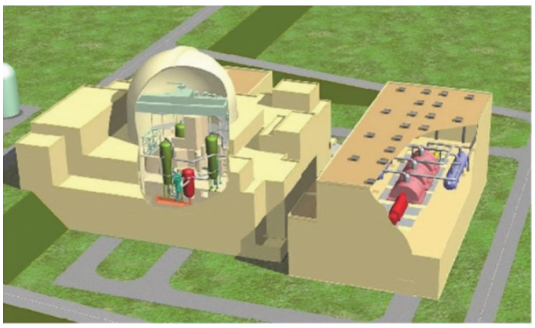
Development of Innovative Next-generation PWR



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Mitsubishi Heavy Industries (MHI) is developing a far-sighted new PWR (Pressurized Water Reactor). This next-generation MHI's PWR is an innovative mid-sized nuclear power plant with an electrical output of around 1.2 GW that features dramatically improved safety and reliability compared with existing technology based upon the experience obtained from the Fukushima Daiichi Accident. This new plant can appropriately respond to future Japan's energy situations such as the expanding use of renewable energy. This report summarizes the development concept and basic specifications.

1. Introduction

Nuclear power generation is a carbon-free power source that can supply power on a large-scale and in a stable manner. It is also positioned as an important energy source from the perspective of achieving decarbonization targets and Japan's energy security (self-sufficiency rate). The need for the construction of new nuclear power plants is expected to increase in the future toward achieving the nuclear power ratio of 20% to 22% in the 2030s, which is stated in the energy policy.

We have been responsible for the construction of as many as 24 PWR plants in Japan, from Kansai Electric Power Co. Inc.'s Mihama Nuclear Power Station Unit 1 (which started operation in 1970) to Hokkaido Electric Power Co. Inc.'s Tomari Nuclear Power Station Unit 3 (which started operation in 2009), and have been continuously involved in safety improvement measures and the installation of equipment to deal with specialized severe accidents since the Fukushima Daiichi Accident. We are one of the world's leading experts with experience and knowledge in the construction of PWR plants.

Utilizing this experience and knowledge, we are developing the next-generation MHI's PWR to meet the needs of future society.

2. Concept of next-generation MHIs PWR

The construction of a nuclear power plant is a very long-term project that takes more than 10 years from planning to the start of operations, and such plants must be designed appropriately to meet future social needs at the time when the power plant commences operations. Accordingly, we analyzed future social and energy situations and organized the requirements that next-generation MHIs PWRs should meet.

2.1 Safety and reliability

Conventionally, nuclear power plants have been required to have high levels of safety. However, after the Fukushima Daiichi Accident, it became the norm that unless a plant ensures a higher level of safety and reliability and provides a sense of security, it will not be accepted by society at large.

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We are developing the next-generation MHI's PWR with the following concepts so that it is safer, more reliable and able to provides sense of security.

(1) Ability to deal with external events (earthquake resistance, tsunami resistance)

The essential conditions that the next-generation MHI's PWR must meet include being able to withstand natural phenomena such as earthquakes and tsunamis with a sufficient margin of safety based on the lessons learned from the Fukushima Daiichi Accident. We set site conditions that reflect the knowledge we have gained so far and are developing a plant that features a sufficient ability to withstand such natural phenomena.

(2) Ability to deal with internal events (safety concept)

We are developing the next-generation MHI's PWR with the following safety improvement concepts.

- Strengthening the redundancy of safety equipment to deal with accidents that lead to core damage, while also ensuring reliability and enabling early accident resolution by appropriately combining the advantages of dynamic devices and static devices for each component.
- Reducing the probability of core damage to 1/10 level of the conventional plant in which safety measures were strengthened after the Fukushima Daiichi Accident by implementing the aforementioned safety improvement measures.
- Installing independent equipment so that even in the unlikely event of core damage, safe countermeasures can be implemented. Furthermore, even if the molten core is released into the containment vessel, as was the case in the Fukushima Daiichi Accident, the radiation dose can be kept at a level at which the evacuation of local residents would not be necessary.

(3) Security (ability to deal with intentional external events)

Taking into consideration of some of the recent social disturbances, countermeasures to deal with intentional obstructive behaviors, such as terrorism are also important for safety. The next-generation MHIs PWR is being developed so that it resists intentional aircraft crashes and is protected against cyberattacks such as electronic intrusions.

