Completion of the Fuel Debris Trial Retrieval Contributing to the Stabilization of Fukushima Daiichi Nuclear Power Plant


Testing of fuel debris trial retrieval device with mockups

FUMIHIRO HOSOE[*1] YOSHINAO ISHIHARA[*2]
YOSHIHIRO TSUJITA[*3] DAISUKE HARA[*2]
YOSHIFUSA TOBATA[*4] SHOYA HONDA[*5]

Since immediately after the Fukushima Daiichi Accident, Mitsubishi Heavy Industries, Ltd. has been cooperating with the efforts of Tokyo Electric Power Company Holdings, Incorporated toward the early stabilization of the power station. Currently, various projects are underway at the Fukushima Daiichi Nuclear Power Plant to achieve early stabilization, including fuel removal and contaminated water treatment, but the core of early stabilization is the retrieval of the fuel debris, which is the molten, cooled, and solidified nuclear fuel and reactor internals, and this is considered to be the most technically challenging part of them. This paper presents the details of the successful trial extraction of the fuel debris by the equipment developed by Mitsubishi Heavy Industries, Ltd.

1. Introduction

After the Fukushima Daiichi Accident, various efforts have been made for the early stabilization of the power station, but the treatment (removal/storage) of fuel debris that has leaked outside the pressure vessel is the most technically challenging task because it must be performed by teleoperation due to the high-radiation environment. This report introduces the work carried out at the Fukushima Daiichi Nuclear Power Plant to establish an access route for the robotic arm for the fuel debris trial retrieval and the progress status for the fuel debris trial retrieval, as well as the progress in the efforts of Mitsubishi Heavy Industries, Ltd. (hereinafter referred to as MHI) to date toward the early stabilization and the development of a robotic arm for fuel debris retrieval, which were described in the previous report Vol. 57 No. 4 (2020)(1).

2. Toward fuel debris retrieval

With regard to the fuel debris retrieval plan, Tokyo Electric Power Company Holdings, Incorporated (hereinafter referred to as TEPCO) announced in their Mid-and-Long-Term Decommissioning Action Plan 2024(2) that they will conduct a fuel debris trial retrieval using a telescopic type device around October 2024, starting with the Fukushima Daiichi Nuclear Power Plant Unit 2, followed by a robotic arm investigation. It is planned that the fuel debris retrieval will be scaled up in stages from 2027 onward and started also in Unit 1 and Unit 3 sequentially.

Figure 1 shows the inside of Unit 2. It is considered that the molten nuclear fuel penetrated the bottom of the reactor pressure vessel (hereinafter referred to as RPV), and cooled and solidified together with the internals to become fuel debris at the bottom of the pedestal (foundation structure supporting the RPV) inside the primary containment vessel (hereinafter referred to as PCV). After researching routes for robot access to the bottom of the pedestal, we decided to utilize a PCV penetration (hereinafter referred to as X-6 Penetration) of approximately 550 mm in diameter and 2,400 mm in length, which allows straight and efficient access to the opening of the pedestal.

However, in order to access the bottom of the pedestal with the robotic arm and retrieve the fuel debris, the following issues need to be solved.

*1 Senior Principal Engineer, Decommissioning Engineer Department, Nuclear Energy Systems
*2 Project Director, Decommissioning Engineer Department, Nuclear Energy Systems
*3 Engineering Manager, Decommissioning Engineer Department, Nuclear Energy Systems
*4 Engineering Manager, Construction & Maintenance Engineering Department, Nuclear Energy Systems
*5 Construction & Maintenance Engineering Department, Nuclear Energy Systems

(1) Removal of deposits (interferers) in X-6 Penetration

Inside X-6 Penetration, there are cables that are used for equipment in the PCV, and other objects. These objects are obstacles to the robotic arm passing through X-6 Penetration, so it is necessary to remove them by teleoperation.

(2) Radiation resistance

The inside of the PCV is a high-radiation environment (up to 100 Gy/h), and the robotic arm is required to have high radiation resistance.

(3) Positioning of robotic arm

According to the results of a visual inspection of the inside of the pedestal conducted by TEPCO in January 2018[(3)] (**Figure 2**), the access to the bottom of the pedestal requires passing through the opening which the grating of the platform has fallen off, and it is necessary to position the tip of the robotic arm precisely in narrow gaps.

