Efforts to Support for Restarting BWR Plants

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In order to achieve a 46% reduction in greenhouse gas emissions by 2030 for the realization of "GX" (Green Transformation: a shift toward clean energy with no CO_2 emissions), Mitsubishi Heavy Industries, Ltd. is providing support for restarting BWRs based on its experience with PWRs. To comply with the new regulatory requirements, BWR plants are implementing safety measures, in which we assist with its holistic capabilities and knowledge/experience acquired through past PWR restart projects. This report presents examples of such safety measures. Through these projects, the safe and stable operation of nuclear power plants is supported.

1. Introduction

After the Fukushima Daiichi Accident following the 2011 earthquake off the Pacific coast of the Tohoku region, new regulatory requirements for commercial nuclear power reactors and nuclear fuel facilities, etc., have been enforced. **Figure 1** compares the old and new regulatory requirements. Based on the lessons learnt from the Fukushima Daiichi Accident and Japan's proneness to natural disasters, the new regulatory requirements strengthen the measures against wide-ranging incidents including design-basis events (earthquakes and tsunamis) and natural phenomena (tornadoes, volcanoes and others). Considering the worst-case scenarios such as major accidents and intentional crashes of aircraft, measures against beyond-design-basis events (i.e., severe accidents) and terrorism (intentional aircraft crashes and other terrorist acts) are also prescribed.

For the restarting of nuclear power plants, Mitsubishi Heavy Industries, Ltd. (hereinafter referred to as MHI) helped 12 Pressurized Water Reactor (PWR) units to upgrade safety measures in compliance with the new regulatory requirements and get approval for plant restart. However, achieving a 20-22% share of Japan's energy mix with nuclear power is considered a precondition for achieving "a 46% reduction in greenhouse gas emissions by 2030" (GX Basis Policy). It is therefore essential to restart Boiling Water Reactor (BWR) plants, in addition to PWR plants. Under such circumstances, MHI has also started providing support for BWR restart by utilizing its holistic capabilities and knowledge/experience acquired through past PWR restart projects. In this report, examples of technologies and products used in the safety measures construction are introduced.

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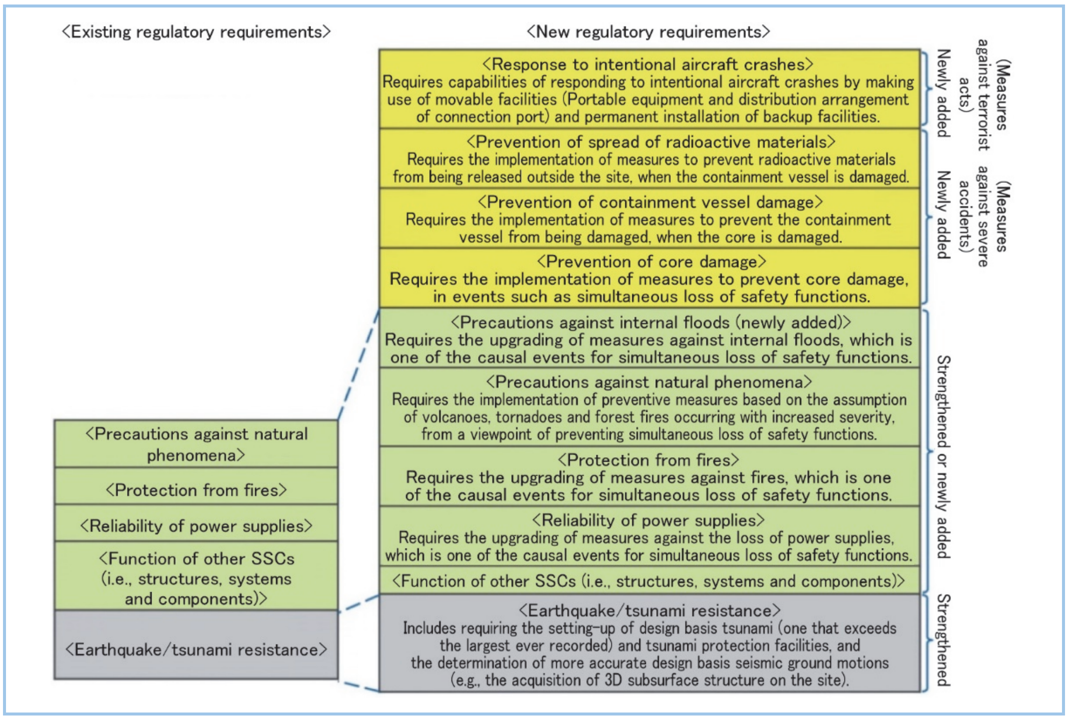

