Improvement of On-site Work Processes for Nuclear Power Plant

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Construction and after-sales service of nuclear reactor facilities require construction technologies to fulfill a wide variety of design requirements in order to ensure safety and to allow the facilities to start/resume the operation in a short period of time. Furthermore, in recent years, further improvement of work efficiency and streamlining such as manpower saving are also required in response to the work style reform promoted in Japan. In order to meet these requirements, Mitsubishi Heavy Industries, Ltd. is working to identify issues faced in various construction projects and streamline and improve on-site work processes by upgrading the construction technology through expanding the scope of utilization of existing products and systems and utilizing the latest ICT technology.

1. Introduction

Nuclear facilities, which are in a radiation environment, are subject to strict laws, national regulations, design requirements, and security, and work to be performed in their construction and after-sales service (hereinafter referred to as A/S) is also subject to many restrictions. In addition, the decrease in the labor force due to overtime work restrictions in response to the work style reform recently promoted in Japan and due to the decline in population also have become apparent. Therefore, there is a major issue of how to improve work efficiency and reduce manpower when performing on-site construction work under various restrictions. On the other hand, information technology has developed remarkably in recent years, and various information terminals, software, etc. have appeared on the market. Mitsubishi Heavy Industries, Ltd. (hereinafter referred to as MHI) is currently implementing a variety of initiatives to solve problems in on-site construction by effectively utilizing these tools. This report presents the upgrading of construction technology that we are currently working on.

2. Issues and background for next construction and A/S

2.1 On-site measurement of buried objects [construction]

Nuclear facility buildings are concrete structures, and tens of thousands of buried objects (buried plates and sleeves) are embedded in floors, walls, and ceilings to support (fix) equipment, piping, ducts, etc. and to make penetrations through the structures. Therefore, it is anticipated that a huge amount of manpower and time will be required for installation, measurement, and inspection of them during the construction of future advanced light water reactors. Among these, the position measurement for post-installation inspections, which requires skilled techniques and takes time, has been streamlined using a digital camera-based 3D measurement technology (photo measurement) that we have developed to reduce the time required for measurement and documentation after the installation of buried objects before concrete is placed. However, this measurement technology can be applied only to buried plates in walls due to the following technical issues, and manual measurement of the installation positions has been required for other products (sleeves) and installation locations (floors and ceilings). In order to solve these issues, we have researched on the

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extension of the application scope of the photo measurement technology.

[Technical issues of 3D measurement technology (photo measurement)]

- Measurement cannot be made in floor and ceiling areas because false recognition points emerge due to sunlight reflection on steel plates used for building the structure (other than the object to be measured).
- Sleeves, which are hollow, cannot be measured with the existing fixture used for the measurement of embedded plates.

2.2 Handover of equipment from installation phase to commissioning phase [construction]

In the construction of nuclear facilities, when the equipment installation is completed, commissioning (testing) is conducted to confirm the function and performance of the equipment, thus the equipment is handed over from the installation team to the commissioning team at that time. However, with the decrease in the number of new construction projects, the number of workers who experienced construction and are familiar with the equipment handover method decreased, and young and mid-career workers have limited opportunities to experience equipment handover on-site or directly come into contact with the know-how of experienced workers, making it difficult to pass on sufficient skills and knowledge.

If this situation continues, there is a risk that equipment handover will not be carried out appropriately and in a timely manner, leading to process delays in the construction of the upcoming advanced light water reactors. We considered improving the handover process to resolve the issue.

2.3 Installation of cable tray supports [construction]

In electrical instrumentation work in nuclear facility construction, installation of cable trays for the purpose of electrical signal transmission/receipt cable protection and equipment operation cable protection, which are often installed on ceilings or wall upper areas, is high elevation work. In addition, since the cable tray supports are heavy (approximately 70 kg each), the risk of accidents is high and safer work is required.

In addition, as labor shortages are becoming more apparent due to the recent decline in the labor force caused by the falling birthrate and aging population, as well as the reduction in working hours caused by the work style reform promoted in Japan, more efficient work is required.