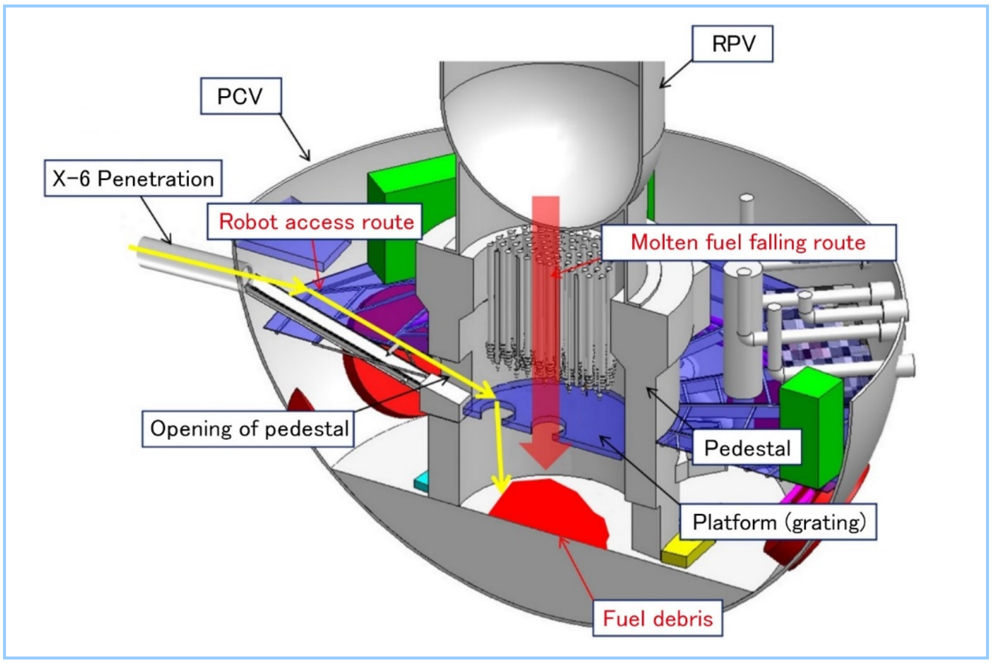
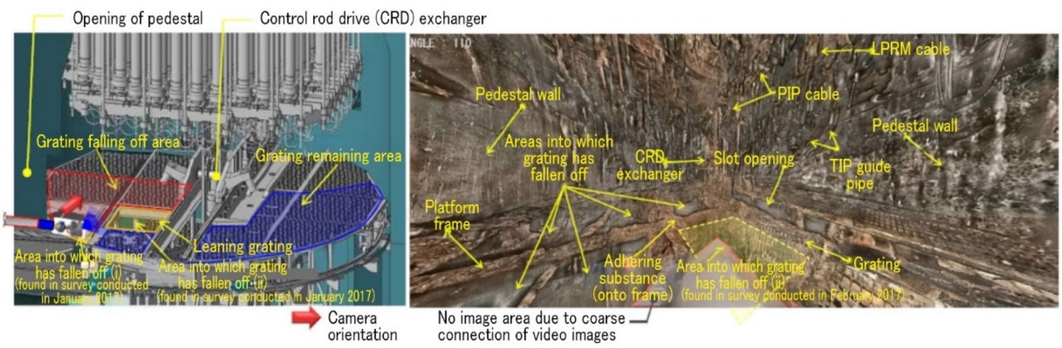


Figure 1 Internals of Fukushima Daiichi Nuclear Power Plant Unit 2



Excerpts from the material dated April 26th, 2018 for the meeting of Team for Countermeasures for Decommissioning and Contaminated Water Treatment, TEPCO and 53rd Secretariat Meeting

Figure 2 Result of visual inspection inside PCV

The following chapters present the removal of deposits in X-6 Penetration conducted by MHI at the Fukushima Daiichi Nuclear Power Plant and the fuel debris trial retrieval, as well as the development status of the robotic arm for investigating the inside of the PCV and the study status of equipment to scale up the fuel debris retrieval.

3. Access route establishment

It is thought that cables and other materials in X-6 Penetration remain in a state where they are difficult to remove easily due to the melting of cable sheathing by heat and complicated cable entanglement that were caused by the accident (these remaining objects are called deposits). This chapter describes the examination on deposit removal methods, device design and production, functional verification and training, and results of the on-site work.

3.1 Examination on deposit removal method, and design/production of device

(1) On-site survey

TEPCO conducted a survey in 2020 to investigate the nature of the deposits in X-6 Penetration through an opening of 115 mm in diameter provided in a part of the flange lid of 55 mm in thickness that closes X-6 Penetration. In this survey, the measurement of the shape of the remaining cables and deposits through 3D scanning using a remote monitoring camera, and palpation of the deposits using a stick were conducted. As a result, the range where deposits exist was clarified, and it was confirmed that the deposits collapsed when pressed with a force of approximately 20 N and that the cables are able to be lifted, not adhered. The results obtained were reflected in the device design and work planning.

(2) Design and production of deposit removal device

MHI designed and produced a tele-automatic device with the following functions as a deposit removal method (**Figure 3**).

(i) A traveling function to access X-6 Penetration by teleoperation.
(ii) A function to grip on and provide sealing to the penetration flange to prevent the spread of contamination to floor surfaces outside of X-6 Penetration.
(iii) A function to remotely monitor the inside of X-6 Penetration using a radiation-resistant camera.
(vi) Rotation and linear motion functions for positioning the following tools for deposit removal.
- An abrasive water jet (hereinafter referred to as AWJ) tool (water pressure: 245 MPa, flow rate: 4 L/min.) to cut deposits with high-pressure water
- A washing tool (water pressure: 30 MPa, flow rate: 60 L/min.) to wash the bottom of the penetration
- A pushing tool (approximately 1500 N) to push out the remaining deposits into the PCV

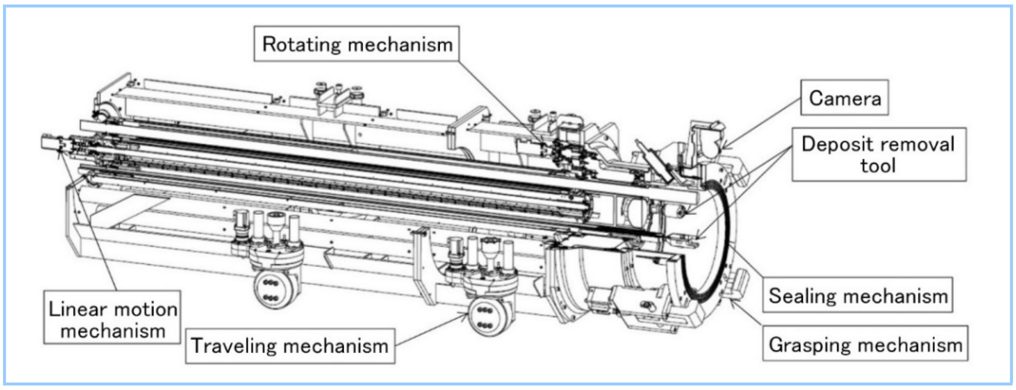


Figure 3 Debris removal device

Since the inside of the Unit 2 reactor building, which is the work area, is a high-radiation environment, remote control was made possible from the control room, approximately 0.4 km from the area. **Figure 4** shows the work situation in the control room.