Figure 1 Comparison of existing and new regulatory requirements

2. MHI's support in restarting BWR plants

2.1 Scope of our support

With regard to the requirements strengthened or newly added by the new regulatory requirements, MHI provides wide-ranging supports including the application for installation permit, the application for construction plan approval, upgrading of safety measures and installation of specialized safety facilities to respond to severe accidents, etc. The scope of our support is shown in **Figure 2**. This report especially focuses on the following: penetration seals made in the building walls for piping or electrical instrumentation installation purposes as upgrading of a measure against tsunamis, fires and internal floods; MHI's tornado protection device and high-performance volcanic ash filtration system as upgrading of measures against natural phenomena (tornadoes and volcanoes); and air-cooled standby power supplies as upgrading of measures against the loss of power supplies. The following sections give their summaries.

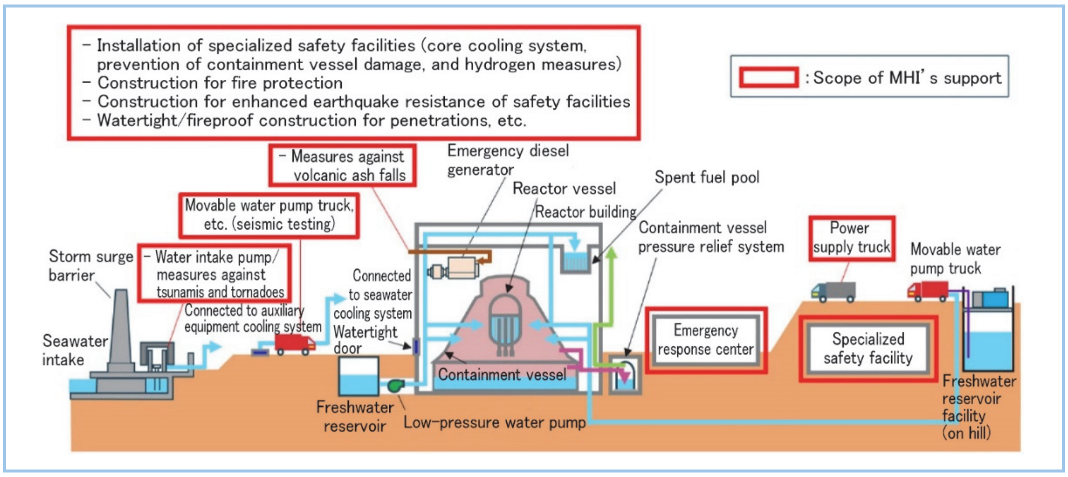

Figure 2 Scope of our support for BWR plants

2.2 Penetration Seals

The new regulatory requirements necessitate preventing the spread of tsunami waters, floods or fires into the adjacent sections through the penetrations in the building walls. It is therefore required to develop/design/implement a penetration sealing system in compliance with the requirements. The waterproof sealing structure for tsunamis and floods needs to fulfill its intended functionality after earthquakes and aftershocks. Therefore, the performance verification tests were conducted to develop a structure with superior performance in terms of seismic displacement following capability and pressure durability. Compared with the conventional structure, the following capability of the new structure has been improved by at least a factor of two, while it can withstand pressure equivalent to a static head of 40 m or higher. When it comes to the fireproof sealing structure, we have selected a lightweight sealing material with 3-hour fire-resistance performance, so the impact is reduced on the earthquake resistance of piping and such installed through the penetrations. **Figure 3** gives some waterproofing examples and their penetration sealing structures adopted in accordance to the requirements.

Moreover, the number of penetrations in nuclear power plants is enormous (in the order of several thousand to tens of thousands). Of these, the relevant ones have to be extracted before conducting the design/construction/examinations necessary to satisfy the new regulatory requirements regarding the measures against tsunamis, floods and fires. MHI provides centralized management of the penetrations of the entire plant buildings, from the extraction of relevant penetrations, to design, execution of construction and examinations, thereby helping to enhance the reliability of precautionary measures against tsunamis, floods and internal fires.

MHI continues helping to restart more nuclear power plants by installing the requirements-compliant waterproof/fireproof sealing systems to the penetrations and offering the centralized management of these penetrations.

