Basic Design of SRZ®-1200 Advanced Light Water Reactor for the World's Highest Level of Safety

NAOKI KAWATA[*1] TAKAFUMI OGINO[*2]
AKIRA KIRITA[*2] YOSHIYUKI TANIGAWA[*3]
KENTARO MORI[*3] YASUFUMI TAKAHASHI[*3]

SRZ-1200 is an advanced light-water reactor with the world's highest levels of safety, while in conformance with Japan's new regulatory requirements based on the lessons learned from the Fukushima Daiichi Accident. The probabilities of occurrence of severe accidents with core damage and containment vessel failure are indicated by the frequencies of core damage frequency and containment failure frequency. Those values of SRZ-1200 are set to be 1/10 of the regulatory requirements. To achieve such safety levels against design-basis events, the safety design policy of the SRZ-1200 includes the enhancement of redundancy and diversity in the design-basis safety systems to prevent severe core damage and ensuring the separation of these systems to prevent simultaneous loss of their functions. This report presents the SRZ-1200 plant's basic design that achieves the world's highest levels of safety, together with concrete examples such as the enhanced redundancy by 3-train for the safety systems at the design-basis accidents, the improved safety by permanent installation of the specialized safety facility and dedicated systems to prevent a core damage.

1. Introduction

To achieve the world's highest levels of safety, the performance targets of the advanced light-water reactor SRZ-1200 of Mitsubishi Heavy Industries, Ltd. (hereinafter referred to as MHI) have been set to be comparable to those of overseas new builds reactor design. Following the Fukushima Daiichi Accident, our basic design concepts are improved durability against natural hazards and strengthened functions of core cooling and radioactive material confinement.

One of the key elements in the safety design policy for SRZ-1200 is the defense-in-depth concept, which deals with the nuclear power plant's fundamental safety functions of "control of reactivity," "removal of heat from the core" and "confinement of radioactive material, shielding against radiation and control of planed radioactive release." Based on this design policy the independence of each level of the defense-in-depth ensures by enhancing the redundancy and diversity of the safety systems for the design-basis accidents and the specialized safety facility for severe accidents. Specifically, this means that failure of one safety function at one level does not affect the safety functions at the other levels.

The SRZ-1200 plant's basic design is in progress based on this safety design policy. One example is the adoption of redundancy by the 3-train for the safety systems that prevent severe core damage against the design-basis accidents. As another safety enhancement, the specialized safety facility is permanently installed to ensure cooling of the molten core and confinement of radioactive material, even when a core meltdown does occur as in the case of the Fukushima Daiichi Accident. The employment of the specialized safety facility further ensures cooling of the molten core.

*1 Chief Manager, Nuclear Plant Designing Department, Nuclear Energy Systems
*2 Engineering Manager, Nuclear Plant Designing Department, Nuclear Energy Systems
*3 Nuclear Plant Designing Department, Nuclear Energy Systems

2. Safety design policy for SRZ-1200

Learning from the Fukushima Daiichi Accident, and as the plant with the world's highest levels of safety, SRZ-1200 have been set the core damage frequency (hereinafter referred to as CDF) and the containment failure frequency (hereinafter referred to as CFF) to be 1/10 of the reference levels of safety goals in Japan (i.e., CDF of 10^{-5} per reactor year and CFF of 10^{-6} per reactor year). The basic design concepts include strengthening the durability against natural hazards (e.g., resistance to earthquake or tsunami), appropriately combining active and passive equipment to enable quick response during the early stage of accident and promptly bring it under control, and preventing simultaneous loss of their functions by isolating the redundant safety systems.

The defense-in-depth concept is our top priority in the safety design policy for achieving the world's highest levels of safety. Specifically, the defense-in-depth levels consist of the following: prevention of failure occurrence (Level 1), responding to anticipated operational occurrences (Level 2), and measures against design-basis accidents (Level 3). When the accident comes to beyond-design-basis (design extension conditions), the measures are taken to prevent core damage (Level 4a) and prevent containment vessel failure (Level 4b). The measures for the scenarios such as airplane crashes and terrorist attacks are also taken in its design conditions.

In principle, the safety systems, which are handled in Level 2 and 3, are designed to have redundancy, diversity and independence. This means that the safety function of each safety system can be maintained, even assuming a single failure of the component comprising the relevant system and the loss of off-site power supply.

