Digital Technologies for Operation & Maintenance Efficiency of Nuclear Power Plants - Leading to Further Safety, Reliability, and Performance -

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The domestic nuclear power plants have achieved the world's highest standards of safety and successfully resumed operations through the implementation of severe accident prevention and mitigation facilities. As a result, the addition of safety measures has increased the number of managed facilities, leading to a greater workload on personnel responsible for their operation and maintenance. The reduction in the number of operating units has resulted in fewer opportunities for experience, and the succession of skills due to the retirement of experts is also a concern.

In nuclear power plants, while automation of operational procedures has been advanced, indirect operation and maintenance tasks involve many personnel. By leveraging rapidly evolving digital technologies, we expect significant improvements in integrated equipment management, workload reduction, and the transfer of technical knowledge.

Mitsubishi Heavy Industries, Ltd. proposes the concept of "Digital Twin from Three Perspectives"(1) to address these challenges and is developing solutions based on this concept. We are currently implementing and piloting some aspects while incorporating feedback from electric power companies, and we aim to further advance through the development of new solutions and the interconnectivity of multiple solutions.

1. Introduction

Mitsubishi Heavy Industries, Ltd. (hereinafter referred to as MHI) is working daily in collaboration with electric power companies to enhance the safety, reliability, and performance of nuclear power plant operations and maintenance.

The implementation of new regulatory standards following the Fukushima Daiichi Accident has led to the addition of a variety of equipment aimed at preventing and mitigating severe accidents. As a result, the number of managed facilities has increased, leading to a heavier human workload in operations and maintenance. Moreover, the reduction in the number of operational units, coupled with the retirement of experts, has resulted in insufficient technology transfer.

In response to these challenges, MHI is proposing the concept of "Digital Twin from three perspectives", utilizing the latest digital technologies and plant expertise to enhance operations and maintenance.

This report will provide an overview and features of this concept, as well as specific examples of the solutions we are currently implementing and piloting.

2. Challenges and solutions in operations and maintenance

As indicated in Chapter 1, the immediate challenges in operations and maintenance of nuclear power plants are threefold: (1) the increase in managed facilities, (2) the increase in human workload for operations and maintenance, and (3) technology transfer.

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To address the increase in facilities (1), it is necessary to implement integrated management of equipment, including structural information, and to collect and organize information according to specific purposes. To mitigate the increased workload in operations and maintenance (2), partial automation of manual tasks and the provision of information to assist decision-making are effective measures. To facilitate technology transfer (3), it is essential to conduct training and education, as well as to formalize the tacit knowledge held by experts (**Figure 1**).

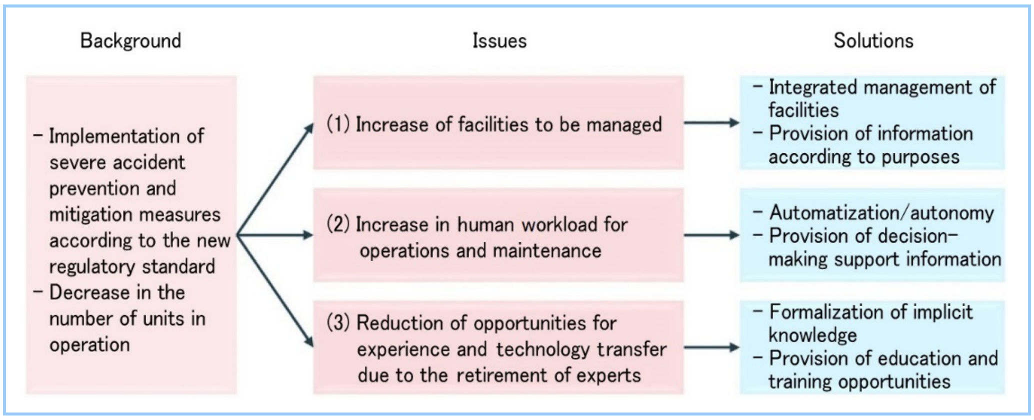

Figure 1 Challenges and solutions in operations and maintenance of nuclear power plants

In nuclear power plants, efforts have been made to expand the automation of operational controls; however, the operations and maintenance tasks related to the aforementioned challenges (1 to 3) predominantly involve many personnel. Therefore, leveraging digital technologies in this context can lead to significant improvements.

The utilization of digital technologies aims to:

Enhance the information that can be provided through the collection, organization, and enrichment of data. Deliver sufficient and timely information by processing and optimizing the data.