In order to solve these issues, we focused on cable tray support installation, which has a higher risk of accidents and handles more objects than other electrical instrumentation work, and developed and considered a new installation method to improve safety and efficiency.

2.4 Radiation measurement [A/S]

In nuclear facilities, radiation levels vary with changes in plant conditions, so during A/S, radiation levels in the work area are measured and communicated to those involved in the work in order to reduce exposure.

The current method of this radiation measurement is generally performed by two persons, one to measure and the other to record, because it takes time if a single person changes the measuring instrument, recording paper, and writing tools each time while measuring and recording the data. The procedure is as follows: the measurer moves with the measuring instrument to a predetermined position, measures the radiation dose, and the recorder records the value read by the measurer on a paper. This procedure is repeated dozens to hundreds of times, the same number of times as the number of measurement points. In addition, after the measurements, records drafted on the paper on-site have to be re-created as digital records after returning to the office, which requires manpower and time, thus saving labor in the measurement process is required. However, because the Internet and Wi-Fi are not available in radiation controlled areas of nuclear facilities from the viewpoint of nuclear security, it is difficult to improve operations using ICT technology. To solve these issues, we researched process improvement by using voice recognition software.

2.5 Equipment isolation in piping work [A/S]

In piping work during A/S at nuclear facilities, welding is performed with inert gas (argon) filled inside the pipe to ensure the quality of the welds, and the ice plug method is applied to isolate equipment to minimize the range of inert gas filling (**Figure 1**). The ice plug method is a method to close the pipe by cooling the water inside the pipe from the outside to generate ice plugs at any points inside the pipe. However, to determine the applicability of this method, mockup verification testing simulating the pipe size (diameter and thickness) and orientation (horizontal and vertical) is required, which requires significant cost and time.

We developed and reviewed a method to improve this situation and to enable early determination of the applicability of the ice plug method without mockup verification tests.

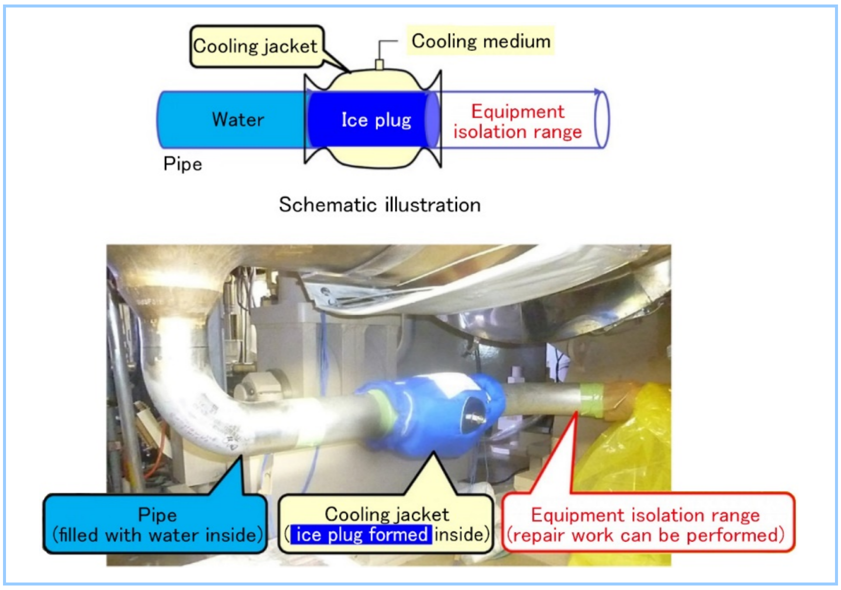

Figure 1 Schematic and work example of ice plug method

3. Application to on-site work

3.1 Expansion of application of photo measurement to all buried objects in all locations

Photo measurement, which is used for the buried object measurement, is a technology that uses a digital camera to take pictures of the measurement targets with target stickers attached and create a 3D model by combining the images, recognizes the flash light reflections from the target stickers as the measurement targets, and analyzes them to calculate the distance, enabling comparison of the measurement results with the design values and even their automatic recording. In the past, the application of the photo measurement was limited to embedded plates in walls, but the improvements described below have made it possible to apply it to all buried objects (embedded plates and sleeves) in ceilings, floors, and walls, realizing highly accurate measurement, reduced measurement and recording time, and labor savings.