2.2 Flexible operability

After coming into effect of the Kyoto Protocol international agreements to reduce CO_2 emissions are announced to deal with global warming and it is expected that CO_2 emission regulations will become stricter in the future. Even at present, the proportion of carbon-free power sources in the domestic power source composition is increasing remarkably, mainly in the field of renewable energy. It is considered that this tendency will not change significantly even at the time when the next-generation MHI's PWR is constructed.

The operation of coal-fired power plants and other thermal power plants, which have played the role of large-capacity core power sources together with nuclear power so far, is gradually being restricted. Solar and wind power plants, which are the mainstays of renewable energy, are inferior in terms of stability due to their characteristics, and it is difficult for them to fully take on the role of replacing thermal power plants. Accordingly, nuclear power generation, which is a carbon-free and stable large-capacity power source, is expected to play an alternative role to thermal power plants as the domestic core power source in the future.

On the other hand, since coexistence with the expanding use of renewable energy is necessary, the next-generation MHI's PWR is being developed with the concept of enabling flexible operation by improving the ability to quickly change the electrical output according to demand from the power grid (load following capability), as well as resistance to the instability of the power grid.

2.3 Competitive power generating costs

When positioning nuclear power generation as a core power source in the future, high quality in power generation (stability and reliability) and economic merits (low power generation costs) are necessary.

At the nuclear power plants currently in operation in Japan, many measures have been implemented to significantly improve the safety in order to comply with the strengthened national safety standards after the Fukushima Daiichi Accident. The next-generation MHI's PWR can be

designed to include these safety measures from the early development stage, which is significantly more rational than retrofitting them later.

Including these steps, we have been making efforts to improve economic efficiency from the development stage, aiming to achieve lower power generation costs.

2.4 Operability and maintainability

MHI has a track record of constructing 24 PWR plants in Japan and being involved in the maintenance of all these plants. For the development of the next-generation MHI's PWR, we utilize our experience obtained in these efforts and have adopted a design that is easier to operate and more efficient to maintain. Ease of operation leads to operating reliability, and ease of maintenance leads to a reduction in operating costs. Accordingly, we incorporate these aspects from the design stage and proceed with development based on the concept of making it excellent in operation and maintainability.

3. Specifications of next-generation MHI's PWR plant

Based on the development concept described in the previous chapter, MHI is studying the plant specifications for the next-generation PWR. This chapter outlines the main specifications of the next-generation PWR.

3.1 Basic specifications of plant

(1) Electrical output of plant

The electrical output of Japan's nuclear power plants tends to increase gradually in terms of pursuing the economies of scale, and plans call for the latest improved PWR to be able to have an electrical output of around 1.6 GW. On the other hand, in terms of requiring a large enough alternative power supply during the shut downs and being easy to coexist with other power sources including the expanding use of renewable energy, it is thought that the need to have too large a capacity would be less. Accordingly, plans call for the electrical output of the next-generation MHIs PWR to be mid-sized at around 1.2 GW.

(2) Safety equipment

The safety equipment of the next-generation MHI's PWR is designed to have sufficient capacity to ensure safety, reflecting the lessons learned from the Fukushima Daiichi Accident.

As measures to withstand natural phenomena, seismic resistance twice as that of conventional PWR plants is targeted in order to counter earthquakes. And with the prerequisite condition of the site elevation above the standard tsunami height, measures to make the building watertight and optimize the equipment layout are adopted in order to counter tsunamis.

In order to deal with so-called design standard events, while in previous plants two series (trains) of impact mitigation equipment were installed for accident prevention so that functionality could be maintained in the event of a failure (single failure) occurring in one series, in the case of the next-generation MHI's PWR, the number of series (trains) has been increased to three to strengthen the redundancy.

In addition to equipment for dealing with design standard events, equipment for dealing with severe accidents that exceed the design standard are installed independently to enhance safety.

Plans also call for the installation of dedicated equipment to ensure that the molten core can be cooled and confined even in the event of meltdown, as was the case in the Fukushima Daiichi Accident.

Finally, a system that suppresses the release of radioactive materials around the power plant is introduced to keep down the radiation dose to a level at which the evacuation of local residents would not be necessary, even if the aforementioned equipment failed to function properly.

Table 1 and **Figure 1** show the safety equipment of the next-generation MHI's PWR.

