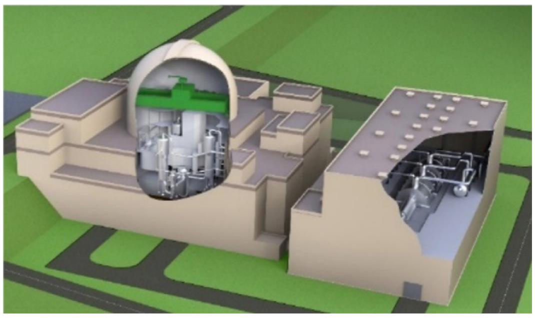
Development Status of Advanced Light Water Reactor "SRZ®-1200"



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Mitsubishi Heavy Industries, Ltd. has been developing "SRZ-1200" as a state-of-the-art nuclear power plant to be constructed after the Fukushima Daiichi Accident. The SRZ-1200 is an advanced light water reactor designed to achieve a level of safety as high as rationally achievable by incorporating safety measures derived from lessons learned from the Fukushima Daiichi Accident and various advanced technologies, including molten core cooling systems. We have nearly completed the basic design of the SRZ-1200 and is currently preparing for verification of the technologies and the detailed design activities. The development of individual technologies and design progress are detailed in other reports.

1. Introduction

Nuclear power is a carbon-free, stable and large-capacity energy source essential for the realization of a decarbonized society. The construction of a nuclear power plant involves a long-term and large-scale project which can extend beyond 10 years from planning to completion due to its complexity and enormousness. With the current Japanese government targeting the generation of 20% to 22% of electricity from nuclear power due to energy mix point of view, it is necessary to construct new nuclear power plants as early as possible.

As Mitsubishi Heavy Industries, Ltd. (hereinafter referred to as MHI) was engaged in the construction of 24 domestic Pressurized Water Reactor (PWR) plants and has also been continuously involved in enhancing the safety of existing plants in response to the Fukushima Daiichi Accident, it has gained one of the most extensive expertise and experience of PWR construction globally. Leveraging this advantage, MHI has been working on the basic design of the SRZ-1200 in cooperation with four domestic power companies (Kansai Electric Power Co. Inc., Hokkaido Electric Power Co., Inc., Shikoku Electric Power Co., Inc. and Kyushu Electric Power Co., Inc.) (hereinafter referred as to "Four power companies"). Furthermore, MHI has been implementing a variety of demonstration tests to attain a high level of perfection of each design and advancing activities required to optimize manufacturing and procurement processes to facilitate plant construction.

2. Development concept of SRZ-1200

MHI has been developing the SRZ-1200 as an innovative nuclear power plant in Japan to be constructed after the Fukushima Daiichi Accident, with the safety being the highest priority, aiming for a design adaptable to the state of society and energy situation anticipated in the future. In light of these considerations, MHI has defined the development concepts of the SRZ-1200 as follows: (1) Supreme Safety, (2) Eco-friendly (Zero Carbon & Sustainability) and (3) Safe Supply of Large-scale Electricity (Resilient Light Water Reactor). The SRZ-1200 was named after the combination of the capital letters representing these concepts and the electrical output of 1,200 MW[(1)].

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3. Plant specifications and features of SRZ-1200

In line with the aforementioned concepts, MHI has been developing the SRZ-1200 by incorporating the technologies applied in existing PWRs, which possess extensive operational experience. Additionally, the design of the SRZ-1200 takes into account lessons learned from the Fukushima Daiichi Accident alongside various advanced technologies. Through the rational integration of these measures and technologies, the SRZ-1200 achieves an elevated level of safety.