In the process of deposit removal in X-6 Penetration, there is a major risk of process extension due to the spread of radioactive materials caused by scattering of free dust during the work using the AWJ. So, we have decided to take the following countermeasures.

(i) Prior to the work using AWJ, the free dust is pre-cleaned at low water pressure (2 MPa).
(ii) Application of a spray curtain, which sprays fine mist to prevent dust scattering, at the position where the AWJ is discharged from the X-6 Penetration into the containment vessel (Figure 4).

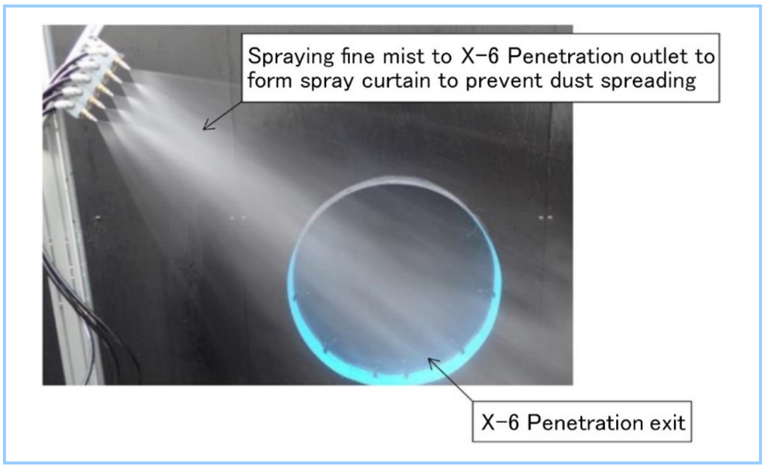


Figure 4 Spray curtain (factory test)

3.2 Verification test and familiarization training

The work site environment is tough: high levels of radiation are present, and depending on the area, the work time per person per day is limited to about 20 minutes; the floor surfaces are uneven and lighting is insufficient because the work site is inside a building where the accident occurred; and the time available for site inspections is limited in order to reduce radiation exposure. In order to proceed smoothly with the work in such an environment, we prepared a training facility that simulated the inside of the reactor building at full scale in our factory, and conducted training for the work.

During the training, the trainees wore actual radiation protection equipment to simulate visibility deterioration and difficulty in breathing caused by the full-face mask, heat caused by the non-breathable protective clothing, and difficulty in hand work caused by the three-layered rubber gloves.

In particular, for human-power work in a high-radiation environment, such as transporting equipment weighing approximately three tons in a narrow building using a carrying dolly and laying approximately 200 operating cables and hoses in the building, multiple one-through training sessions were conducted in addition to individual skill-improving training in order to facilitate smooth handover between tasks and enable continuous work.

Keeping in mind that the slightest pause or hesitation could affect the work process from the viewpoint of radiation control, the missing points in the procedure manual were crushed until all workers understood the procedures, which were then incorporated into the on-site work procedure manual as detailed working methods.

3.3 On-site work

Figure 5 shows the situation inside X-6 Penetration just after opening. Deposits were seen on almost the entire penetration surface. We connected the deposit removal device to the flange of X-6 Penetration and started the deposit removal work remotely. After gradually removing the deposits inside X-6 Penetration using various removal tools, we were able to remove almost all of the deposits remaining inside X-6 Penetration (**Figure 6**). And, the situation of remote control in the control room is shown in **Figure 7**.

In order to complete this work, all the participants read through the on-site work procedure manual together in advance and confirmed that there were no problems with the start of the work. Since there were multiple worker turnovers, such as up to seven-team consecutive work shifts, 30 minutes each, a time chart for daily work was prepared in minutes, and each worker checked the work details together with all other workers every morning to ensure the same recognition and to prevent rework.

In addition, work progress was checked via walkie-talkies as needed to grasp the movements of all workers, and minute-by-minute time adjustments were made to thoroughly eliminate waste and reduce exposure to radiation. We made sure to observe a rule: whenever there was even the slightest difference from the on-site work procedure manual or trained content, stop the work, make a discussion and check, and resume the work only after it was confirmed that there were no problems and the work was ready. After making a steady accumulation of steps while learning a lot of lessons such as feedback to the subsequent work, we completed the establishment of the access route for the fuel debris retrieval and internal investigation in the period from November 27, 2023 to June 28, 2024 with no accidents and no disasters.

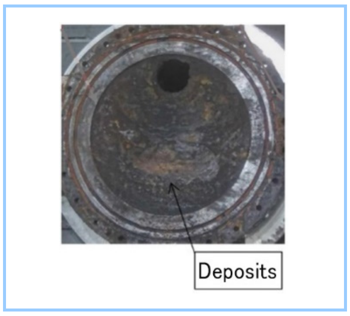


Figure 5 Status of X-6 Penetration entrance before work

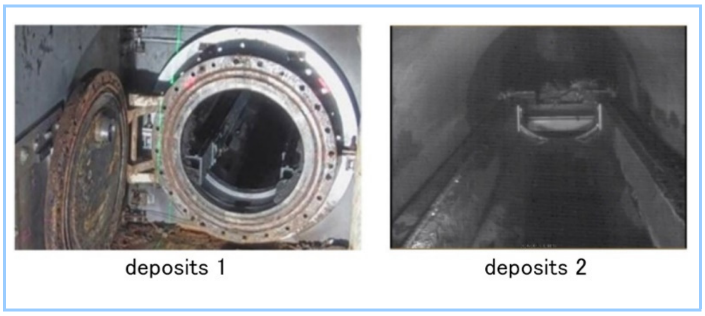


Figure 6 Internal status of X-6 Penetration after removal

Figure 7 Teleoperation work

4. Fuel debris trial retrieval

Since the removal of deposits in the Unit 2 X-6 Penetration has been completed and an access route has been established, we have conducted a fuel debris trial retrieval in order to quickly investigate the characteristics of the fuel debris prior to a full-scale internal investigation of the PCV. This chapter describes the results of the research on the trial retrieval method, the design and production of the equipment, the functional verification, and the training and on-site construction.