Table 1 Characteristics of next-generation MHI's PWR safety facilities

Safety measure facilities	Handling method in the case of next-generation MHI's PWR	
Design standard accidents	Installation of 3 series (trains) of equipment	Improvement of safety through strengthening redundancy
Severe accidents	Installed independently of equipment for dealing with design standard accidents Permanent equipment	Even in the event of a severe accident, safety has been improved by installing permanent equipment independently of the equipment for dealing with design standard accidents.
Molten core	Molten core coolant system	Securely confining and cooling molten core even in case it occurs.
Prevention of radioactive substances release	Radioactive material release suppression system	Controlling the release of radioactive materials to the surrounding environment and maintaining the environmental dose at a level at which evacuation is not necessary.

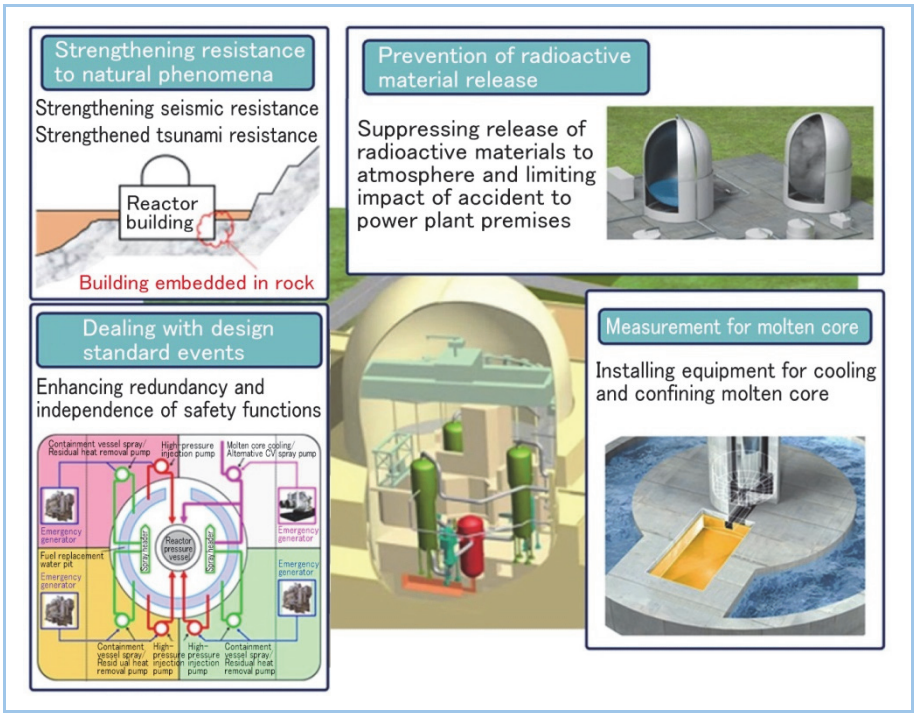

Figure 1 Examples of safety facilities for next-generation MHI's PWR
Ensuring sufficient safety in light of the Fukushima Daiichi Accident

(3) Turbine equipment

The latest high-efficiency steam turbine was adopted for the turbine equipment. The final blade row of the low-pressure turbine is 74 inches, which is one of the largest in the world, aiming for higher efficiency and compactness of the entire facility (**Figure 2**).

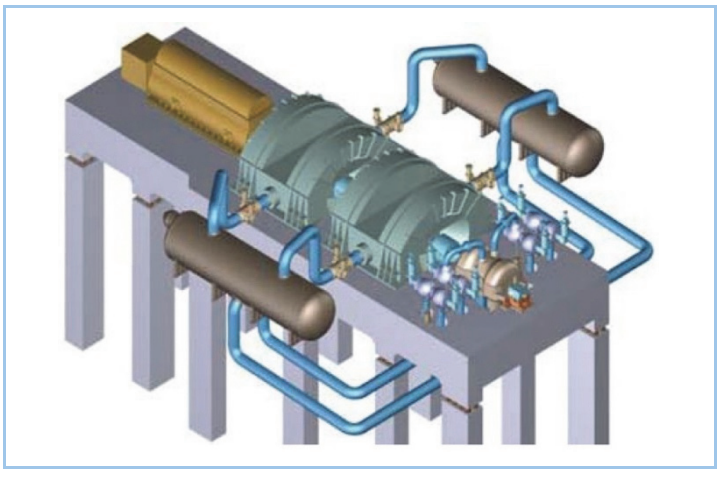

Figure 2 Turbine equipment of next-generation MHI's PWR
Adopting 74-inch large final blades, making all the equipment compact

(4) Security measures

As a measure to strengthen the physical security of next-generation MHI's PWR based on the concept of the further strengthening security, resistance to intentional aircraft crashes in particular has been increased. From the building design stage, consideration has been given for maintaining sufficient safety functionality of the nuclear power plant to deal with an aircraft crashes and facilities to deal with specialized severe accidents has been appropriately installed. As a result, security measures have been dramatically improved compared with existing technology (**Figure 3**).

