling and disposal).

### <Current issues (Technologies to be necessary)>

Regarding the measures for solid waste, further possibilities for more waste volume reduction shall be examined and in order to construct waste streams suitable for the characteristics of solid waste studies shall be conducted towards presenting appropriate measures for practical solid waste management.

The main issues to be addressed at present are as follows:

- To reflect the overall solid waste management, acquisition and evaluation of analysis data shall be conducted, and activities for efficient waste characterization shall be conducted
- For safe and reasonable storage and management, reduction and recycling technologies in order to reduce the amount of waste, as well as technologies for the volume reduction and stabilization of waste resins affected by the Great East Japan Earthquake .
- With respect to processing technology, an investigation shall be conducted on issues related to the applicability of low-temperature processing, the stability of the solidified waste manufactured by various processing technologies, the interim processing technology contributing to expanding the range of applications of the low-temperature processing technology, and flexible and reasonable processing technology.
- Regarding disposal technology, disposal concept options shall be established and proposed, necessary parameters shall be obtained, and safety assessment technologies shall be improved. Based on these efforts, safety assessments of the solid waste disposal shall be carried out.

<Development in fiscal year 2026>

Waste Characterization

- Acquisition and Evaluation of analytical data to be reflected in the overall solid waste management
- Enhancement of efficiency of waste characterization

Storage and Management

- Development of volume reduction and recycling technologies for contaminated metals
- Development of volume reduction and stabilization technologies for waste resins

Processing and Disposal

- Full-scale testing of low-temperature processing technologies.
- Feasibility study on flexible and reasonable waste processing technologies; Proposal of conceptual options for solid waste disposal
- Implementation of safety assessments for disposal concept option of solid waste