4.1 Research on fuel debris retrieval method and design/production of device

(1) Preliminary investigation

Based on the results of the investigation conducted by TEPCO from 2018 to 2020 as described in the previous chapter, the locations of fuel debris assumed to be able to be trial-retrieved and the access routes for the device were determined.

(2) Design and production of trial retrieval device

We developed a device with the following specifications and functions in order to perform the trial retrieval (**Figure 8**).

(i) The device was designed specifically for fuel debris retrieval, and the telescopic mechanism is adopted for the extendable part for simplicity. This device is hereinafter referred to as "telescopic type device". The telescopic mechanism is housed in a steel container called an enclosure, and it is a mechanism to feed the telescopic mechanism by being pushed from the rear of the device by a push-in pipe.

(ii) The size of the device was minimized to 390 mm in width and 210 mm in height to ensure a clearance with the inner surface of X-6 Penetration when passing through it. As a result, a clearance of 27 mm or more was secured over the entire circumference of the X-6 Penetration inner wall, and cameras were installed to allow remote visual confirmation.

(iii) Four radiation-resistant cameras were installed to visually position the device in the pedestal.

(iv) The device has a structure that allows it to be taken out of the PCV by pulling an emergency escape wire from the outside, even in the event of device failure.

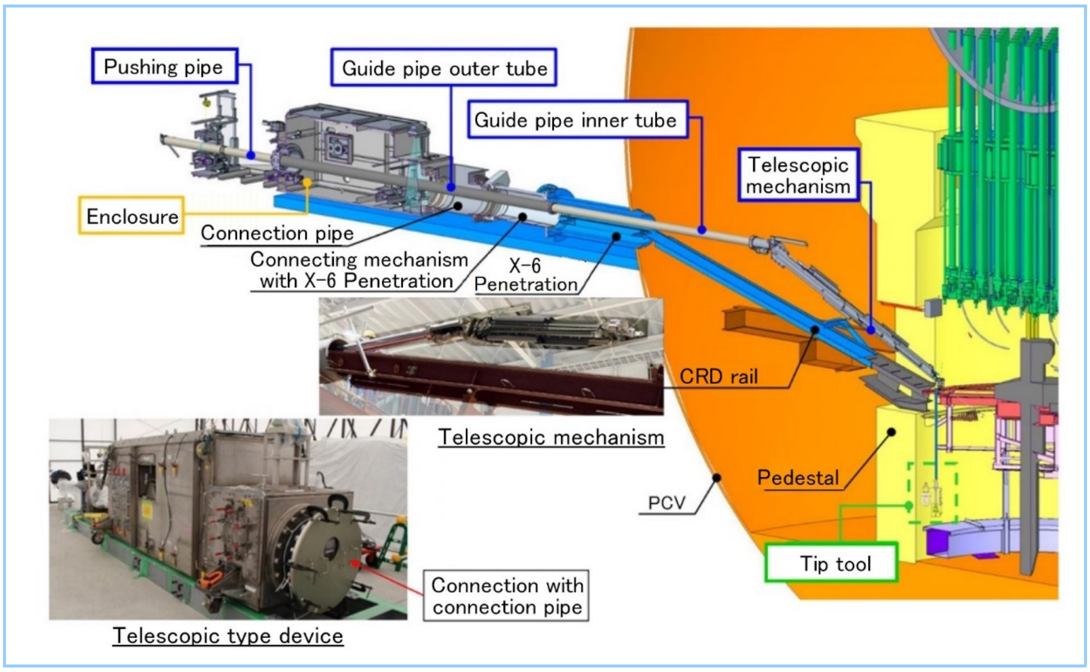


Figure 8 Fuel debris trial retrieval device

The structure of the tool at the tip of the device to grasp the fuel debris was determined by conducting elemental tests related to the grasping performance. Several kinds of the gripper type- and brush-type tools were prototyped and elemental-tested as candidates. As a result of verifying operability during retrieval and handling capability after retrieval using simulated fuel debris (lead spheres of 0.35 to 15 mm in diameter, gravel of complex shapes, etc.), the gripper type was selected. **Figure 9** shows the element test.

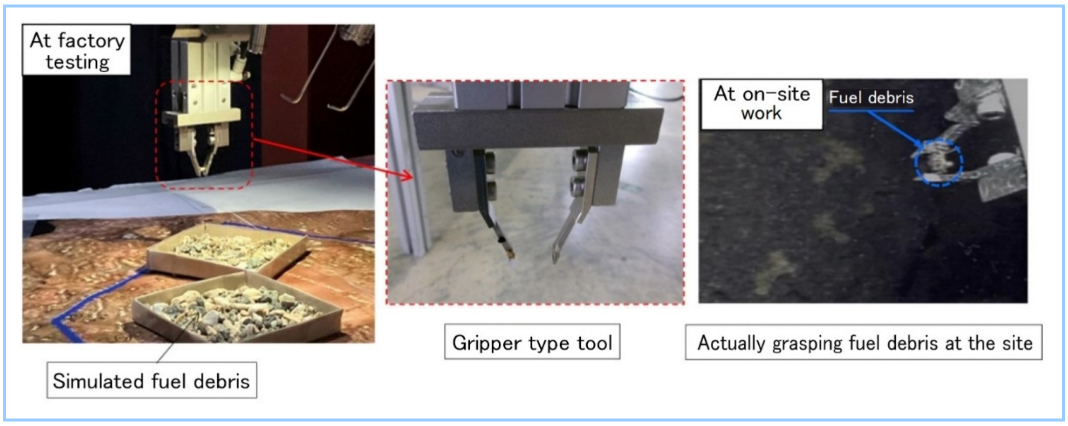


Figure 9 Advanced tool element test and situation at site work

4.2 Verification test and familiarization training

Similar to the deposit removal described in the previous chapter, fuel debris retrieval also requires work in a high-radiation environment. In order to train the workers more effectively, the following approaches have been taken.