The goal is to realize solutions that contribute to further safety, reliability, and performance improvements in nuclear power plants.

3. Concept of "Digital Twin from Three Perspectives"

To realize the solutions described in Chapter 2, MHI proposes a digital twin concept consisting of three perspectives: "Functional Twin," "Physical Twin," and "Locational Twin," as shown in **Figure 2**. We are advancing the development of digital solutions based on this concept.

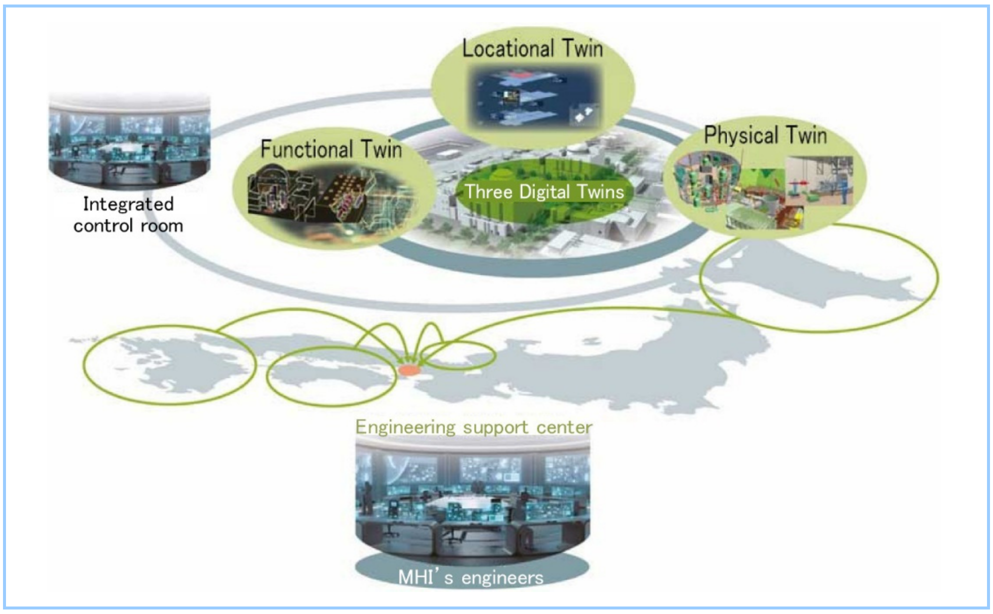

Figure 2 Concept of the "Digital Twin from Three Perspectives"

The digital twin from the three perspectives mentioned above serves as a means to realize the challenges and solutions outlined in Chapter 2, and the relationship is illustrated in **Figure 3**.

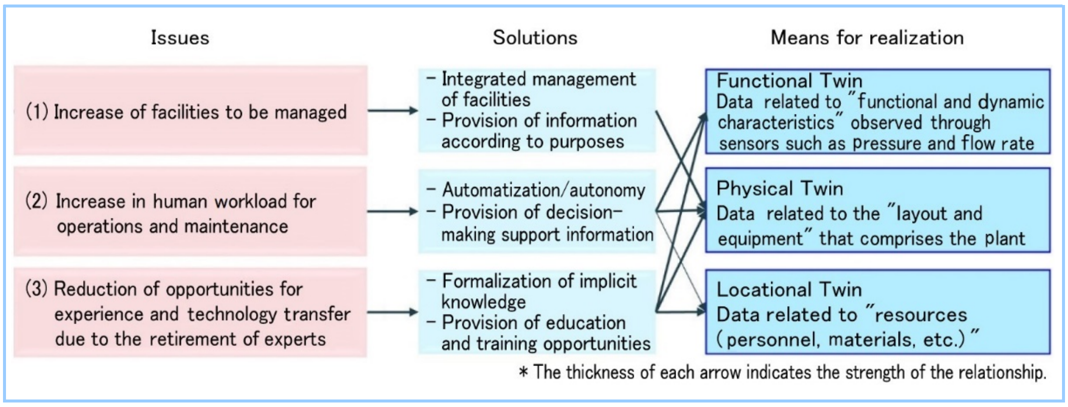

Figure 3　Relationship between challenges/solutions and the "Digital Twin from Three Perspectives"

This "Digital Twin from Three Perspectives" leverages our strength and experience as a nuclear power plant manufacturer and possesses the following features:

- Strengthening data by combining the latest digital technologies, such as AI, with plant expertise (e.g., estimating plant states that cannot be measured by sensors and predicting future values).
- Utilizing our human factors engineering techniques, task analysis methods, and so on to process the obtained data in accordance with specific tasks, while also ensuring that the information can be provided at the appropriate timing.