3.1 Basic plant specifications

Table 1 shows the basic plant specifications of the SRZ-1200, contrasting with those of an existing PWR. As the electrical output of Japan's nuclear power plants has steadily increased to seize economies of scale, a large-scale PWR prior to the SRZ-1200 was designed for an electrical output of 1.6 GW. However, such large-scale reactors faced the disadvantage of requiring a large alternative power supply during its outage. Consequently, in consideration of the improvement of economic efficiency based on economies of scale and the operability of the power grid, the SRZ-1200 has been designed with a capacity of 1.2 GW, comparable to mid-sized plants. To achieve this output, MHI has applied the technologies of the main components, such as steam generators and primary coolant pumps developed for large reactors, to increase the flow rate per reactor coolant loop.

Table 1 Basic specifications of SRZ-1200 plant

Item	SRZ-1200	Existing PWR
Electrical output (gross)	~ 1,210 MWe	1,180 MWe
Core thermal output	3,411 MWt	3,411 MWt
Number of primary coolant loops	3 loops	4 loops
Number of fuel assemblies	193 FAs	193 FAs
Primary coolant flow rate	25,100 m^3/h/loop	20,100 m^3/h/loop

From the viewpoint of coexistence with renewable energy, the SRZ-1200 has enhanced its daily electric load-following capabilities to match those of thermal power plants, ensuring it can adeptly manage daily electric load fluctuations. In addition, the enhanced frequency control capability stabilizes the frequency of the power grid accommodating short-time load fluctuations (**Figure 1**). Furthermore, the house load operation capability has been enhanced to prevent reactor trips in the event of power grid disturbance caused by the instability of renewable energy, enabling the plant to continue to operate without an external power supply.

The capability of load-following operation of the SRZ-1200 is summarized in **Table 2**.

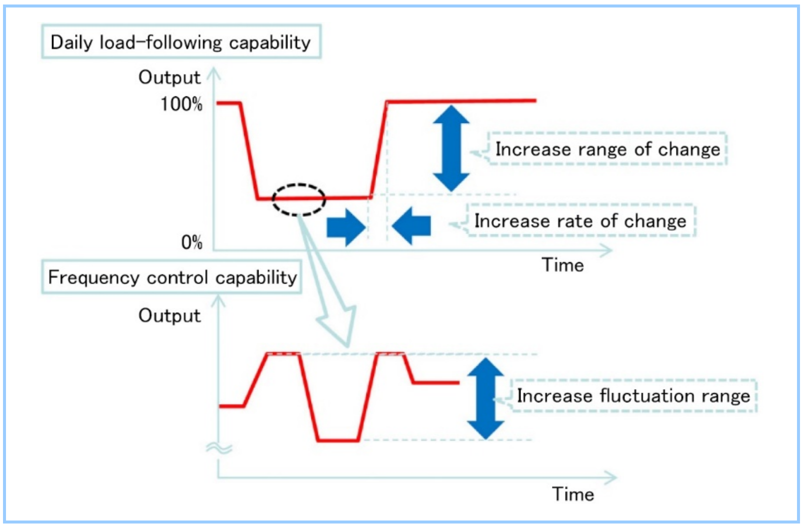

Figure 1 Plant operating performance (daily load-following capability and frequency control capability)

Table 2 Load-following performance of SRZ-1200

Item	Specification
Load change rate	3%/min
Load change range	30 to 100%
Frequency control operating range	±5%
House load operation	Operating with a rapidly lowered reactor output

3.2 Design concept for safety equipment

The safety equipment of the SRZ-1200 is designed to accomplish the world's highest level of safety by integrating the safety measures based on lessons learned from the Fukushima Daiichi Accident and adopting advanced technologies. Target values for core damage frequency and containment failure frequency are set to one-tenth of the government's guidance, as illustrated in **Table 3**, reflecting an aim for the world's highest safety standards. This performance target is achieved by incorporating the following design concepts.