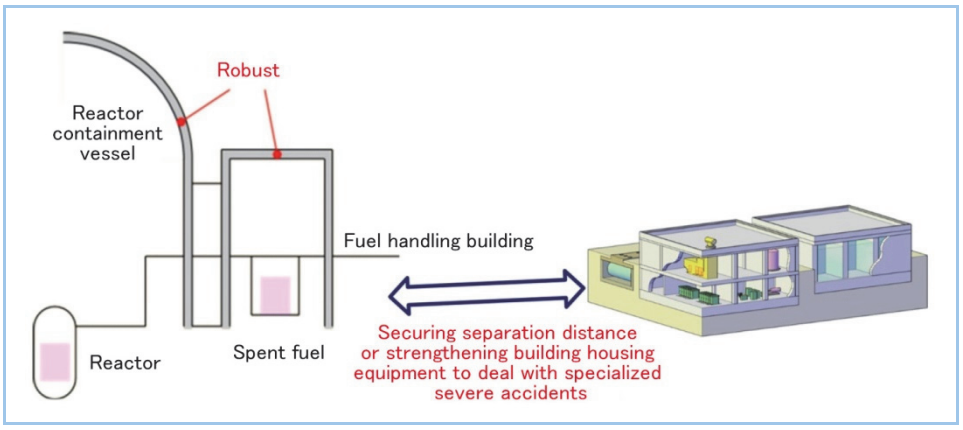

Figure 3 Security measures (to deal with aircraft crashes)
Strengthening of building protection and appropriate installation of specialized severe accident facilities, etc.

In addition, in order to counter cyber terrorism, which is expected to increase in the future, appropriate design has been carried out so that it does not affect the safety of the plant, such as strengthening measures against electronic intrusion both internally and externally. In particular, since the digital technology field is expected to develop significantly in the future, advance consideration has been given so that appropriate measures can be implemented at the start of plant operation, and flexible design measures can also be further implemented to deal with future technological innovations (**Figure 4**).

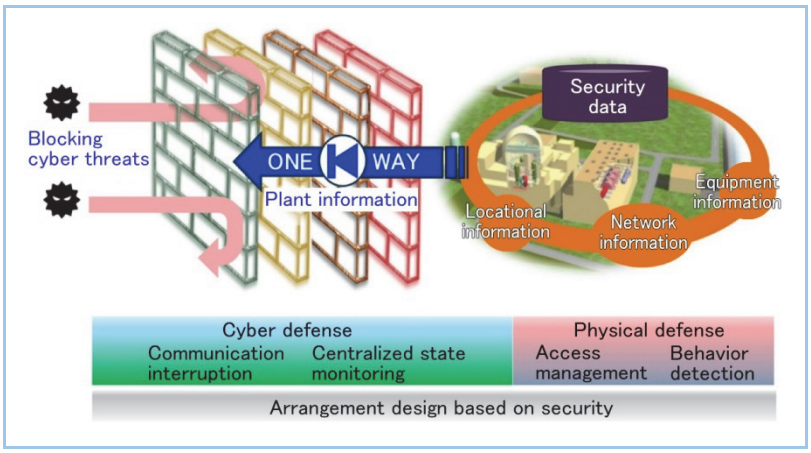

Figure 4 Security measures (cyber security)
Preventing intrusion from the outside and dealing with internal threats

(5) Plant operating performance

Based on the concept of enabling flexible plant operation that meets future social needs, the operating performance of the next-generation MHI's PWR has been enhanced. In order to improve the daily load tracking capability to deal with daily power load fluctuations, to make it possible to deal with load change widths and load change rates that are larger than before and to make it possible to follow short-time load fluctuations, the frequency control capability has been increased. The independent internal operation performance has also been improved in order to prevent the reactor from shutting down when the power grid system is disturbed due to the instability of renewable energy, etc. (**Figure 5**)

