Activities for Restarting of Nuclear Power Plant and Installation of Specialized Safety Facility

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Triggered by the Fukushima Daiichi Accident, new regulatory requirements came into effect in 2013. Mitsubishi Heavy Industries, Ltd. (MHI) has been working on measures to improve the safety of nuclear power plants so far in order to contribute to the restoration of public confidence in nuclear power. This report presents examples of support service for electric power companies and safety improvement for restarting nuclear power plants, which are activities we have been working on, as well as our support for installation of specialized safety facility for further safety improvement. By performing these activities continually, we will keep on working with electric power companies to improve the safety of nuclear power plants.

1. Introduction

In Japan, 54 nuclear power plants (24 PWRs (Pressurized Water Reactors) and 30 BWRs (Boiling Water Reactors)) were in service and had supplied electricity. However, after the Fukushima Daiichi Accident caused by the Great East Japan Earthquake in 2011 forced the nuclear power plants to be shut down.

Triggered by this accident, it was determined that the concept of nuclear safety would be reviewed, and the Nuclear Regulation Authority was established in 2012, with new regulatory requirements coming into effect in 2013. Under these new regulatory requirements, safety measures were strengthened for the following items from perspective of preventing loss of safety functions caused by common factors under extrinsic incentive events, based on lessons learned of the Fukushima Daiichi Accident. **Figure 1** compares conventional and new regulatory requirements.

[1] Reinforcing safety measures against events assumed in the design (earthquakes and tsunamis)
[2] Reinforcing safety measures against natural phenomena (volcanoes, tornadoes, external fires, etc.) and newly introducing measures against internal flooding
[3] Newly introducing safety measures against accidents that exceed the design conditions (severe accidents)
[4] Newly introducing safety measures against terrorism (intentional aircraft crashes, other terrorism, etc.)

This report presents activities to support electric power companies for audit approval and pre-service inspections, as well as measures to improve the safety of PWR plants that we designed, manufactured and constructed, for the purpose of complying with the new regulatory requirements introduced in 2013. This report also introduces an overview and current status of activities regarding specialized safety facility, which is safety equipment to deal with crashes of large aircraft and other terrorism required under the new regulatory requirements.

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2. Our support for restarting of PWR plants

2.1 Our activities in light of the Fukuichi accident

On March 11, 2011, the day of the Great East Japan Earthquake , we established a task force for countermeasures, prepared 600 personnel, considered accident scenarios for PWR plants and prepared necessary improvement measures (refer to **Figure 2**). Our personnel implemented emergency safety measures, short-term measures such as stress tests and medium- to long-term measures to further improve safety, so as not to decline public confidence for nuclear power, and not to lose stable supply of electricity. We have contributed to early restart by assisting in applications for the government approval of engineering work plans, evaluating integrity of equipment, and carrying out safety improvement work, all of which are required to comply with the new regulatory requirements.