Table 3 Performance targets of SRZ-1200

Item	SRZ-1200	Government's guideline
Core damage frequency (target)	Less than 1×10^{-5}/reactor year	Approx. 1×10^{-4}/reactor year
Containment vessel breakage frequency (target)	Less than 1×10^{-6}/reactor year	Approx. 1×10^{-5}/reactor year

(i) Enhancement of resistance to natural disasters (seismic and tsunami resistance, etc.)
- The outline of the building housing the safety equipment is designed to be as square as possible, with the center of gravity positioned lowered and the foundation embedded into solid bedrock. Consequently, the stability of the building in case of earthquake is improved.
- The ground level of the site is elevated above the design-standard tsunami height, and the building is designed to be watertight, significantly improving the resistance against tsunami.

(ii) Enhancement of mitigation functions for core cooling and confinement of radioactive materials in case of severe accidents
- Conventional PWRs are equipped with two series (trains) of safety systems; SRZ-1200 possesses three trains of safety systems to reinforce redundancy. The physical separation of these trains (divisional separation) contributes to reducing the possibility of simultaneous failures of the multiple trains of safety systems, improving overall safety.
- The SRZ-1200 incorporates a newly-defined defense-in-depth concept derived from the experience of the Fukushima Daiichi Accident. The safety measures of SRZ-1200 are assigned with functions associating with each level of accident progression, with the augmented independence of the systems across all the levels of defense-in-depth, contributing to the improvement of safety.
- The SRZ-1200 aims to achieve the best mix of novel passive equipment such as the advanced accumulator and active equipment already installed in conventional plants, allowing for prompt response to early-stage accidents and swift recovery from abnormal conditions.
- The containment vessel features double-shell structure, comprising a containment vessel made of high-tensile steel plate and a robust external shielding wall to ensure both robustness against airplane crash and seismic resistance, enhancing the capability of confining radioactive materials.
- Even if the molten core is released into the containment vessel, the molten core cooling system and the heat removal system of the containment vessel prevent damage to the containment vessel.
- Furthermore, should the heat removal system of the containment vessel fail to function, a dedicated venting system allows for depressurization to ensure the integrity of the containment vessel and the reduction of exposure to radioactive materials.

4. Development status of SRZ-1200 and demonstration tests for key components

4.1 Development status of SRZ-1200

Since 2019, MHI has been proceeding with the standard design of the SRZ-1200 without specific site information in cooperation with the four power companies, targeting commercial operations by the mid-2030's. During the standard design phase, the plant equipment specifications required to obtain permission of the plant installation are being explored. Now that most of the design has been completed, MHI is poised to transition to detailed design upon the determination of the site (**Figure 2**).

The method of systems engineering is applied to the standard design to clarify requirements for each system. Additionally, a document structure as described in **Figure 3** was established at the early stage of the design activity, streamlining interfaces between the three levels of documentation. Specifically, requirements essential to satisfy the plant performance are defined at each level; plant, system and equipment, serving as inputs to the design specifications. As of now, the primary design documents have been already issued.