The first of the improvements is correction of false recognition points in floors and ceilings, which are not target stickers but recognized as them due to reflection on steel plates or sunlight. To solve this misrecognition, we incorporated a program into the system that uses data from both the correct targets, the measurement points, and the false recognition points, the reflections on steel plates or sunlight, as teacher data for machine learning to determine whether the reflected light is the correct target or false recognition point. As a result, the system was able to automatically remove false recognition points with 98% accuracy, enabling the application of photo measurement to buried objects in floors and ceilings in addition to walls (**Figure 2**).

The second of the improvements is to improve the method to measure buried sleeves, which has been difficult to measure in the past. Sleeves are hollow and thus the conventional magnetic target cannot be installed in their center, which is the point to be measured. For this reason, photo measurement cannot be applied, and sleeve installation positions were determined based on manual measurement. Manual measurement of sleeve installation positions requires measurement of the center point of both end faces and the inclination, which is a complicated process involving measurement from both the front and back sides of the wall. Therefore, we have developed a new target sticker fixture and introduced an analysis function that calculates the center position of both end faces based on the measured value of one end face, thereby enabling the application of photo measurement. Specifically, as shown in **Figure 3**, the developed fixtures are attached to four points on one end face of the sleeve, images are taken, and the virtual center point of the sleeve end face and the normal vector are calculated to identify the center point of the sleeve end face on the far side, which enables measurement of the center point of both end faces of the sleeve, which is hollow.

As a result, the conventional manual measurement of sleeves, which involved both-side measurement, took time, but the use of photo measurement has significantly shortened the time required.

This technology has already been used in many actual projects and is expected to be effective in the construction of advanced light water reactors.