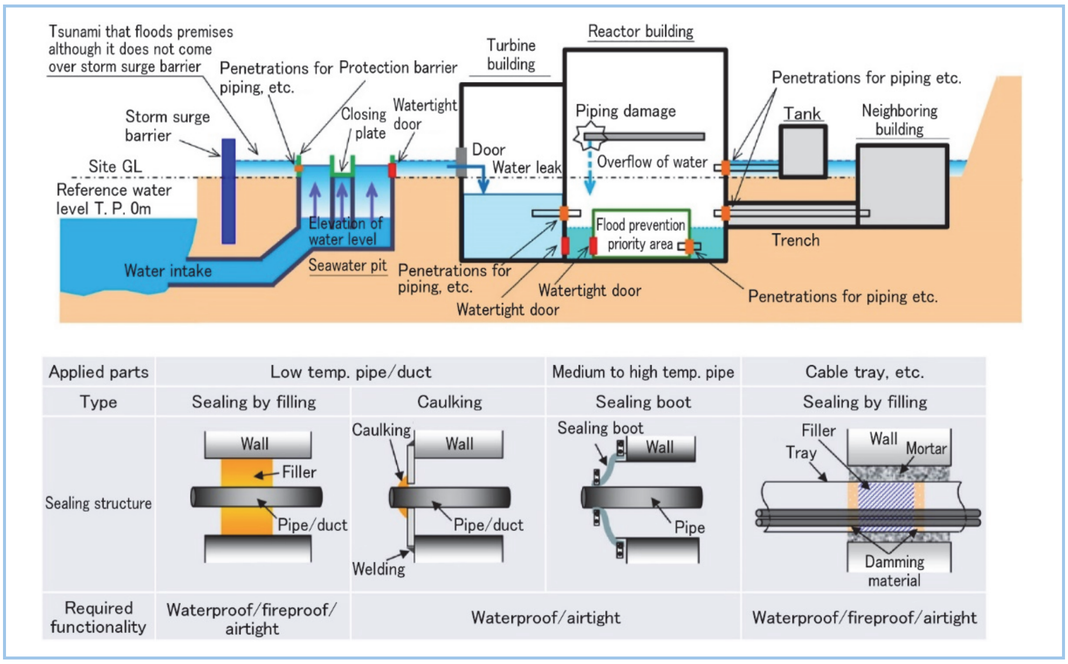

Figure 3 Penetrations of nuclear power plant building

2.3 Tornado protection device

The new regulatory standards require protection against tornadoes, which are a natural phenomenon. Having designed, produced and installed such safety measure systems in PWR plants, MHI takes advantage of its knowledge and experience to help restart BWR plants. This section especially focuses on MHI's tornado protection device for the seawater pump area.

Generally, the seawater pump is installed in a concrete pit, so the impact of wind during a tornado is minimal. However, the steel parts and other objects around the pit may be blown away by a tornado and fall into the pit through its upper opening, disabling the seawater pump. It is therefore necessary to equip the pit's top opening with a protection device and keep the seawater pump safe from flying debris during a tornado.

As the maximum impact speed of flying steel debris would be about 50 m/s, the tornado protection device structure has to be robust enough to withstand such impact. On the other hand, the pit opening is a square with each side measuring about 25 m. If only steel or concrete is used to cover the opening, the structure would be heavy and the inertial force during an earthquake would result in large seismic loads. We have therefore decided to use high-strength hard steel wire mesh to cover most of the opening, making it lightweight. At the four corners of the frame where the frame is fixed to the pit, rubber bearings (with a laminated structure of vulcanized rubber and steel plates) are placed between the frame and the pit. With this seismic isolation system, we have deliberately allowed the device structure to have a long vibration cycle, thereby preventing resonance with seismic waves. **Figure 4** shows the structure of our tornado protection device.

In addition to the technology for road bridges, which has been applied extensively and has already been verified, the rubber bearing was newly verified for structural integrity in the event of the flying debris crash required by the new regulatory standards. Specifically, we conducted a mock-up test by which the data on the rigidity of rubber bearings at the moment of collision were obtained. The results were reflected in the flying debris crash simulation analysis model to confirm the health of the rubber-bearing structure at the time of collision. Our tornado protection device has thus been approved for use in nuclear power plants.