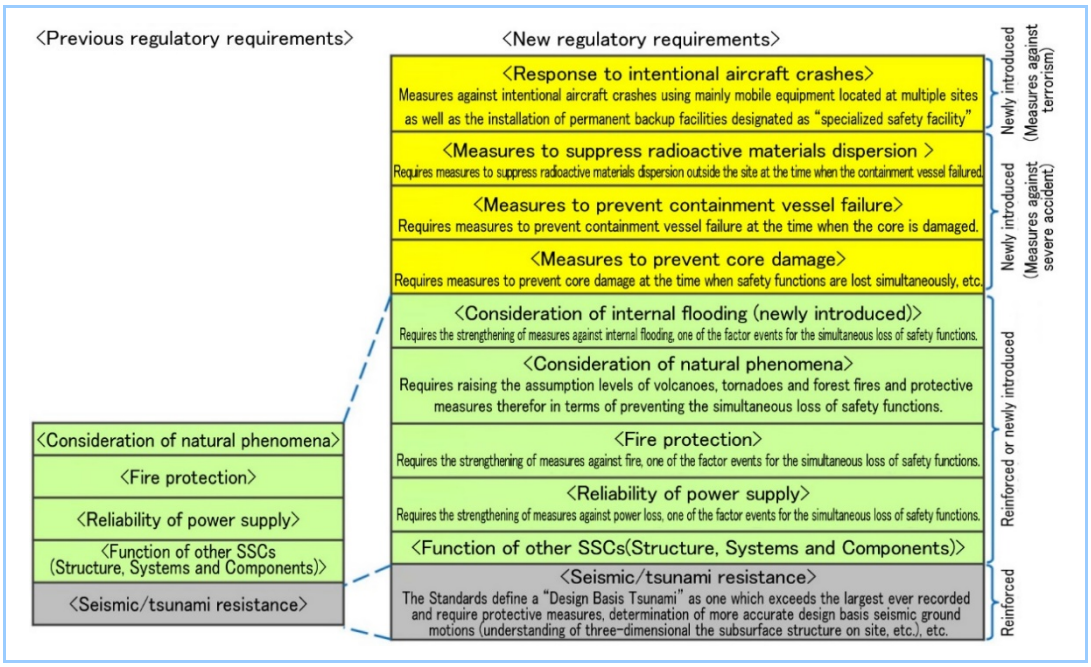

Figure 1 Comparison between previous and new regulatory requirements

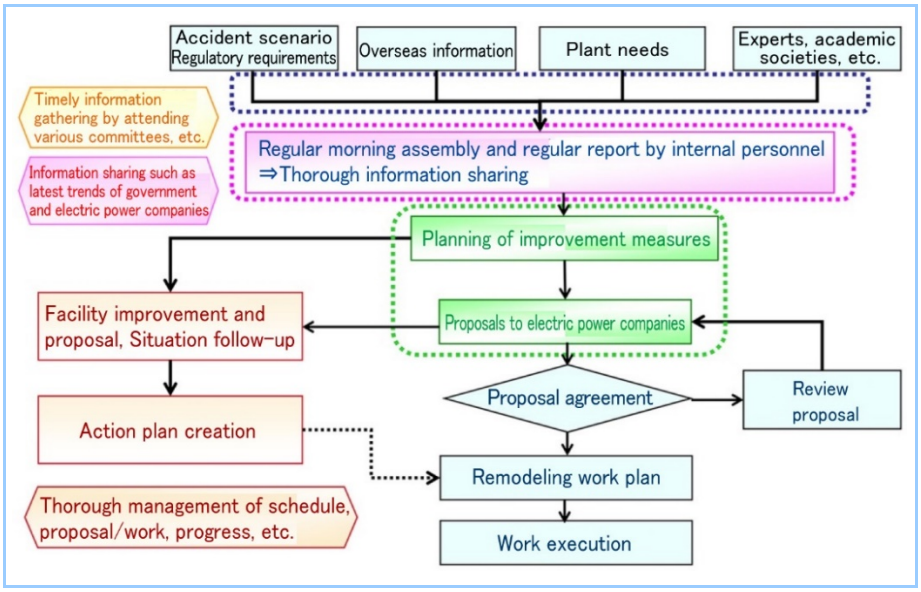

Figure 2 Business process in light of the Fukushima Daiichi Accident

(1) Establishment of support system

For the purpose of early understanding of the plant status, as well as the early restoration of the plant and ensuring safety, we have built a system to offer technical support to promptly provide design and technical information to electric power companies utilizing all our strengths as a plant engineering farm.

[1] Prompt assistance for audit of electric power companies regarding compliance with new regulatory requirements
[2] Dispatching and stationing our engineers at each plant of electric power companies
[3] Establishment of a base for nuclear safety measures in our company (Kobe)

(2) Support details

As a plant engineering farm, by monitoring the status of compliance of electric power companies with the new regulatory requirements, and the proposal of equipment improvement for each plant and the related progress status, we carried out thorough horizontal analysis of safety improvement measures. By sharing the latest status of activities on a regular basis, we have shared a common awareness of problems with electric power companies and have provided the following support for the restarting of PWR plants.