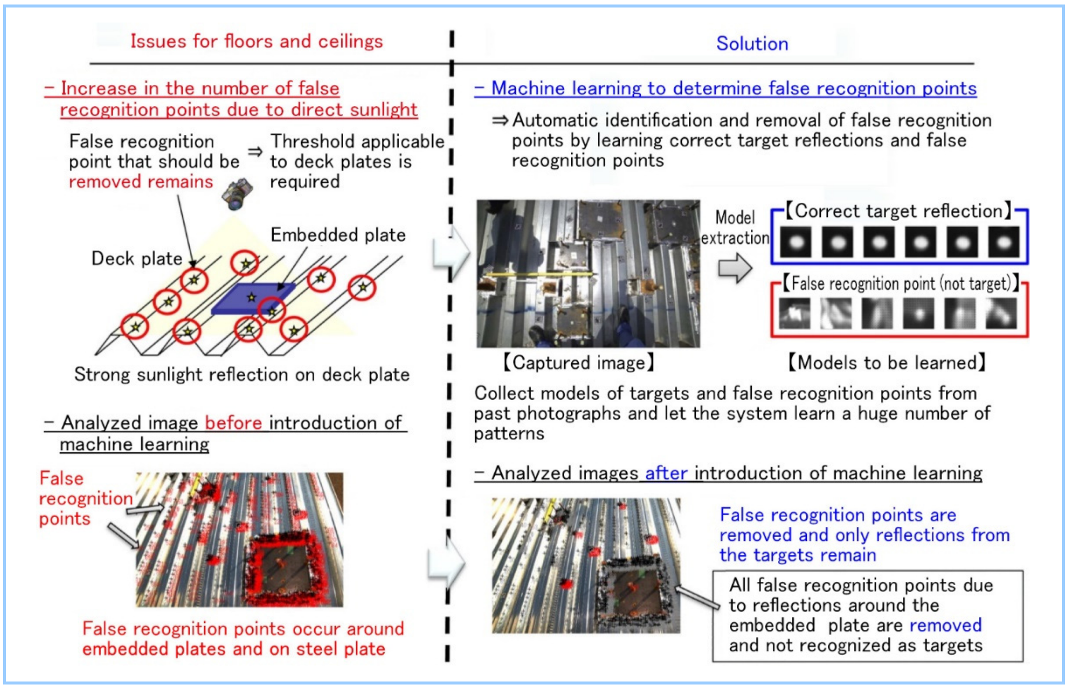

Figure 2 Solution for false recognition of target reflection light

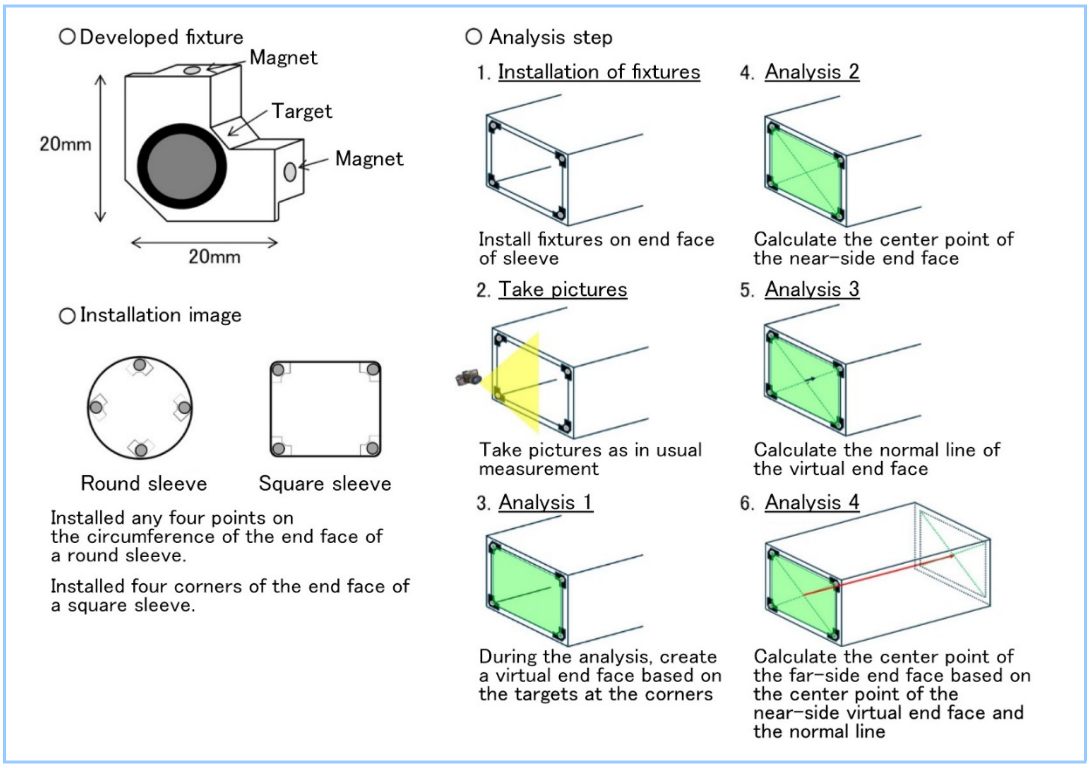

Figure 3 Embedded sleeve measurement procedure

3.2 Introduction of hand-over package (HOP) process [construction]

In the construction of nuclear reactor facilities, when starting the commissioning (testing) of each equipment, the commissioning team indicates to the installation team the equipment to be handed over by coloring or line-enclosing in the drawings. The installation team extracts the equipment to be handed over (devices (pumps, etc.), piping, valves, electrical instrumentation, etc.) from the drawings, and then searches and checks the large number of related construction records (paper-based) to ensure that the transition to the commissioning phase can be made. In this handover process, the extraction of the equipment to be handed over and the search and confirmation of the related work records were time-consuming issues. In addition, there were some cases where a part of equipment to be handed over was not extracted, resulting in rework.