Furthermore, when applying new technologies to nuclear power plants, careful consideration is necessary due to the high safety standards required. While it is ideal to automate all operational and maintenance tasks, there are challenges, such as the fact that AI technologies often operate as black boxes, making it difficult to meet the necessary standards of accountability and traceability required for operations and maintenance in nuclear power plants.

Therefore, advanced digital technologies such as AI will be utilized with consideration for the aforementioned issues. For non-routine and complex tasks, these technologies will function as "human support" tools, where humans make the final decisions. For routine and simple tasks, the policy will be to advance automation as a "human substitute" function. Additionally, anticipating the future evolution of digital technologies, we will continue to work on the transition from "human support" functions to "human substitute" functions.

The overview of the digital twins is shown in **Figure 4**. In the next chapter, the examples of specific solutions that are under development for each of the "Digital Twin from Three Perspectives".

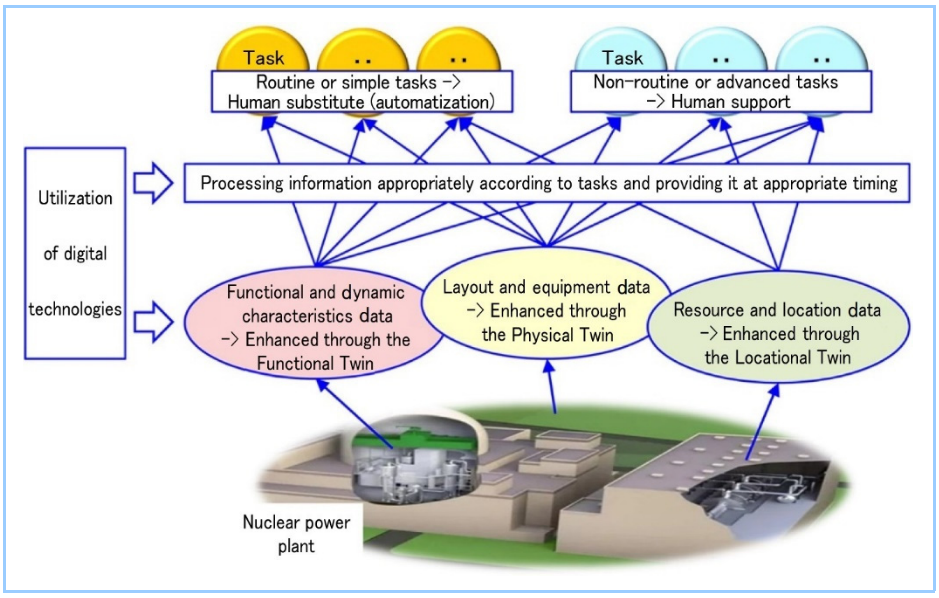

Figure 4　Overview of the "Digital Twin from Three Perspectives"

4. Examples of specific solutions

Below, we will summarize an overview of each of the "Digital Twin from Three Perspectives" along with specific examples of digital solutions.

(1) Functional Twin

✓ Overview

The Functional Twin is a feature that analyzes and processes data related to the functional and dynamic characteristics obtained from the central control panel and field parameters (e.g., pressure, flow rate, temperature, vibration, current) to make it easier for humans to recognize and make judgments. Additionally, it provides information that includes evaluations and optimizations of the current detailed state and future state predictions. This helps realize solutions to the challenges of (2) increased human workload and (3) technology transfer discussed in Chapter 2.

✓ Specific example (anomaly prediction monitoring solution)

This solution features systematic, continuous monitoring of the precise behavior of multiple parameters, enabling early determination of normal and abnormal conditions, as well as providing functions for estimating causes and making recommendations after anomalies have manifested. An overview of this solution is illustrated in **Figure 5**. By utilizing design rationale and plant expertise, we have developed a predictive monitoring model that incorporates data preprocessing aligned with operational realities and AI learning related to cause estimation and recommendations. The effectiveness of this model has been confirmed, and it is currently undergoing final validation for full-scale operation.

Moving forward, we plan to advance the implementation of the developed predictive functions and various evaluation functions, while also promoting collaboration with MHI engineers.