[1] Backup for audit of electric power companies regarding compliance with new regulatory standards
[2] Equipment integrity evaluation and verification test
[3] Promotion for planning, management and completion of safety improvement work
[4] Planning of medium- to long-term measures for each plant such as specialized safety facility

2.2 Equipment integrity evaluation and verification test

In the Fukushima Daiichi Accident, it is believed that the loss of the emergency power supply (loss of all AC power) and the loss of cooling means for the core (loss of final heat sink), which were caused by combination of earthquake and tsunami, caused the core and containment vessel to reach high temperature and pressure levels and resulted in damage.

The new regulatory requirements require equipment to be stabler against larger natural disaster (earthquakes, tsunamis, tornadoes, etc.) than the previous requirements. We confirmed the safety of the equipment important for the safety of PWR plants through evaluation and verification tests. These include verification tests conducted to verify that the nuclear power plant equipment meets the applicable conditions of the commercial standards used for the evaluation and can be evaluated appropriately therewith. This section describes the on-site vibration tests[(1)(2)] conducted to confirm that the damping ratio of the reactor coolant loop in an earthquake is appropriate.

The damping ratio (3%) of the reactor coolant loop in an earthquake is stipulated in a commercial standard (JEAG4601-1991), but its basis is the vibration test result simulating a three-point-support steam generator. Based on overseas literature, it can be judged that the same damping ratio can be applied to a reactor coolant loop with a two-point-support steam generator. In order to reconfirm its validity, we conducted a vibration test using the steam generator of an actual plant (refer to **Figure 3** for the difference in the number of steam generator support points).

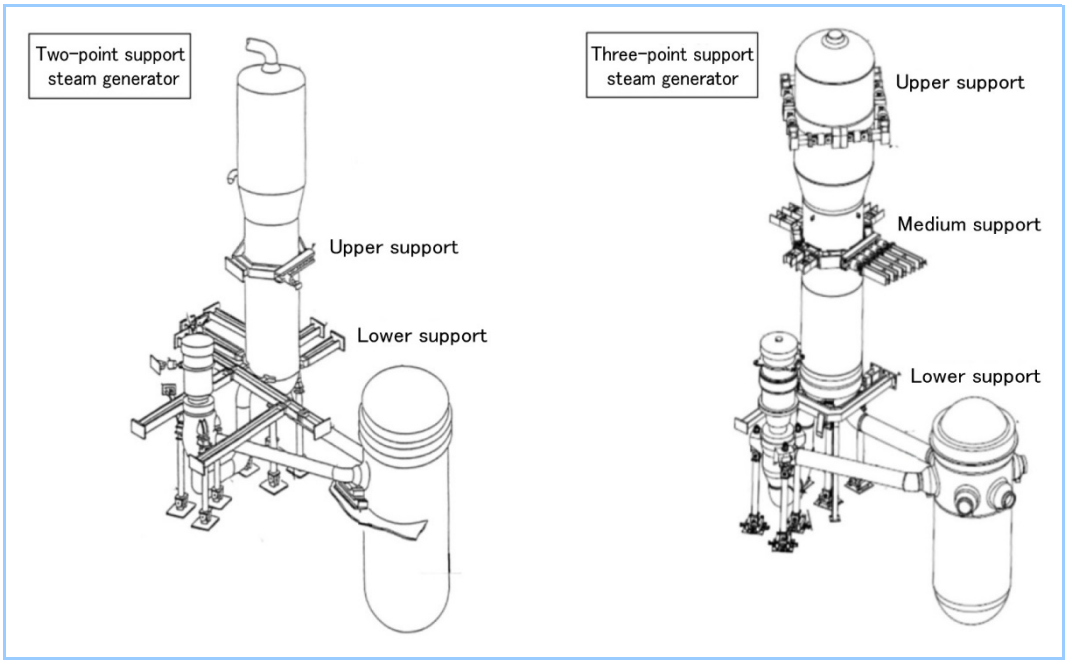

Figure 3 Difference in the number of steam generator support points

In order to obtain vibration test data during the examination period, we newly planned a rational test method of applying excitation to a plant (preceding plant) using a hammering system (developed and manufactured by MHI) and to the other plant (subsequent plant) using a reaction force type exciter installed on upper part of the steam generator (refer to **Figure 4** and **Figure 5**). This was an unprecedented test method, but it could be used to apply excitation to the actual steam generator properly, and as a result, data with a target damping ratio of 3% or more was acquired. Accordingly, it was confirmed that the damping ratio of the reactor coolant loop in an earthquake (3%) was appropriate regardless of the number of support points.