Against this situation, we developed and introduced the hand-over package (hereinafter referred to as HOP) process, which is a system to search electronically stored work records for each equipment related to testing at the project planning stage, in order to establish a handover process that enables an appropriate and timely handover from the installation team to the commissioning team. The handover composition table of the HOP process provides a package of records necessary for handover, which significantly improves the accuracy of handover and the searchability of work records (**Figure 4**).

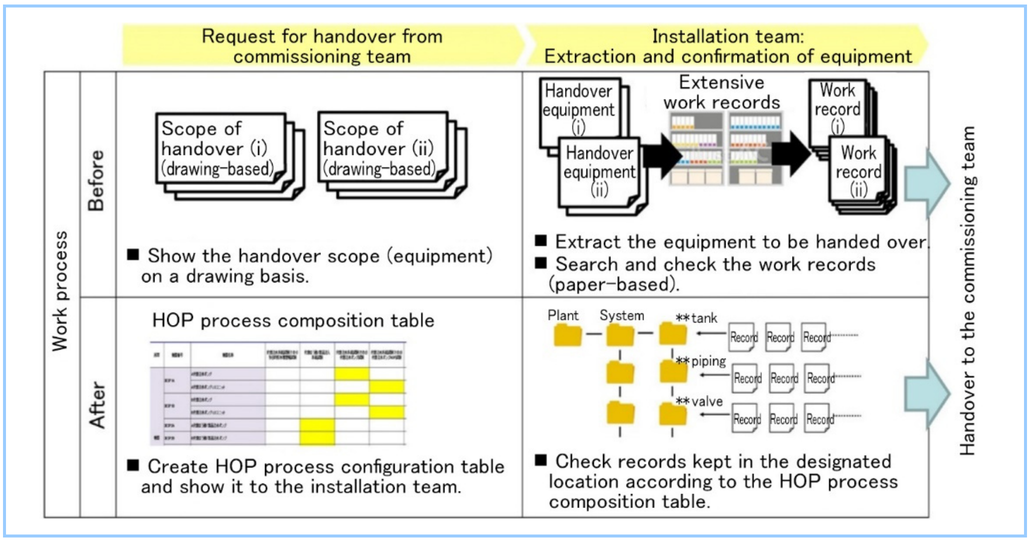

Figure 4 Outline of HOP process

The HOP process was verified by applying it to the construction of a special safety facility (a facility installed as a backup measure to mitigate the effects of damage to the reactor core and containment vessel in the event of an intentional aircraft collision), which is a medium-scale construction project, and comparing it with the conventional process. As a result, we confirmed that the HOP process is effective in improving the accuracy of handover (including prevention of missing or omitted equipment), greatly improving the searchability of work records, and increasing the efficiency of handover operations (**Figure 5**). In the future, with an eye on larger-scale projects such as the construction of advanced light water reactors, we will utilize ICT technology for automatic preparation and automatic storage of work records in order to improve the preliminary preparation of the HOP process composition table.