(i) Case examples in the deposit removal work that were favorable or should be reflected were extracted and fed back to the fuel debris retrieval work training procedures without omission.

(ii) A training environment simulating the inside of the reactor building at full scale was constructed in our factory. A full-scale mockup of the inside of the pedestal was used to confirm the feasibility of a series of work procedures and emergency recovery mechanisms (**Figure 10**).

(iii) The trainees wore actual radiation protection equipment to simulate visibility deterioration and difficulty in breathing caused by the full-face mask, heat caused by the non-breathable protective clothing.

(iv) Visualization of the procedure manual was promoted. The manual had been paper-based in the past, but it was made easier to read by devising its visual such as, incorporating a check sheet with captured images of robot operation screens and making procedure videos (3D-animation) of all work in the building. In addition to the work procedures, precautions and key points for important work were incorporated, thereby promoting activities to further improve the level of understanding for reducing exposure and taking countermeasures against heat stroke.

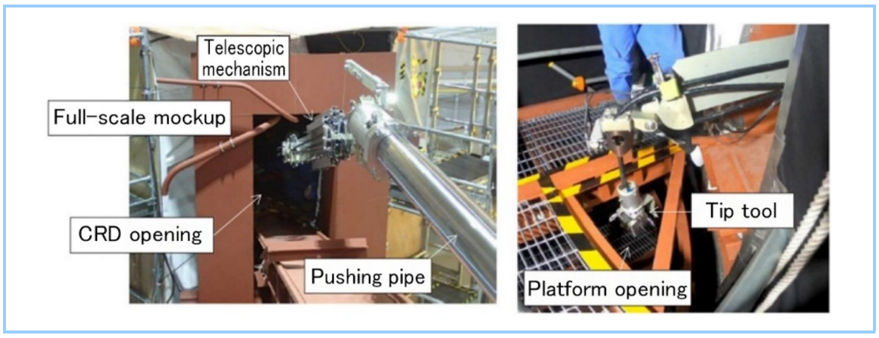


Figure 10 Training

4.3 On-site construction

In considering the work plan, we utilized knowledge and data obtained from preceding work such as deposit removal work to optimize the allocation of workers under high radiation dose conditions and to optimize work hours, thereby improving the accuracy of the plan. We started the on-site work in June, and after conducting visual inspections and functional checks of the device in an area on the Fukushima Daiichi Nuclear Power Plant premises (outside the building), the device was brought into the building. All of the work was carried out in accordance with trained procedures, always taking safety into consideration.

In addition to measures to reduce exposure, we also focused on measures to prevent heat stroke. We took physical measures such as wearing coolant vests and using more spot coolers, as well as devised working hours (starting work early in the morning and completing it before the temperature rises). By carrying out the time chart of minute unit which was also carried out in the preceding construction, high construction quality was ensured, and the field construction was completed without accident.

The fuel debris was brought to the enclosure after confirming its appearance with a camera mounted on the equipment. After that, the radiation dose of the fuel debris itself was measured according to the measurement procedure considering the high radiation environment, and the fuel debris was transported to TEPCO.

5. Status of development of robotic arm for internal investigation of PCV

We plan to conduct a detailed internal investigation of the PCV after the fuel debris trial retrieval at Unit 2. The robotic arm to be used for the investigation has been completed to be assembled and is undergoing verification testing using a full-scale mockup in preparation for on-site deployment in FY2024. This chapter describes the status of the verification tests and our efforts to improve the positioning accuracy of the arm.

5.1 Outline of device

The robotic arm has an articulated structure and sensors mounted on its tip to acquire information on the internal structure of the PCV (shape and dimensions), distribution of fuel debris, distribution of γ-ray dose, etc. The arm is retracted into the enclosure in a folded state, and when performing investigation, extended to access the pedestal in the PCV passing through X-6 Penetration (**Figure 11**).

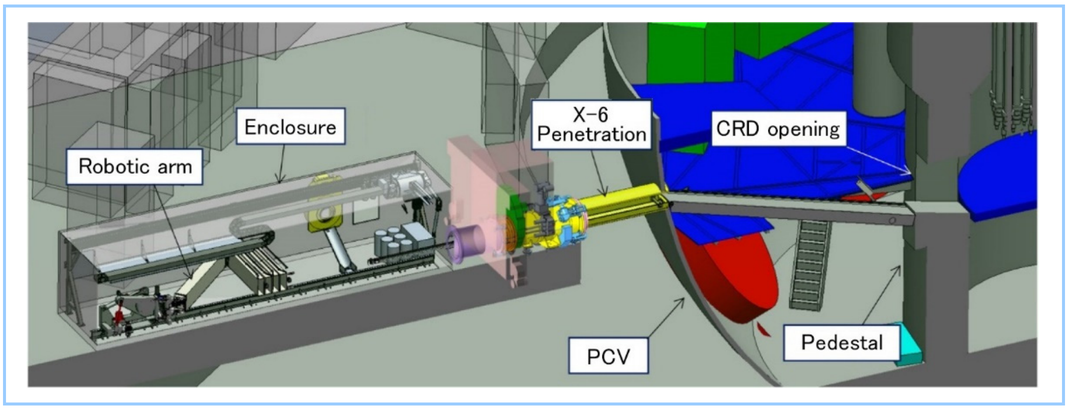


Figure 11 Robotic arm for internal investigation of PCV

5.2 Status of verification testing

For the robotic arm, we are now conducting tests using mockups and operational training (**Figure 12**). In the test currently conducted, we are checking operation to deploy the robotic arm and have its tip through X-6 Penetration and the narrow opening on the platform. The operation to move the robotic arm tip through the opening is carried out using information from the camera at the tip and VR information (virtual reality image of 3D CAD, which projects the robot's posture on a monitor). In order to improve the reliability in terms of avoiding interference, we gained a prospect to improve the positioning accuracy of the arm tip to ±10 mm from the initial ±100 mm.