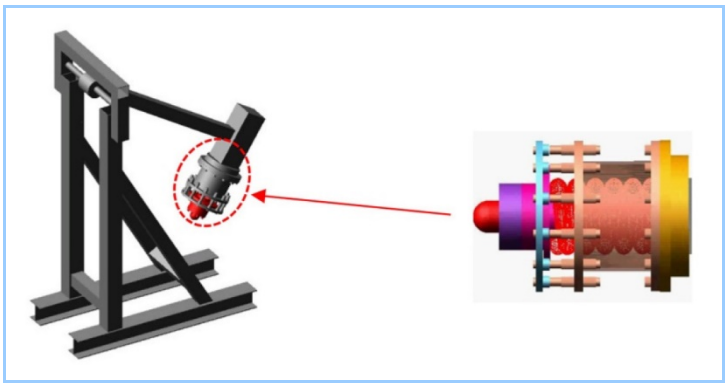

Figure 4 Hammering system (preceding plant)

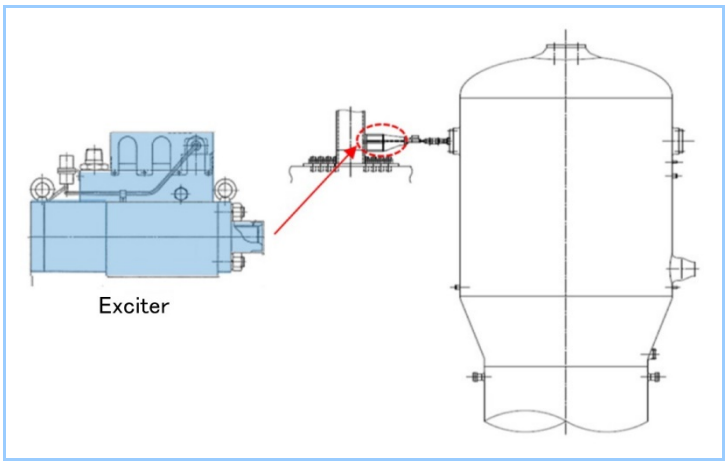

Figure 5 Exciter installed on upper wall of steam generator (subsequent plant)

2.3 Details of safety improvement work

After the Fukushima Daiichi Accident, the new regulatory requirements require improvement of equipment to deal with severe accidents that exceed design conditions, prevent core damage and containment vessel failure, and suppress radioactive materials dispersion. Specifically, the following various equipment remodeling work and new equipment installation work have been carried out.

(1) Power supply improvement measures

To increase the capacity of the power supply that is required to prevent significant damage to the core and containment vessel in the event of a severe accident caused by a loss of the power plant emergency power supply due to an earthquake or tsunami. In addition to the existing equipment, the following measures were taken for the further improvement of safety.

[1] Increasing the capacity of existing storage batteries or adding spare storage batteries (*). The power supply was diversified by using existing regular storage batteries, power supply vehicles or small generators. A schematic diagram of the countermeasures is shown in **Figure 6**.

*Increasing the capacity to supply electricity to 24 hours in total, 8 hours without disconnecting the load of the on-site storage battery and a further 16 hours with any load other than the required one disconnected.

[2] Ensuring the diversity of the power source by installing air-cooled generators with

earthquake resistance on a hill (*). The power supply configuration was changed so that the power supply capacity required for the safe shutdown of the plant can be supplied to the emergency AC and DC systems even when the emergency power supply is lost due to a tsunami. **Figure 7** is a schematic diagram of the countermeasures.

*The capacity for supplying electricity for 7 days.