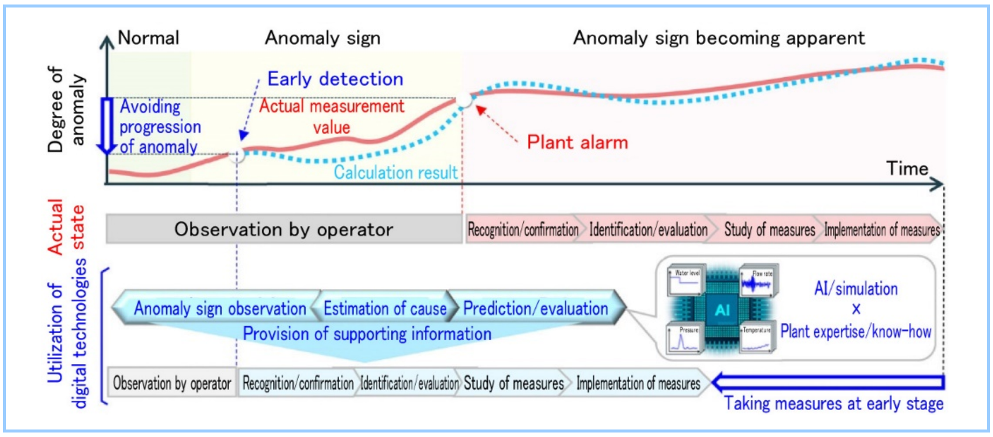

Figure 5 Overview of the benefits of anomaly prediction monitoring solution.

(2) Physical Twin

✓ Overview

The Physical Twin is a function that structurally organizes data related to the layout and equipment of nuclear power plants, making it easier for humans to recognize and make judgments by providing information in the form of overlay displays comparing the actual layout with the ideal or optimal configuration, as well as in a 3D format. Additionally, it provides equipment specifications and protection evaluation results linked to the relevant layout and equipment, along with functionalities for collaboration with our engineers and stakeholders. This helps realize solutions to the challenges of (1) increased managed facilities and (2) increased human workload discussed in Chapter 2.

Furthermore, by enabling interoperability with the Functional Twin, we aim to expand towards even more advanced solutions.

✓ Specific example (EPC* + maintenance data utilization solution)

We are developing a solution that integrates and manages design and construction information, such as 3D models, equipment maintenance history, and site images, in a visible manner while presenting it at appropriate timings according to specific goals. This allows for effective utilization throughout the plant's lifecycle. By utilizing this information in operations and maintenance, we expect to provide capabilities such as configuration management of equipment and remote technical support. An overview is illustrated in **Figure 6**.

In the future, we plan to collaborate with stakeholders to enhance this system.