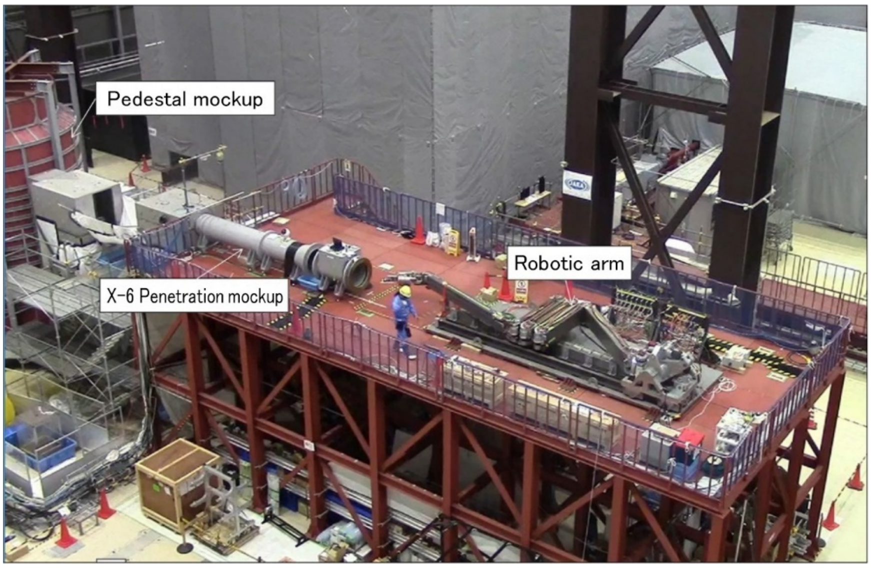


Figure 12 Testing of robotic arm for internal investigation of PCV using mockups

5.3 Efforts to improve positioning accuracy

The rotation angle of arm articulations is detected by a detector (Output resolver) attached to the moving part, and the arm is currently controlled using the value of the Output resolver. In order to further improve the accuracy, we devised a method to utilize a detector installed in the motor (Motor resolver) to use both of them together.

Figure 13 shows the structure of the Output resolver and the Motor resolver. The motor rotation is detected by the Motor resolver, which is directly connected to the motor, and rotates the Output resolver after being transmitted through the reducer. Therefore, the Motor resolver rotates at a higher speed than the Output resolver and has higher detection accuracy, but it has the disadvantage of being affected by the backlash and mechanical hysteresis (internal torsion) of the reducer. Based on these factors, we devised hybrid control that takes into account both the Output resolver and Motor resolver features.

The hybrid control monitors, at the start of motor rotation, the value of the Motor resolver, and corrects it, after getting out of the nonlinear region of the reducer, with the value of the Output resolver to offset the amount of false detection due to the nonlinear component. As a result of adopting this control method, the positioning accuracy at the arm tip was 8 mm, achieving the target value.

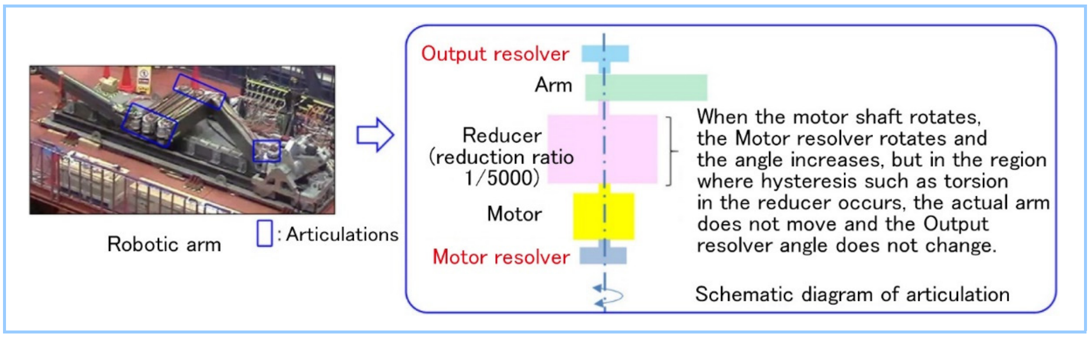


Figure 13 Advantages and disadvantages of angle detector (resolver)

6. Consideration toward gradually scaled up fuel debris retrieval

We are also working on the development of a device to gradually scale up the fuel debris retrieval after the internal investigation of the PCV in Unit 2. This chapter describes the status of the research on equipment for the gradual scaling up.

6.1 Robotic arm for gradual scaling up

(1) Outline of equipment

We are working on the development of a robotic arm for the gradual scaling up of the fuel debris retrieval in Unit 2, and it is currently in the detailed design phase. As in the preceding equipment, the under-development robotic arm will develop from the enclosure outside the PCV toward the inside of the PCV, pass through X-6 Penetration and the platform opening in the pedestal, reach the bottom of the pedestal, and investigate and retrieve fuel debris there by teleoperation (**Figure 14**). Though the sampling of about 3 grams was aimed at in the fuel debris trial retrieval, the retrieval of approximately 3 kilograms per day is aimed at in this equipment.