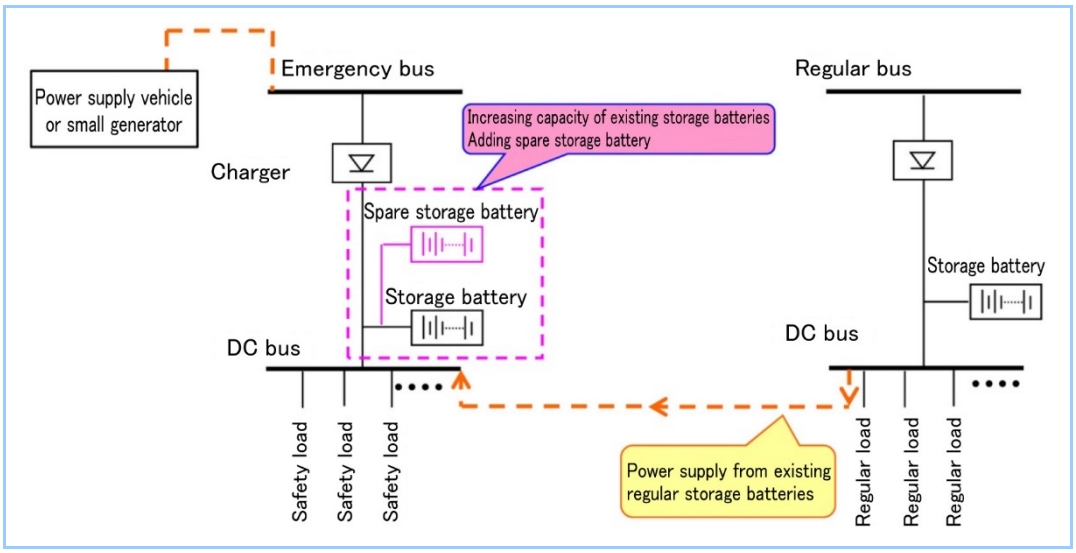

Figure 6 Schematic diagram of measures to increase power supply time of storage batteries

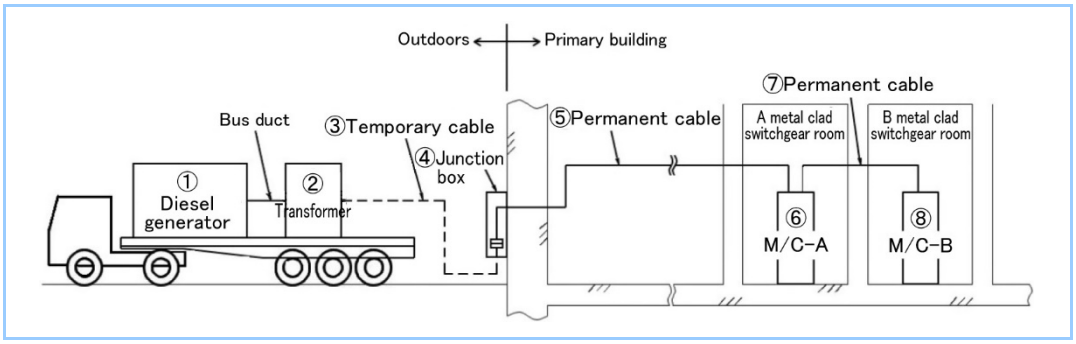

Figure 7 Schematic diagram of air-cooled emergency generator

(2) Measures to prevent core damage and containment vessel failure

As described above, in the case of the Fukushima Daiichi Accident, the cooling function of the core was lost due to the loss of the emergency power supply caused by combination of the earthquake and tsunami. Then the reactor coolant pressure boundary composed of the reactor vessel and the pipes connected to it reached a high level of temperature and pressure, resulting in damage to the core and failure to containment vessel. The following measures are taken to secure various compensating cooling means in case that the core cooling functions installed as existing equipment are lost at the same time and a severe accident occurs.

[1] Reactor cooling when reactor coolant pressure boundary is at a high level of pressure

Modifications were made to enable manual start in cases where the automatic start of the cooling equipment (turbine driven auxiliary feed water pump) assumed in the design fails under the condition that the reactor coolant pressure boundary is at a high level of pressure. In addition, the operation was clarified so that even if the turbine driven auxiliary feed water pump is caused malfunction, the core is depressurized and cooled by water injection with a (filling) high-pressure injection pump and drainage (primary system feed and bleed) from pressurizer relief valve.