*: Capital letters of Engineering, Procurement and Construction

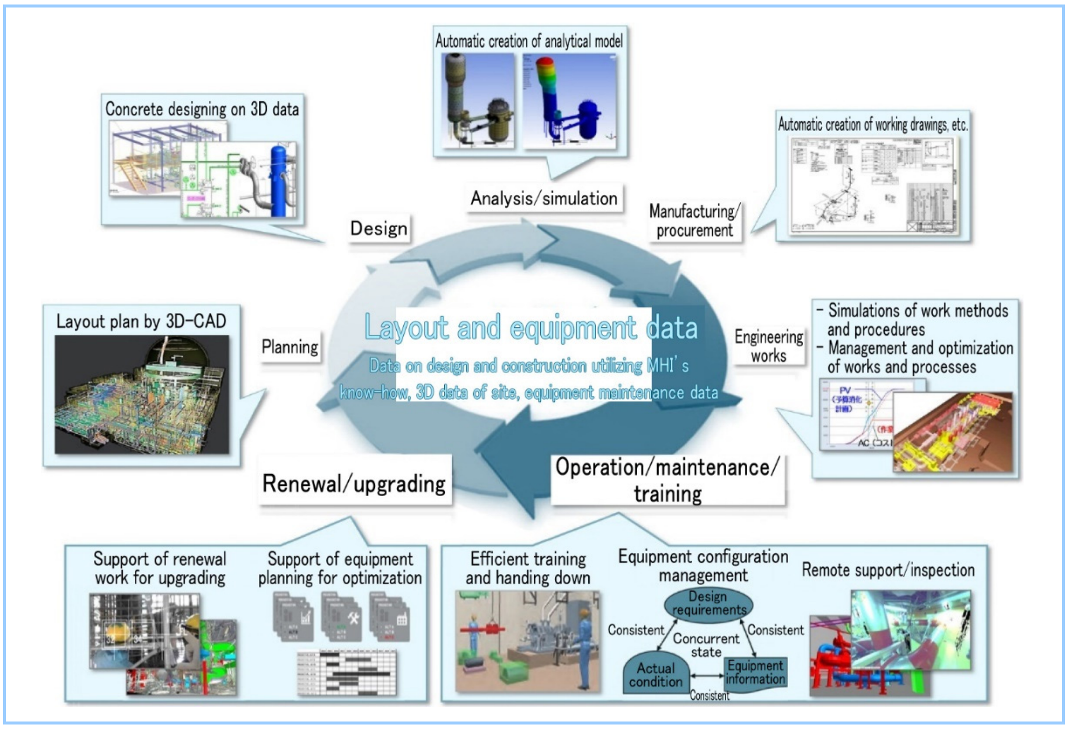

Figure 6 Overview of the EPC + maintenance data utilization solution.

(3) Locational Twin

✓ Overview

The Locational Twin is a function that automatically collects data related to resources (such as personnel and materials) and processes it into a visual format that is optimized for human recognition and judgment. It provides information that contributes to formulating response policies and enables rapid actions thereafter. This functionality addresses the challenges of (2) increased human workload and (3) technology transfer discussed in Chapter 2.

Additionally, by enabling interoperability with the Functional Twin and the Physical Twin, which handles layout and equipment data, the Locational Twin aims to create an organic connection between humans, data, and equipment, thereby facilitating the development of even more advanced solutions.

✓ Specific example (emergency decision-making support solution)

We have developed a solution that utilizes our expertise in human factors engineering to appropriately provide information that supports the situational awareness and decision-making of command and control personnel. One key feature of this solution is the Emergency Action Level (hereinafter referred to as EAL) Management Support System, which assists in the monitoring, judgment, and notification tasks related to the EAL, a criterion for determining the need for emergency response or personnel evacuation. We are currently customizing this system by incorporating feedback from electric power companies in preparation for implementation (**Figure 7**).

This system can be utilized not only in emergencies but also in disaster preparedness training, making it effective for education and technology transfer. In the future, we plan to implement voice recognition and synthesis technologies currently under development to enhance usability.

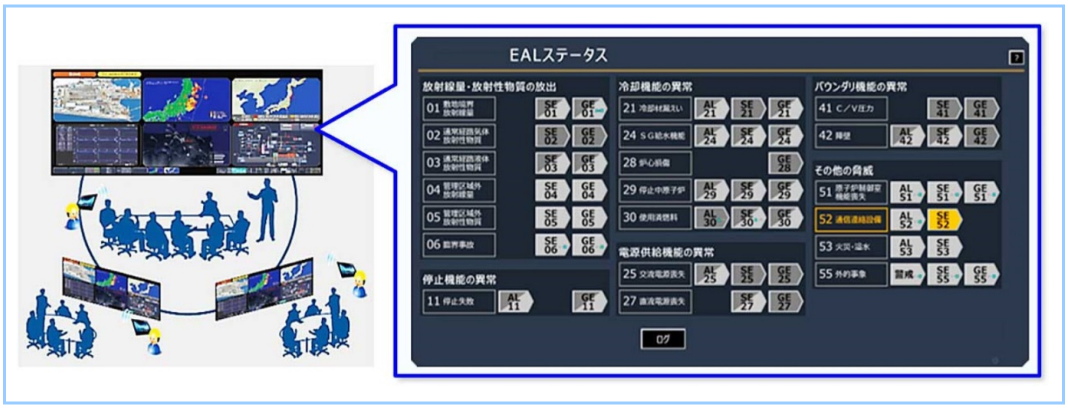

Figure 7 Image of the decision support system and screen example of the EAL management support system.

5. Conclusion

As a solution to the challenges in the operations and maintenance of nuclear power plants—such as the increase in managed facilities, the increase in human workload, and insufficient technology transfer—we have presented the "Digital Twin from Three Perspectives" concept, which corresponds to the three essential types of data: "functional and dynamic characteristics," "layout and equipment," and "resources (people and materials)."

We have secured understanding from electric power companies regarding the effectiveness of this concept and its various solutions. Customization is being carried out sequentially based on feedback from these companies, and we are advancing the introduction and trial operation in existing plants.

Moving forward, we will continue to push for development and reflection of feedback, aiming to provide more effective functionality and support the enhancement of operations and maintenance.

References

(1) Mitsubishi Heavy Industries, Ltd., Press Release, Innovative Light Water Reactor SRZ-1200 Brochure. https://www.mhi.com/products/energy/advanced_light_water_reactor.html

(2) The 19 Annual Meeting of the Japan Society of Maintenology, EAL management support system (in Japanese)