The conventional safety system is dual-redundant (two trains); when one subsystem fails, the other maintains functionality. In SRZ-1200, a 3-train system is adopted for enhanced safety redundancy. Each system is installed in a separate compartment that is completely isolated from each other, with every one of them physically divided from the other two by a wall or floor. This design can prevent internal events such as fires from spreading from one compartment to another.

The specialized safety facility, which is addressed by Levels 4a and 4b, is supposed to have the highest possible degree of diversity and independence from other systems, so as not to be disabled simultaneously by common cause failure on the safety systems. The dispersion of locations for installation should be taken into consideration for appropriate measures. The dedicated facility is to be put in place to ensure cooling of the molten core and confinement of radioactive materials, even when core meltdown does occur as in the case of the Fukushima Daiichi Accident.

Moreover, with the aim of maintaining the necessary functions in the event of a natural disaster, the durability against expected earthquake and tsunami is strengthened, for example, by robust buildings with high earthquake resistance and locating the site at an altitude as high as or above the expected tsunami height (i.e., a dry site).

3. Basic design of SRZ-1200

The SRZ-1200 plant's basic design is underway based on the safety design policy described above.

The following sections provide system design summaries by referring to some examples of the safety systems, that is, the safety injection system, containment spray system, support system, and specialized safety facility. Brief overview of plant layout design is also described.

3.1 SRZ-1200 system design

3.1.1 Design-basis systems

In SRZ-1200, independent 3-train configuration has been adopted for the safety injection system and the containment spray system. **Figure 1** is a configuration diagram of these safety systems.

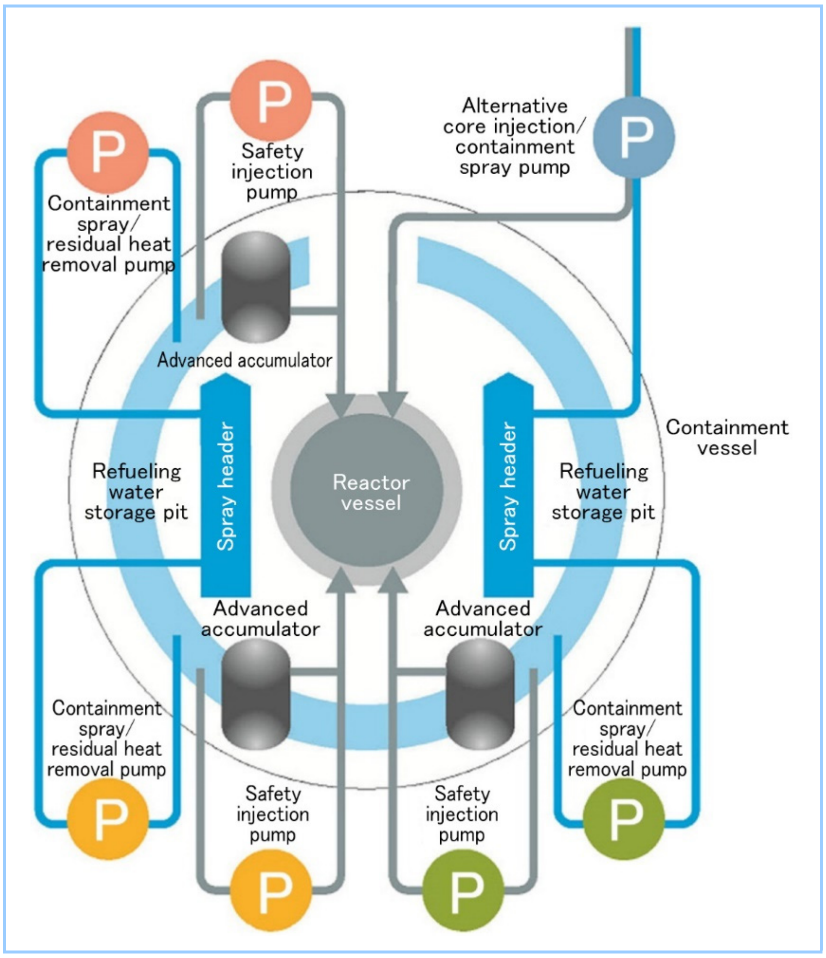

Figure 1 Configuration of triple-redundant safety systems

(1) Safety Injection System

The safety injection system injects cooling water into the reactor in the event of Loss of Coolant Accident (hereinafter referred to as LOCA).