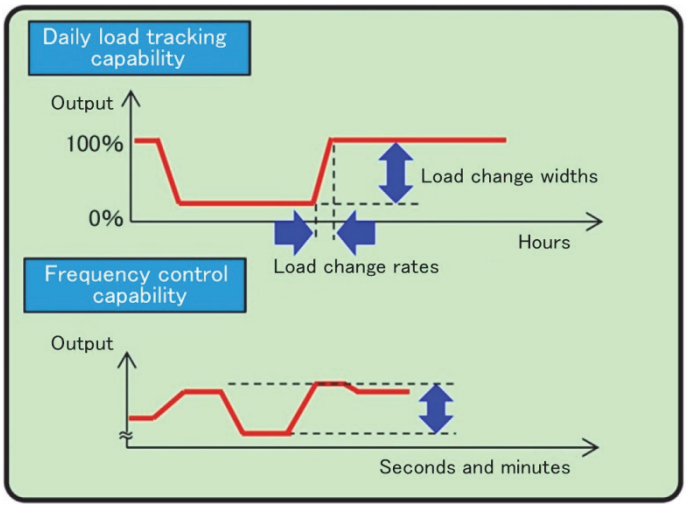

Figure 5 Plant operating performance
Daily load tracking capability and frequency control capability

(6) Maintainability

Improving maintainability is an important factor not only from the perspective of power generation costs, but also from that of safety. For this reason, the improvement of the maintainability of the next-generation MHI's PWR is considered from the design stage through simulations using 3D-CAD. Furthermore, using the latest technology operators' workloads are mitigated and operability is improved.

3.2 Construction period

The Japan's PWR plants that MHI worked on in the past have reached the criticality of the nuclear reactor about four years after the start of construction (passing the bedrock inspection). Shortening the construction period of power plants is an important issue for electric power companies.

On the other hand, it is expected that the construction period of nuclear power plants to be constructed in the future will be longer than before since the additional measures have to be implemented to improve safety. In the case of the next-generation MHI's PWR, by making efforts to shorten the construction period from the development stage, we are working on limiting the extension of the construction period to about one year excluding uncertainties due to locational conditions, etc.

3.3 Construction costs

Controlling construction costs contributes significantly to reducing power generation costs, which is one of the concepts of the plant. Construction costs depend on the equipment specifications of the plant. In the case of the next-generation MHI's PWR, we are proceeding with development in consideration of making the equipment specifications more rational from the design stage in order to reduce construction costs, aiming to realize lower power generation costs.

4. Improvement of design process

As mentioned above, while we are considering the specifications of the next-generation MHI's PWR we are promoting the introduction of a design process that is more rational and advanced in line with the times. This chapter gives examples thereof.

4.1 Appropriate Configuration Management (CM)

Since the enforcement of the new inspection system (revision of the Reactor Regulation Law) in April 2020, all inspections that were previously carried out by the Nuclear Regulation Authority (NRA) are now carried out by the electric power company, and the results and validity are evaluated by the NRA through nuclear regulatory inspections. In addition, all activities of the electric power company from the design and construction stages to maintenance work are to be monitored and evaluated by NRA, and its inspectors now have access to the project freely through visits, documents, interviews, etc. This new inspection system is also applied to the next-generation MHI's PWR, so it is necessary to realize more appropriate CM than ever before in order to respond accurately and promptly to arbitrary access by NRA inspectors. Based on this, as an effort to optimize CM, we

clarify the design requirements and rectify the upstream and downstream interface (I/F) to review the document system, and have introduced a mechanism to maintain and manage the upstream and downstream relationships and consistency between documents (**Figure 6**). Furthermore, in addition to efforts to optimize CM, we are also considering reviewing the document number and device number systems by applying WBS (Work Breakdown Structure). The application of such unified code system contributes to the improvement of information aggregation and searchability, in addition to the advancement of the cost and process progress management of the entire project.