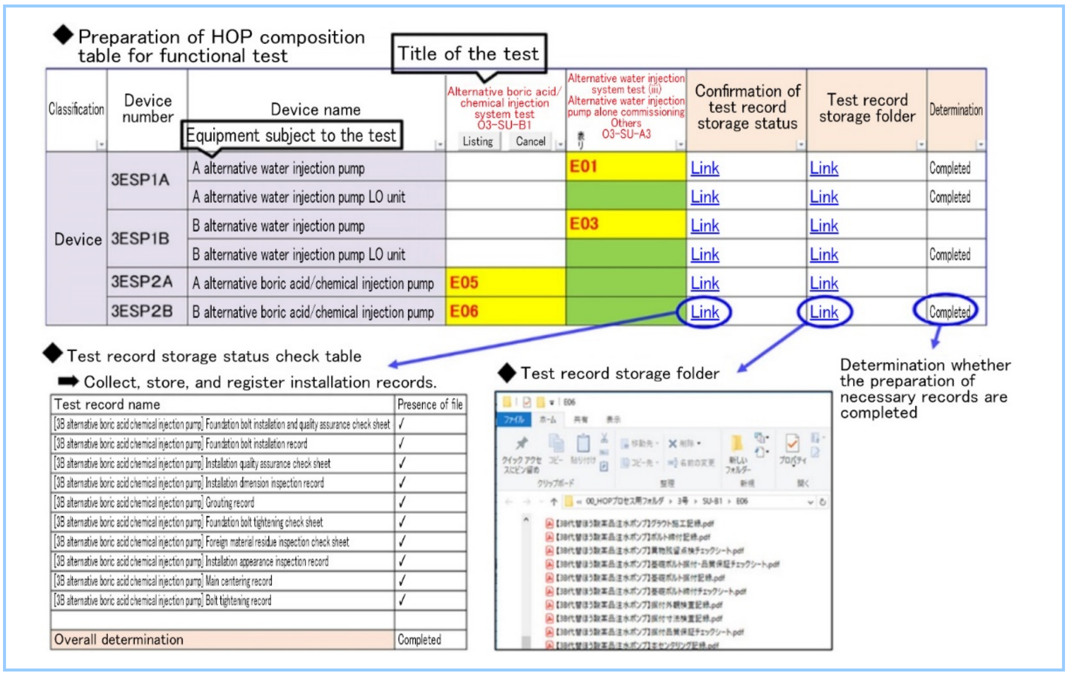

Figure 5 HOP composition table and process verification for construction project

3.3 Development of new tray support installation tool [construction]

Conventionally, tray supports have been installed by hoisting them using chain blocks, as shown in **Figure 6**. However, this method requires an assistant to be nearby to position the hoisted load, which leads to an increase in man-hours and the risk of accidents in the event of a falling load.

To solve the issues of the conventional method, we developed a new-type installation tool based on the concept of lifting the tray support from the bottom, instead of hoisting it, for the installation.

The developed tool is configured by attaching a fixture for fixing the tray support to a highly stable lifter and adding an outrigger for fall prevention, as shown in **Figure 7**, and is capable of stably installing tray supports of various shapes. The fixture is equipped with a horizontal position adjustment mechanism (X/Y axes) and a height and tilt adjustment mechanism (Z axis) that are independent of the lifter, enabling fine adjustment after lifting the tray support.

As a result of its trial use under various on-site conditions, a 26% reduction in installation man-hours and a reduction in the risk of accidents were confirmed. In the future, in order to address issues found in the trial use, such as the maneuverability of the large lifter, we will make improvements (reduction of the lifter size and weight of the fixture, etc.) with the aim of applying the system to future advanced light water reactor construction projects.

The main functions of this tool are fixing, lifting, and fine adjustment after lifting, and it can be used for a wide range of applications where objects having a similar shape are to be installed, including but not limited to construction projects at nuclear facilities.

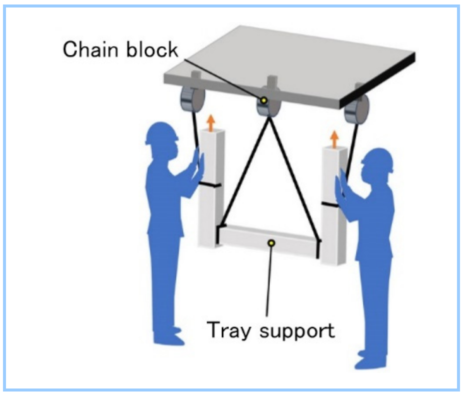

Figure 6 Conventional method

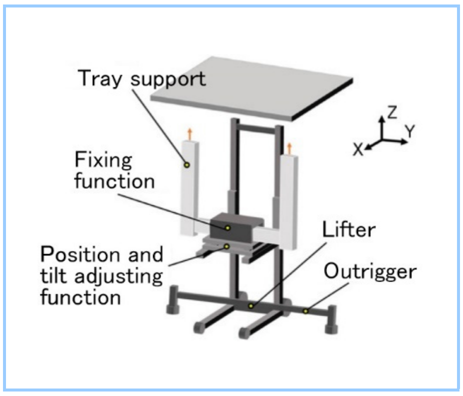

Figure 7 Method using new tool

3.4 Utilization of tablet computers and voice recognition software in radiation measurement [A/S]

To improve the efficiency of the radiation measurement, we have employed off-line tablet computers in which the necessary data have been stored in advance and voice recognition software as shown in **Figure 8**.