This safety injection system consists of two systems: high-head safety injection system and accumulator injection system. The refueling water storage pit, which serves as a source of cooling water in the event of accidents, is installed inside the containment.

The high-head safety injection system consists of independent 3-train subsystem. Each subsystem comprised of the safety injection pump, piping and valves. The safety injection pumps are put on standby during normal operation. Once the emergency core cooling system actuation signal is issued, the pumps are automatically started to inject borated water into the core from the refueling water storage pit. The design of direct injection into the reactor vessel makes it possible to supply cooling water to the core even when the main coolant piping is ruptured and one subsystem fails to pump, because the other two subsystem pumps remain functional.

The accumulator injection system is so-called a passive safety system, consisting of the accumulator, piping and valves. Each reactor coolant loop is equipped with the accumulator injection system. The system employs an advanced accumulator in which a vortex damper is installed to automatically switch the flow rate from high to low depending on the water level in the tank. With this function, the function of the low-pressure injection pump, which was required in the conventional plant, could be integrated into the advanced accumulator, and the system was simplified by eliminating the low-pressure injection pump.

In conventional plants, post-accident long-term recirculation operation involves switching the water source from the refueling water storage pit installed outside the containment to the recirculation sump in the containment. In SRZ-1200 design, this switching operation is not needed because the refueling water storage pit is installed in the containment.

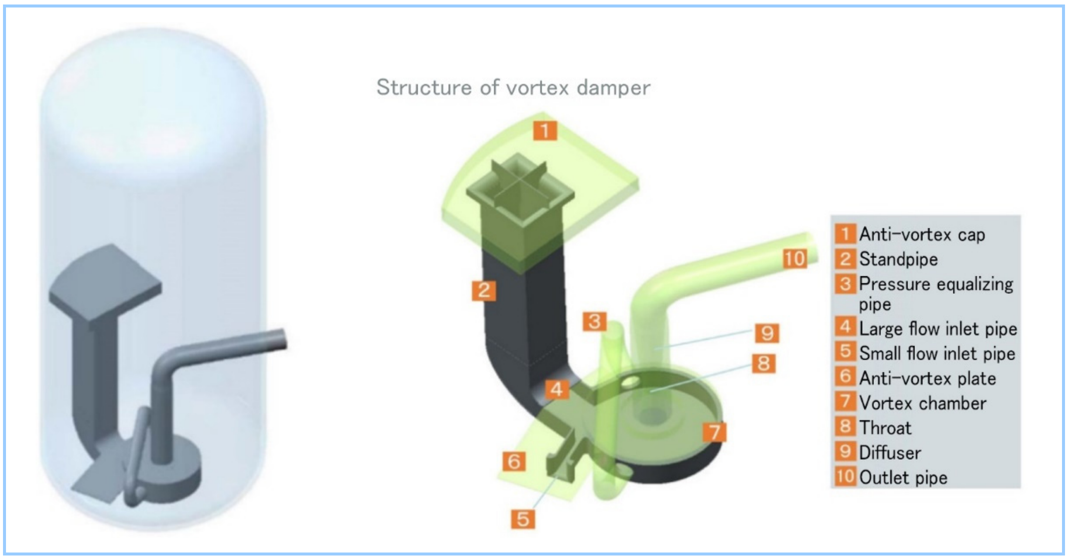

Figure 2 Advanced accumulator

(2) Containment Spray System

The containment spray system provides spray water to the inside of the containment to reduce the pressure and temperature in the containment that have been increased due to accidents such as LOCA.

As shown in Figure 1, the containment spray system also consists of independent 3-train subsystem. Each subsystem consists of the pump, heat exchanger, piping and valves. The use of the advanced accumulator allows the accumulator injection system to function as the low-head injection system as well. For further simplification, the pump and the heat exchanger of the containment spray system are also used for the residual heat removal system.

Once containment spray signal is generated, the pumps are automatically started to operate the heat exchanger to cool borated water in the refueling water storage pit and spray it into the containment from the spray nozzles of spray rings that are installed to the upper part of the containment.