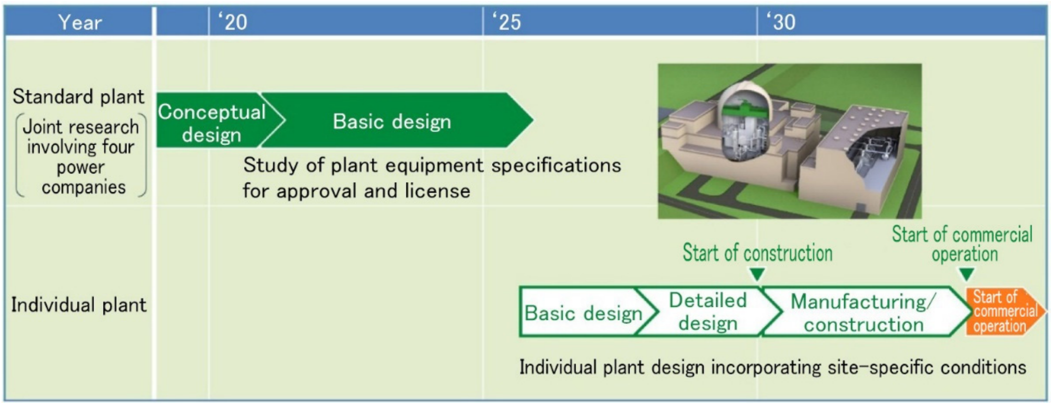

Figure 2 SRZ-1200 development process

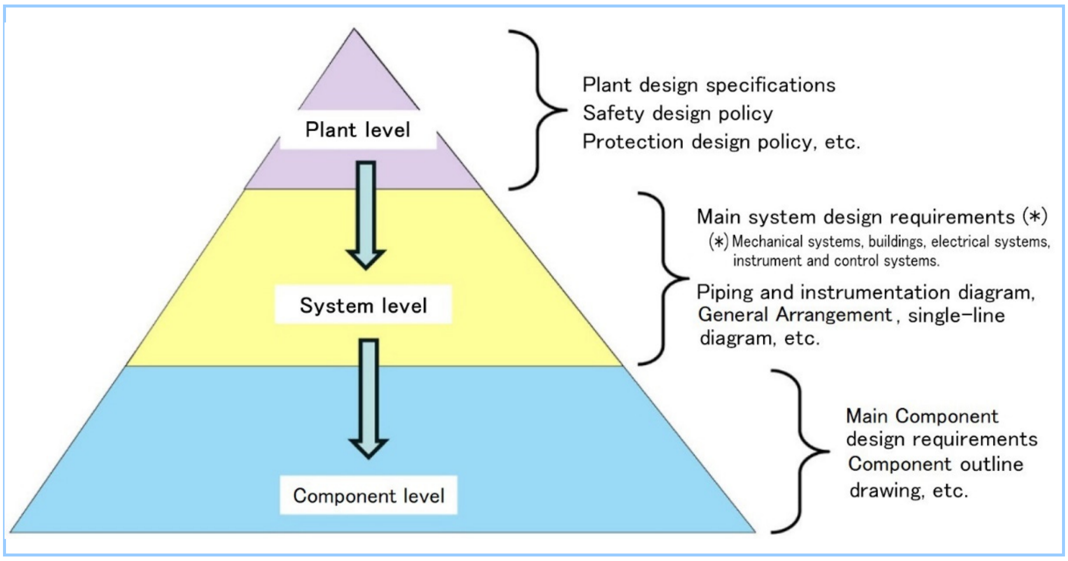

Figure 3 Document control system for SRZ-1200 standard design

4.2 Demonstration tests for key components

The SRZ-1200 integrates improved versions of conventional components and advanced technologies not present in existing plants to enhance safety, economic viability and operability. The situations of demonstration tests for several advanced technologies and components intended for the SRZ-1200 are described below.

(1) Reactor vessel

In the SRZ-1200 design, the instrumentation nozzle mounted at the bottom of the reactor vessel has been removed to reduce the risk of leakage from the bottom. Additionally, the volume of the lower plenum at the bottom of the reactor vessel is decreased to increase safety margins in the event of an accident. With an increased primary coolant flow rate, in-vessel flow dynamics may differ from conventional plants, necessitating ongoing demonstration tests to ensure safety and operational stability.

(2) Head-inserted in-core nuclear instrumentation

Unlike conventional reactors, where the instrumentation equipment for monitoring the condition of the core is inserted from the bottom of the reactor vessel, the SRZ-1200 incorporates this equipment from the head of the reactor vessel. Therefore, in addition to the implementation of in-vessel flow tests described in the above (1), demonstration tests for maintenance procedures under actual plant operations are being conducted.

(3) Molten core cooling equipment

In the SRZ-1200 design, dedicated molten core cooling equipment, which is an advanced technology, is installed to secure the cooling of the molten core. With feasibility study and basic design of this equipment completed, demonstration tests to collect performance data and evidence for permission of plant installation are in progress.