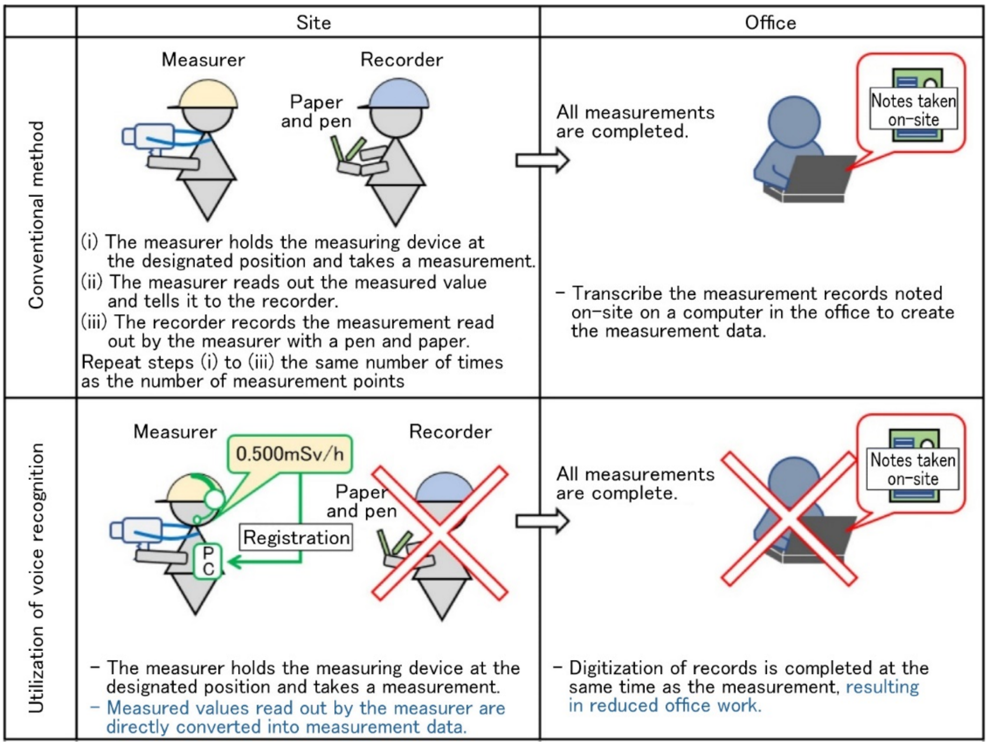

Figure 8 Improvement of radiation measurement in contrast to conventional method

The adoption of a hands-free system, in which measurements read out by the operator are converted into data by voice recognition software and recorded, has eliminated the need for a recorder, resulting in a reduction in the number of persons required for measurement from two to one.

In addition, by changing the records taken on-site from paper-based to electronic, the data transcription after returning to the office was no longer necessary, thus reducing the time required to create records. Furthermore, this adoption of electronic recording makes it possible to display error messages when measurement values exceed threshold values, thereby reducing measurement errors and rework and improving the quality of measurement.

Voice recognition is characterized by a technology that receives voice through a microphone and converts it into text using a voice recognition engine. The required time from when the user speaks to when the voice is converted to text is one to two seconds. The user can visually see the measured values on the screen of the tablet computer in real time, and at the same time, the user can also confirm the values aurally, as the voice recognition software reads them out loud. However, the current voice recognition software converts only registered words into text to improve the voice recognition rate, and unregistered words need to be input manually on the tablet computer. In addition, editing of drawings, which occurs when measurement points are added due to changes in the site layout, needs to be done by using the touch function of the tablet computer. Therefore, there is room for further labor-saving improvements by eliminating manual input. We will work to further improve efficiency by combining new tools and by other means.