(3) Support system

To sustain the functions of the safety injection system and the containment spray system, the support system has functions to cool these components and maintain room temperature, and also has independent 3-train subsystem.

The heating, ventilation and air conditioning (hereinafter referred to as HVAC) system for safety systems maintains the environment for functioning of the safety systems including the safety injection system and containment spray system.

Following the 3-train safety system, the HVAC system also has 3-train subsystem, with each subsystem consisting of the fan, air-conditioning unit/cooling unit, ducts and dampers. While the conventional HVAC system provides cooling by ventilation using outside air, SRZ-1200 design employs cooling by circulation using chilled water, etc. This design has therefore improved the resistance to not only internal events by means of compartmentalization, but also external hazards such as high-concentration volcanic ash falls from volcanoes.

3.1.2 Specialized safety facility (Severe Accident Mitigation Systems)

The specialized safety facilities are designed to be installed permanently and function as an alternative safety system for safety injection and containment spray by the permanently installed dedicated pumps. The containment can also be cooled by the containment recirculation units using permanently installed pumps which supply cooling water to the units.

Even when a core meltdown does occur, the system for molten core cooling further ensures the conduct of cooling while reducing the risk of steam explosion. Cooling water is provided to the molten core spreading area from the refueling water storage pit by gravity injection. This injection is enabled by the molten core relief mechanism, which is made up of the fixed end of the molten core relief valve, wire, and molten core relief valve. If the fixed end of the molten core relief valve, which is placed in the spreading area, comes in contact with the molten core and melts/gets damaged, the molten core relief valve is opened to inject cooling water by gravity. **Figure 3** shows a conceptual diagram of gravity injection into the spreading area.

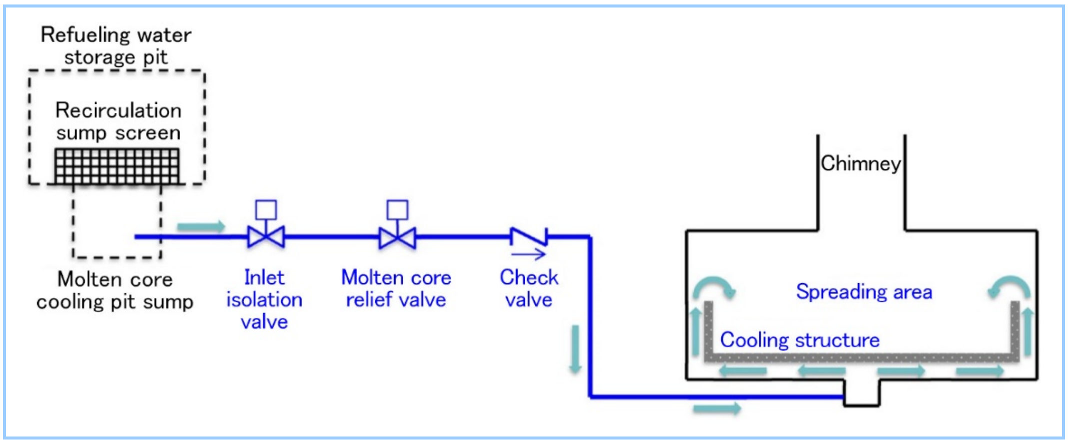

Figure 3 Gravity injection into spreading area

3.2 SRZ-1200 layout design

In SRZ-1200, the physical arrangement of the plant is based on the conventional layout designs with a proven track record for construction on sites subjected to severe earthquake conditions in Japan. To achieve resistance high enough to withstand such severe earthquakes, the buildings in which the safety systems and specialized safety facility are set up (i.e., the containment vessel, fuel handling building, and safety system building) are constructed on a single basemat, and are large and rectangular in shape.

In principle, the safety systems and the specialized safety facility are installed inside the buildings considering external hazards. Their installation is carried out in each of the compartments that are separated from each other. **Figure 4** illustrates the concept of such compartmentalization.