[2] Decompression of reactor coolant pressure boundary

A nitrogen cylinder was newly installed as an alternative to the compressed air supply equipment to diversify the drive source of the decompression equipment (pressurizer relief valve and main steam relief valve). The purpose is to prevent significant damage to the core and containment vessel even when the drive source assumed in the design is lost

under the condition where the reactor coolant pressure boundary is at a high level of pressure.

[3] Reactor cooling when reactor coolant pressure boundary is in a low pressure

Permanent and portable alternative core injection pump equipment was newly installed in order to prevent significant damage to the core and containment vessel even when the cooling equipment (core injection equipment) assumed in the design ceases to function under the condition where the reactor coolant pressure boundary is in a low pressure.

[4] Cooling of inside of containment vessel

Alternative permanent containment vessel water injection pump equipment was newly installed in order to prevent the inside of the containment vessel reaching a high temperature even when the cooling function using water injection into the containment vessel (containment vessel spray pump) is lost.

[5] Prevention of overpressure failure to containment vessel

The water injection function into the heat exchanger (containment vessel recirculation unit) that decompresses (removes heat from) the inside of the containment vessel by natural convection of air without using external force has been reinforced in order to prevent the inside of the containment vessel from reaching a high pressure and being failure due to the evaporation of water caused by significant damage to the core.

[6] Cooling of molten core at bottom of containment vessel

Equipment (communicating pipe) storing the cooling water required to cool the molten core that fell out of the reactor vessel after the occurrence of significant damage to the core was newly installed.

[7] Prevention of failure to containment vessel due to hydrogen explosion

In order to prevent hydrogen generated by damage to the core from accumulating in the containment vessel and causing a hydrogen explosion, a new passive autocatalytic recombiner (PAR) that combines generated hydrogen and oxygen to convert it into steam and a device (igniter) that systematically burns hydrogen to reduce the hydrogen concentration were installed.

Figure 8 is an overall schematic diagram of these core damage and containment vessel failure prevention measures.

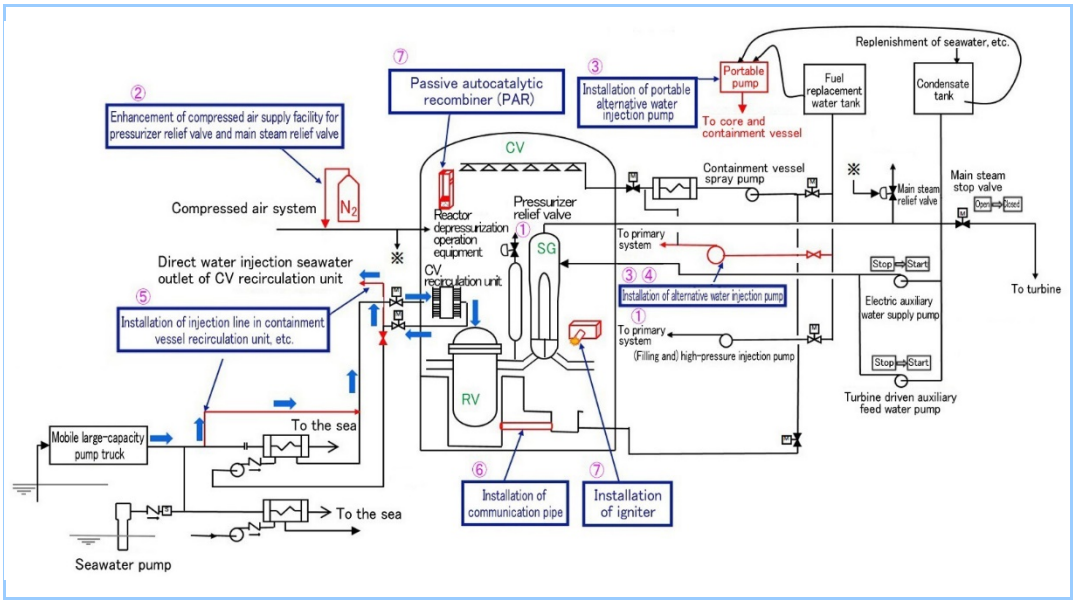

Figure 8 Overall schematic diagram of core damage and containment vessel failure prevention measures