(4) Reactor coolant pump

The SRZ-1200 adopts the MA25S-type reactor coolant pump, which has a higher primary coolant flow rate than conventional plants. The demonstration tests for this component were successfully completed at MHI's reactor coolant pump testing facility, confirming its functionality under high pressure and temperature equivalent to the actual plant conditions.

(5) Advanced accumulator

The accumulator of the SRZ-1200 serves as not only the conventional accumulator but also low-pressure injection system. It features a mechanism that allows for automatic transitioning from high to low flow rate as the water level decreases, thanks to the function of the vortex damper (passive component) installed inside. The demonstration tests for the component at scales equivalent to actual plant operations have been already completed.

MHI has completed the technical development and feasibility study for components (1) to (3) as described above. Future plans include implementation of demonstration tests to collect data for the design, manufacturing and permission required for plant construction, aiming to enhance the degree of completeness of the plant. **Figure 4** shows the plan for the demonstration tests.

If any other equipment improved from conventional plants is utilized for the SRZ-1200 design, demonstration tests will be conducted individually.

Item	Content	'20	'25	'30
In-vessel flow test	Confirm the in-vessel flow dynamic of the cooling water, collect and evaluate data required for plant safety and performance evaluation.			
Molten core cooling equipment	Confirm the behaviors and cooling performance of the molten core and collect data for approval and license.			
In-core nuclear instrumentation	Confirm the measuring performance, soundness and maintainability of the in-core nuclear instrumentation equipment.			

Figure 4 Verification plan for main equipment of SRZ-1200

5. Activities for maintaining manufacturing facilities and supply chain

As the plans to construct new nuclear power plants have been suspended due to the Fukushima Daiichi Accident, it is imperative to advance not only design but also preparation for manufacturing and procurement to resume the activities for plant construction.

Regarding the maintenance of the manufacturing facilities necessary for the production of SRZ-1200 components, the important parts of the large facilities owned by MHI Nuclear Energy Systems have been refurbished and renovated. Moreover, expertise and experience for maintenance of each facility have been accumulated to strengthen the facility maintenance framework. In addition, with the aim of manufacturing of a unit of the SRZ-1200 in the future, the performance of manufacturing nuclear plant components has been steadily improved through the sophistication of the facilities such as increased spindle rotation speed of the machine tool and failure prevention by monitoring the equipment status with sensors.

MHI is proactively collaborating with over 400 business partners specializing in nuclear-related technology to sustain the supply chain. This collaboration includes sharing information about the progress of SRZ-1200 technical development, strengthening relationships through discussions for quality assurance of procurement items and exploring the rationalization of specifications. Efforts to reach out potential suppliers are also ongoing.

6. Conclusion

To realize a carbon-free society and ensure a stable electric power supply, MHI is developing the SRZ-1200 as an advanced nuclear reactor with high social acceptance; being safer and more reliable compared to conventional plants and able to coexist with renewable energy. The basic design of the plant has been almost completed through joint research with the four power companies; furthermore, demonstration tests for the advanced designs and technologies are actively underway.

MHI is committed to steadily moving forward with demonstration tests and preparing for manufacturing and procurement. Upon the determination of the construction site, MHI will advance with detailed design activities incorporating site-specific information.

Acknowledgments:

To promote the basic plan of SRZ-1200, MHI undertook the “Basic design phase 2 for next-generation light water reactor,” a joint research project involving Hokkaido Electric Power Co., Inc., Kansai Electric Power Co., Inc., Shikoku Electric Power Co., Inc., Kyushu Electric Power Co., Inc. and MHI. MHI expresses its gratitude to all of the four companies and other stakeholders for giving a great deal of advice.

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References

(1) Mitsubishi Heavy Industries, Ltd.
https://www.mhi.com/jp/products/energy/innovative_next_generation_pwr.pdf (in Japanese)