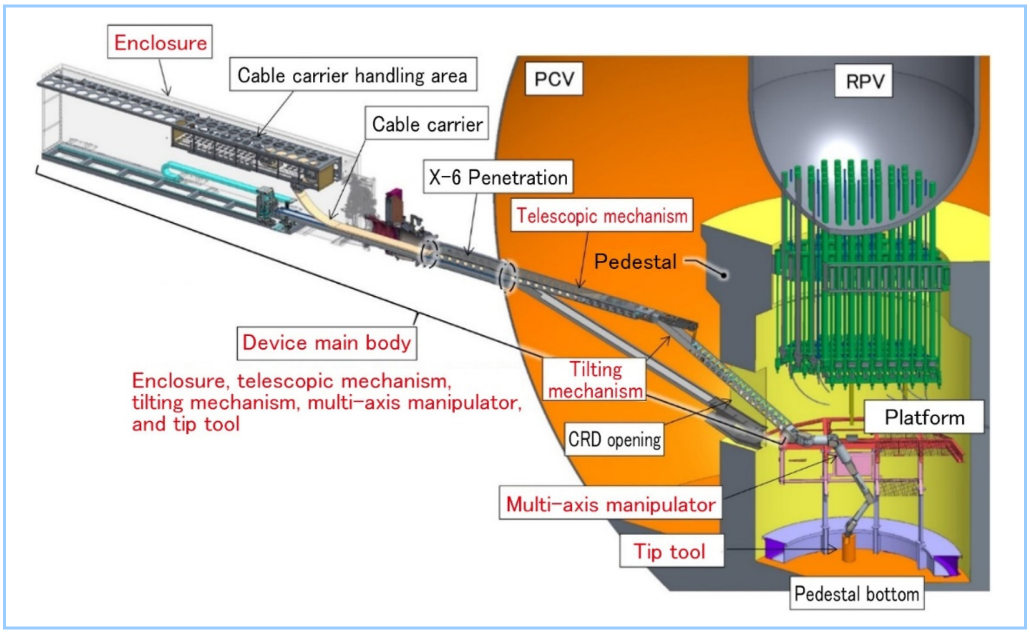


Figure 14 Robotic arm for gradually scaled up fuel debris retrieval

The device has telescopic and tilting mechanisms for linear extension/retraction, a multi-axis manipulator attached to the tip of them, and a working tool (tip tool) attached to the tip of the manipulator, which enables the investigation and retrieval of fuel debris. The ceiling inside the enclosure is equipped with a cable carrier handling area that provides utilities to the multi-axis manipulator and tip tool in conjunction with the arm's extension/retraction.

The multi-axis manipulator has a total length of approximately 4 m and a mass of approximately 200 kg with the tip tool attached, and 10 degrees of freedom to enable guidance of the tip tool to the work area by posture control to avoid interference with the surroundings even in the environment inside the pedestal where the status of fuel debris accumulation is unclear. In addition, remote mounting and dismounting of the tip tool inside the enclosure is also possible by controlling the posture of the manipulator.

For ensuring the emergency escape function in case of a device failure, the drive mechanism is duplicated to improve the redundancy. In addition, in order to allow the device to be used in the high-radiation environment inside the PCV, the development is being proceeded with while verifying the radiation resistance of its components through tests.

(2) Improvement of teleoperability

The robotic arm for the gradual scaling up of the fuel debris retrieval quantity uses a multi-axis manipulator. It enables work to be proceeded with while avoiding obstacles in an environment with many interfering objects. However, because the field of view in teleoperation is limited, avoidance of obstacles by teleoperation places a high burden on the operator, causing a risk of colliding a part of the manipulator with an obstacle. Therefore, we have developed a system that automatically maneuvers the manipulator to avoid obstacles, thereby reducing the operator's workload and improving work safety and efficiency.

The operating system employs trajectory planning, which was developed jointly with Kobe University[(5)]. The trajectory planning consists of two types of functions: global trajectory planning and local trajectory planning (**Figure 15**). Both of these functions calculate trajectories (state transitions) to allow a robot model (e.g., multi-axis manipulator) to reach a destination without interference with a predefined environment model (obstacle model), and reproduce the trajectories with the actual robot.

When the start point and goal point are set at, for example, X-6 Penetration and the bottom of the pedestal, respectively, the global trajectory planning calculates a rough obstacle avoidance route. The operator moves the robot along the route. The posture of the robot that avoids obstacles is calculated sequentially by the local trajectory planning, enabling complex obstacle avoidance that cannot be dealt with by the global trajectory planning. The two-stage configuration, global and local, improves the reliability of obstacle avoidance and reduces the calculation time.

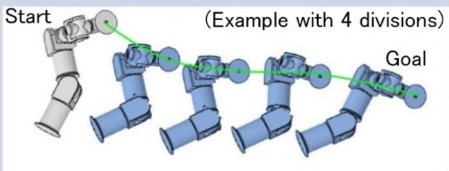
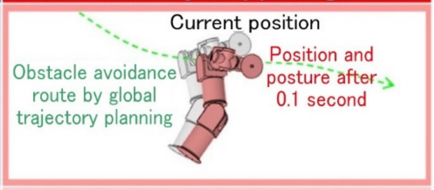
	Automatic access route generation system (global trajectory planning)	Sequential obstacle avoidance system (local trajectory planning)
Conceptual drawing		
Calculation details	A rough obstacle avoidance route is calculated according to the number of divisions from the start point to the goal point.	Robot posture to avoid obstacles is calculated sequentially (every 0.1 second).
How to use	The operator moves the robot along the obstacle avoidance route by stepping on the foot pedal (only adjusts the speed with the foot pedal depressing amount).	- The local trajectory planning is executed sequentially in the background while the robot is moving along the obstacle avoidance route set by the global trajectory planning. - While the operator is guiding the robot's hand to any point using the game pad, the obstacle avoidance posture control is automatically executed (the obstacle avoidance is prioritized over reaching the target).
Advantages over conventional method	The obstacle avoidance route can be created in a shorter time by the computer.	The reliability of obstacle avoidance is improved in combination with global trajectory planning.