(3) Measures against tsunami

The new regulatory requirements assume a standard tsunami water level that considers further conservativeness (+9.5 m) added to the original water level calculated by Japan Society of Civil Engineers formula in 2002, reflecting the experience of the Fukushima Daiichi Accident. We developed multiple tsunami water blocking structures (filling type, caulking type

and boot type) in order to prevent flooding of building penetrations below the standard tsunami water level. By using these newly developed tsunami water blocking structures for building penetration, the safety was improved to prevent a tsunami from entering the interior through building penetration and causing the loss of the emergency power supply and the core cooling function. **Figure 9** depicts a schematic diagram of the developed and installed tsunami intrusion prevention structure [3].

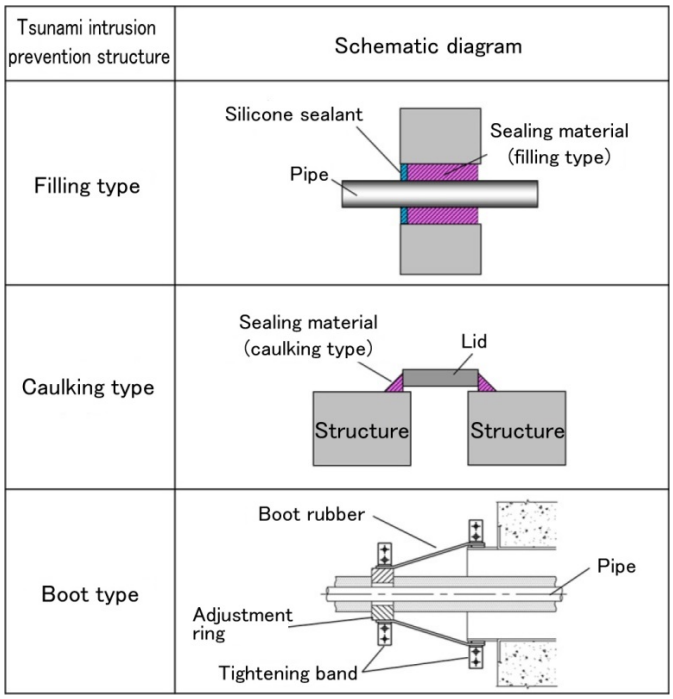

Figure 9 Schematic diagram of seal structure

3. Specialized safety facility

3.1 Outline and legal requirements of specialized safety facility

The specialized safety facility is a facility to prevent damage to the reactor containment vessel and suppress the release of radioactive materials in the event of significant damage to the core due to intentional aircraft crashes or other terrorism. It is stipulated by law for the facility to be newly installed within five years after the approval of the restart work plan.

The specialized safety facility has the following functions (refer to **Figure 10** for a conceptual diagram).