3.5 Creation of ice plug method applicability determination tool [A/S]

We have developed a determination tool to determine if an ice plug can be applied to a given position by CFD (computational fluid dynamics) analysis to calculate the water flow inside the pipe, temperature changes, etc., using past ice plug application results (pipe diameter and thickness, pipe orientation (horizontal and vertical), and environment (water temperature and outside temperature)) as parameters in order to simplify the mockup verification test. Then, we conducted a number of mockup verification tests to validate the determination tool. As a result, it has become possible to derive the application conditions required for ice plug generation by using the determination tool (**Figure 9**).

Now the determination tool developed this time makes it possible to determine the applicability of ice plugs in a short time without conducting mockup verification on a case-by-case basis. Currently, we propose the application of the ice plug method to our clients based on feasibility and cost comparisons for each scope of repair service, apply it after receiving their approval, and accumulate the application results (**Figure 10**).

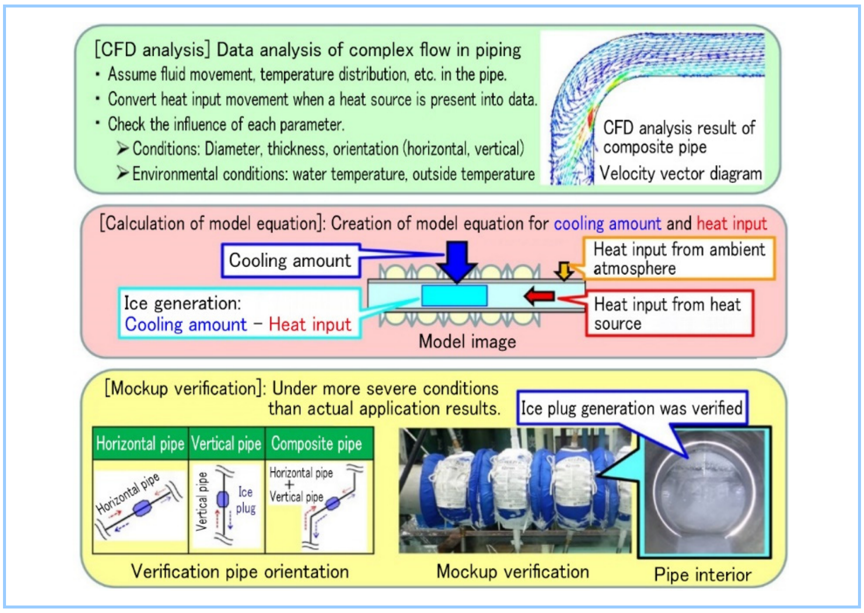

Figure 9　Research on ice plug generation applicability determination tool

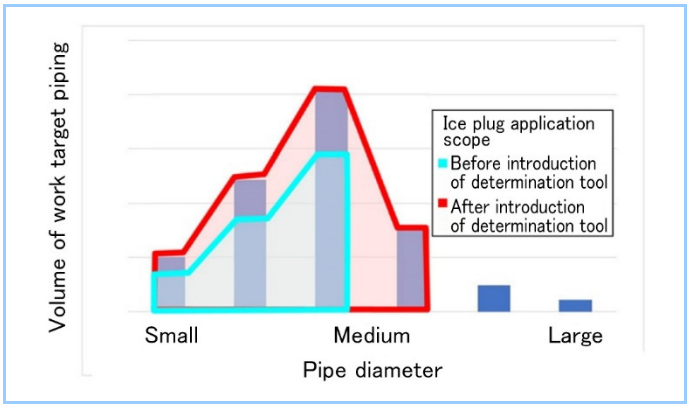

Figure 10　Ice plug application scope expansion effect

4. Conclusion

In response to the recent need for work style reform in Japan, we have been working on streamlining and improving work processes in order to promote safer and shorter-period nuclear reactor facility construction and A/S works. In the future construction projects of advanced light water reactors, it is expected to shorten the process, improve work efficiency, and save manpower by using the approaches introduced in this report. We will work on the upgrading of construction technology by utilizing the latest ICT information while ensuring the security uniquely required for nuclear reactor facilities.