Figure 15 Measures to improve teleoperability of robotic arm for gradual scaling up of fuel debris retrieval

6.2 On-site transport container remote transporter

(1) Outline of equipment

The on-site transport container remote transporter is a device used to transport a shielded transport container (commercially available transport container from LaCalhene [(6)], having a shielding thickness of 200 mm and a mass of 4 tons) holding retrieved fuel debris (**Figure 16**). Since the on-site transport container remote transporter is required to travel inside the reactor building by teleoperation and to connect accurately to the port for fuel debris retrieval, a traveling mechanism (omni-directional moving wheels) that can turn on the spot and traverse is used. In addition, to position the shielded transport container to the retrieval port with an accuracy of 0.5 mm, a positioning mechanism with six axes of mechanical cylinders has been developed and installed to the transporter. Furthermore, the on-site transport container remote transporter is a device that enables accurate transport and handling of the shielded transport container in a high-radiation environment, for example, by having a cable drum mechanism that can automatically feed and wind the cable according to the amount of forward or backward travel by teleoperation.

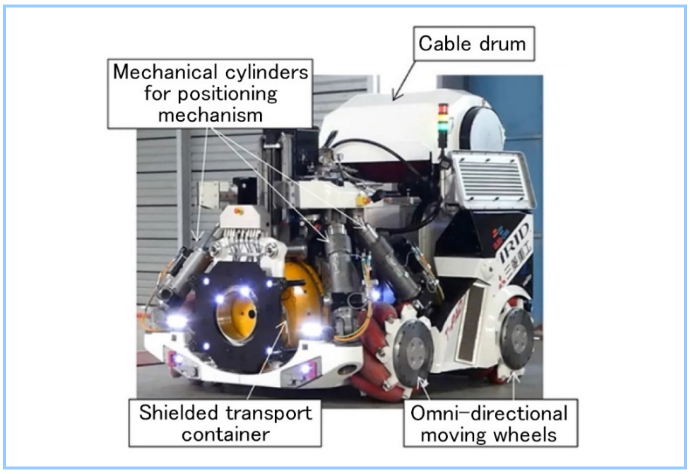


Figure 16 Verification machine for on-site transport container remote transporter

(2) Development status and future prospects

We made a verification model of the on-site transport container remote transporter and factory-tested its connection/disconnection to/from the fuel debris retrieval port by teleoperation (**Figure 17**) and its travel capability in an environment simulating the inside of the reactor building to verify that a series of operations are feasible. We also conducted various verification tests that simulate operation in a severe environment, including handling under high-radiation and other adverse conditions (uneven or wet floor surfaces, etc.), dealing with device malfunctions, etc.

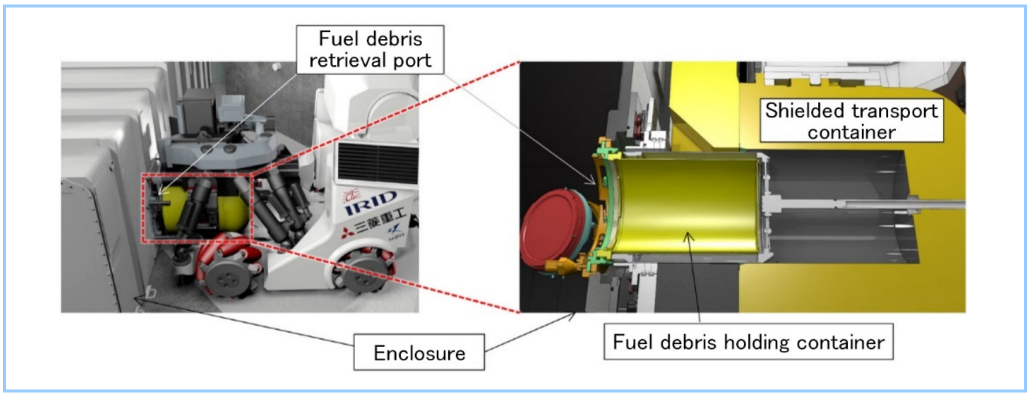


Figure 17 Fuel debris retrieval port and connection with fuel debris holding container

In addition, by having TEPCO operators experience the operation of this verification machine, we are collecting requests from the perspective of operations toward the production of the actual machine, and thereby researching on further enhancement of the machine functions, such as collision prevention against obstacles in the vicinity.

7. Conclusion

MHI recognizes that the early stabilization of the Fukushima Daiichi Nuclear Power Plant is an important issue for Japan and the nuclear power industry, and has provided various support therefor in cooperation with other companies in Japan and overseas. The fuel debris retrieval toward the early stabilization will be scaled up to a full scale in the near future. The work ahead will be in uncharted territory never before experienced by humankind and is expected to be highly challenging, however MHI intends to continue to actively pursue technological development.

Some of the results reported in this paper were developed and achieved by MHI as a member of the International Research Institute for Nuclear Decommissioning (IRID) under a grant from the Ministry of Economy, Trade and Industry for decommissioning and contaminated water treatment countermeasure projects.

References

(1) H. Fujimoto et al., Mitsubishi Activities for Stabilization and Decommissioning of Tokyo Electric Power Company Fukushima Daiichi Nuclear Power Station, Mitsubishi Heavy Industries Technical Review Vol.57 No.4 (2020)

(2) Medium- to Long-term Action Plan for Decommissioning 2024, TEPCO (in Japanese) https://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2024/03/03/4-2-1.pdf

(3) The material dated April 26th, 2018 for the meeting of Team for Countermeasures for Decommissioning and Contaminated Water Treatment, TEPCO and 53rd Secretariat Meeting (in Japanese)

(4) The material dated November 20th, 2020 for the meeting of Team for Countermeasures for Decommissioning and Contaminated Water Treatment, TEPCO and 84th Secretariat Meeting (in Japanese)

(5) Tatsuya H. et al., Experimental Evaluation of Manipulator Teleoperation System Based on Trajectory Planning for Obstacle Removal Task in Nuclear Plant Decommissioning, JRM Vol.36 No.1 (2024)

(6) LaCalhene, PADIRAC A robust, safe transfer and transport solution https://www.lacalhene.com/siteassets/start/products/padirac/lacalhene-padirac-en-2021.pdf