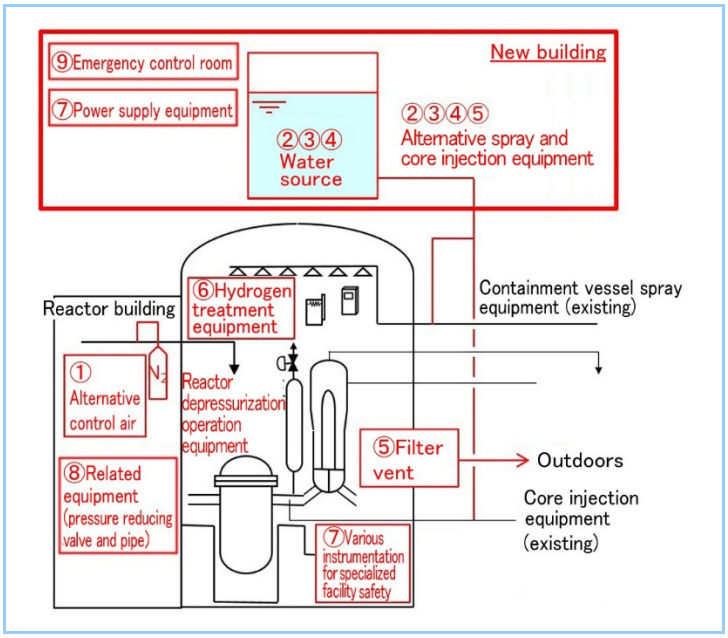

Figure 10 Conceptual diagram of specialized safety facility

[1] Reactor coolant pressure boundary decompression operation function
[2] In-core molten core cooling function
[3] Below-containment vessel molten core cooling function
[4] Containment vessel cooling function
[5] Containment vessel decompression function
[6] Hydrogen control function
[7] Support function (power supply, instrumentation and communication equipment)
[8] Related equipment (pressure reducing valve and pipe)
[9] Emergency control room

3.2 Our support for plants

As of September 2020, for Sendai Nuclear Power Station Units 1 and 2, Genkai Nuclear Power Station Units 3 and 4, Takahama Nuclear Power Station Units 1 ,2, 3 and 4 and Ikata Nuclear Power Station Unit 3, the approval of the construction plan for the specialized safety facility has been obtained and the construction work is beginning. We deal with the overall planning including the buildings, tunnels and shafts to be built, as well as work inside the existing buildings. For Ohi Nuclear Power Station Units 3 and 4 and Mihama Nuclear Power Station Unit 3, the audit by the Nuclear Regulation Authority is ongoing for the approval of the construction plan, and we are providing technical support (seismic evaluation, etc.) for the audit. Furthermore, the electric power company, MHI and construction companies are working together to shorten the overall process (refer to **Table 1** for the review status of the specialized safety facility of PWR plants).

Table 1 Review status of specialized safety facility of PWR plants (as of September 2020)

Electric power company	Plant	Application for Installation license (application time/license time)	Application for work license (application time/license time)
Kansai Electric Power Co. Inc.	Takahama 3/4	December 25, 2014/September 21, 2016	April 26, 2017/August 7, 2019
	Takahama 1/2	December 22, 2016/March 7, 2018	March 8, 2018/February 20, 2020
	Mihama 3	April 20, 2018/July 8, 2020	July 10, 2020
	Ohi 3/4	March 8, 2019/February 26, 2020	March 6, 2020
Kyushu Electric Power Co. Inc.	Sendai 1/2	December 17, 2015/April 5, 2017	May 24, 2017/April 12, 2019
	Genkai 3/4	December 20, 2017/April 3, 2019	May 16, 2019/August 26, 2020
Shikoku Electric Power Co. Inc.	Ikata 3	January 14, 2016/October 4, 2017	December 7, 2017/March 27, 2020
Hokkaido Electric Power Co. Inc.	Tomari 3	December 18, 2015	Not yet
	Tomari 1/2	Not yet	Not yet

: Installation license/construction license obtained : Under review

4. Conclusion

We have carried out the restarting of nine PWR plants through the establishment of a support system after the Fukushima Daiichi Accident and the reliable execution of safety improvement work. In order to contribute to the restoration of public confidence in nuclear power and to perform the safe and secure operation of nuclear power plants, we will provide support also for restarting BWR plants and establishing the specialized safety facility by utilizing the comprehensive coordination and knowledge cultivated through the restart support so far, in addition to continuous support for PWR plants (Tomari Nuclear Power Station Units 1, 2 and 3 and Tsuruga Nuclear Power Station Unit 2).

References

(1) Hiroaki, S. et al., “On-Site Vibration Test of PWR Reactor-Coolant Loop In Application For Construction Plan License After Great East Japan Earthquake”, SMiRT-24.
(2) Ishiguro, T. et al., “On-Site Vibration Test for Measuring Damping Ratio of PWR Reactor Coolant Loop”, ASME PVP 2017.
(3) Watertight performance verification test of penetration seal in nuclear power plant, MHI-NES-1067, Mitsubishi Heavy Industries, Ltd.