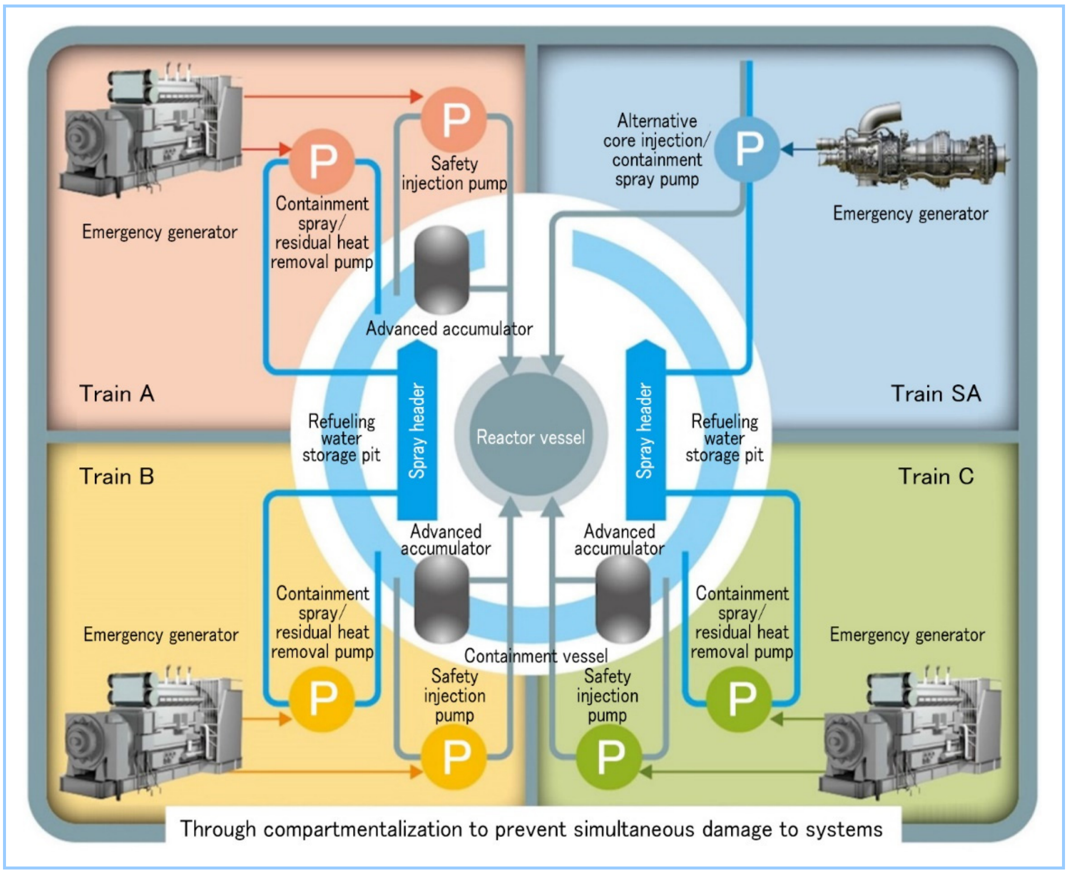

Figure 4 Concept of compartmentalization

Described below are the features of SRZ-1200 layout design.

- Containment vessel

Being made of steel, the containment vessel has a confinement function. Its durability against external hazards and shielding function are enhanced by creating a robust external concrete shield around the outside surface of the containment vessel. This enables the containment vessel to withstand various external hazards.

- Separation of safety systems

Robust concrete walls are used to isolate each subsystem of the same safety system and further separate all the safety systems from the specialized safety facility, thereby preventing events such as fire and flood from spreading to other compartments. Simultaneous loss of safety functions is also prevented.

- Layout for separate installation in safety system building

The appropriate separate installation of each subsystem of the same safety systems, and the appropriate separate placement of the specialized safety facility from all the safety systems prevent simultaneous loss of safety functions in the event of a fire, flood or others.

- Improved robustness of building structure

With a robustness that can ensure resistance to severe earthquakes in Japan, the buildings in which the safety systems and facilities are installed are made strong enough to maintain their necessary functions against external hazards such as tornadoes and large airplane crashes.

4. Conclusion

MHI has been working on the basic design of SRZ-1200. This report presents the safety design policy for SRZ-1200 and system design summaries of design-basis systems such as the safety injection system, the containment spray system, their support system, and the severe accident mitigation systems. The overviews of the layout design of these systems are also described briefly.

The plant basic design is in progress under cooperation with Japanese Utilities, and will be completed in near future. MHI will continue to steadily promote the basic design and execute verification tests on new technologies.