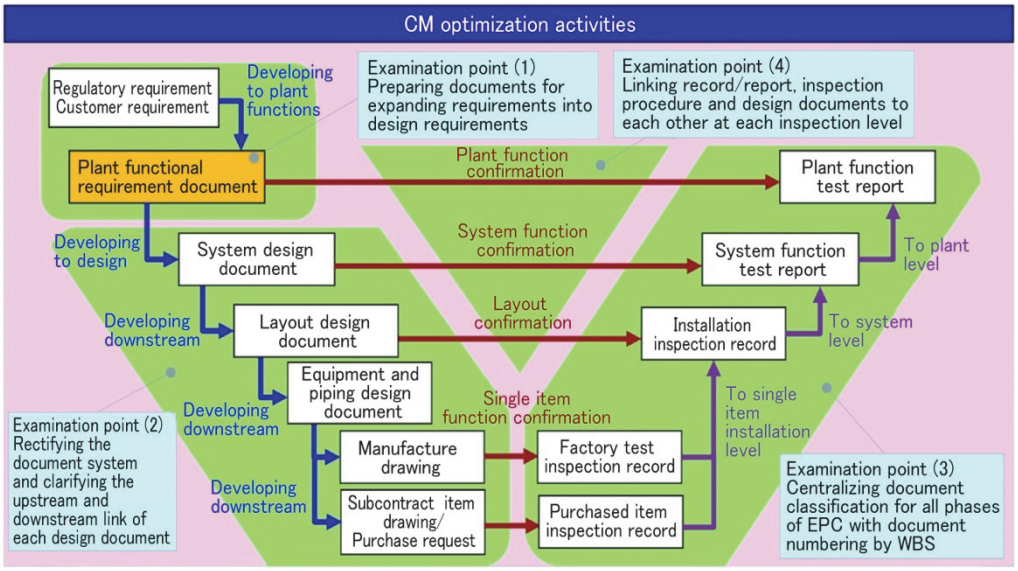

Figure 6 Mechanism of CM optimization
We are proceeding with activities to optimize CM in the development of the next-generation MHI's PWR

4.2 Advanced utilization of 3D-CAD data

In the nuclear field, we have been applying digital technology centered on 3D-CAD since the 1990s. In the case of Tomari Nuclear Power Station Unit 3, which started operation in 2009, 3D-CAD was used for the layout design, customer approval, digital I/F of manufacturing information (welding, inspection, etc.) and construction plan display at the construction site. For the next-generation MHI's PWR, we plan to establish the design early with 3D-CAD and to utilize the 3D-CAD database throughout the entire process from construction planning, production, procurement, on-site construction and I/F with general contractors, to the project management of overall cost and schedule in order to further improve the quality and work efficiency and prevent schedule delays. We are currently considering building a database that links and integrates plant data such as system diagram (2D) data and various equipment specification data in addition to 3D-CAD data, aiming to establish a mechanism that enables seamless information transmission and sharing from upstream to downstream (**Figure 7**).

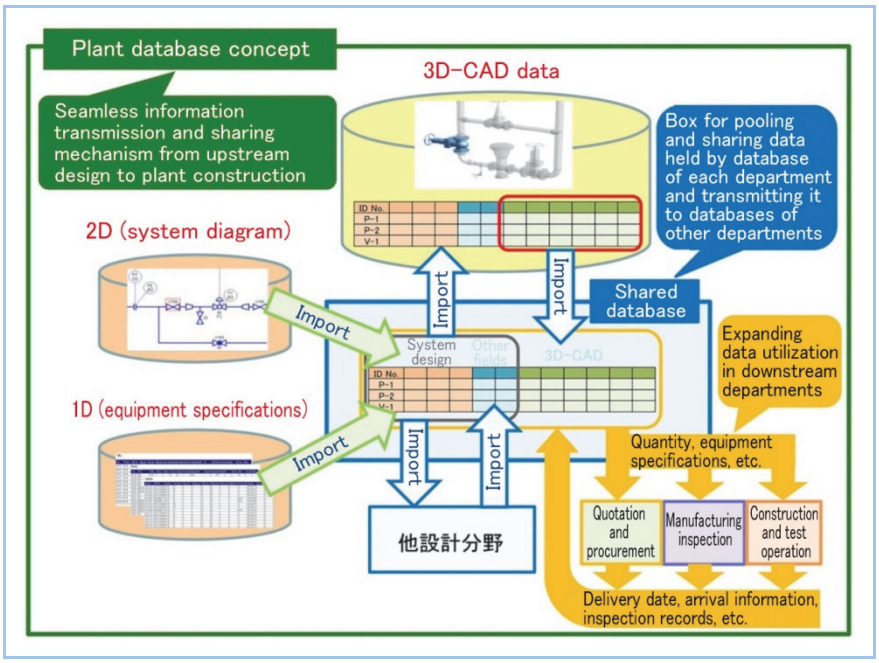

Figure 7 Utilization of 3D-CAD data
Building a seamless information transmission and sharing mechanism from upstream design to plant construction.

5. Conclusion

MHI developed and established the concept and basic specifications of next-generation PWR that improves safety and reliability and can coexist with renewable energy.

We aim to create a highly rational plant that appropriately meets the future social needs and this is being taking into account not only in the plant specifications, but also in the design process.

In the future, we plan to consider more detailed plant specifications and continue its development to make this nuclear power plant acceptable not only to our customers, but also to society at large.