As the tornado protection device needs to be removed during the periodic inspection of seawater pumps, both ends of the frame have been designed to be bolted. Because of its large size, skilled techniques are required for accurate on-site installation of the device in accordance with the bolt-hole arrangements. However, we successfully completed the work by conducting fine-tuned positioning for installation during the temporary assembly of factory production, in which our extensive experience in installing large steel structures worked to the best advantage.

MHI continues helping to restart more nuclear power plants by implementing plant safety measures and protections, which will lead us to meet the needs for electricity.

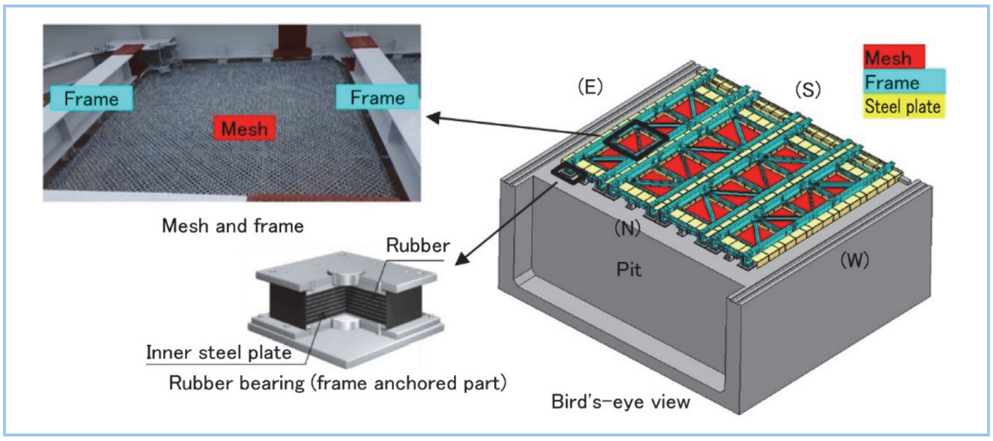

Figure 4 Structure of our tornado protection device for seawater pump area

2.4 High-performance volcanic ash filtration system

MHI has engaged in testing, verification, design and installation of high-performance volcanic ash filtration systems to emergency generator (hereinafter referred to as EDG) of all the restarted PWR plants, as well as the provision of support for the plant restart review by the Nuclear Regulation Authority (hereinafter referred to as NRA). As described above, based on our experience and proven record in supporting PWR plants restart in this matter, we are now helping BWR plants with their EDGs for restart. This report introduces the high-performance volcanic ash filtration system whose adoption in BWR plants is waiting to be approved.

As a correspondence to the natural phenomenon by the new regulation standard, the regulation requirement of the volcanic ash concentration which must be considered in the equipment design was greatly strengthened (the volcanic ash weight per unit volume (g/m^3) increased by three orders of magnitude from the conventional one). In order to maintain the function of EDG under the condition of high concentration volcanic ash, the loss of emergency power source by the intrusion of fallen volcanic ash into the engine of EDG and the induction of failure became a problem. As a solution, we developed a long-lasting high-performance volcanic ash filtration system and installed it in the EDG intake line. In developing this filtration system, actual volcanic ash was blended to imitate the properties of volcanic ash of each PWR plant (e.g., particle size distribution, and concentration), and we conducted a filter test at our laboratory to confirm its long-lasting serviceability with these test ashes. It has also been verified that the clogged filter can be easily cleaned for reuse.

Figure 5 gives a schematic diagram of the system. The EDG intake is not normally equipped with the high-performance volcanic ash filtration system for the sake of preventing airborne dust deposition and degradation over time. The system is to be installed promptly after a volcanic ash alert is issued by the Japan Meteorological Agency, before high concentrations of volcanic ash reach the plant's premises. Two types of filters (that is, filter attachment and filter container) were prepared to facilitate the installation of filters at the EDG intake. Considering the usability by the plant operator, we have determined how small the high-performance filtration system should be. The result is a system with the best portability in terms of size and weight, without causing any problems during installation or filter replacement.

EDG needs to remain operable until the nuclear power plant is safely shut down after a volcanic ash alert is issued. However, as the conventional filtration system collects volcanic ash inside the filter, large ash falls may soon cause clogging. We have therefore employed a metal mesh filter, which can repel volcanic ash and is less susceptible to clogging. As a feature of the high performance volcanic ash filter, the surface area is increased by the pleated shape of metal mesh woven with fine drawn wire. Even if clogging does occur, metal meshes are easy to clean by shaking off or simple air blowing and can be reused.

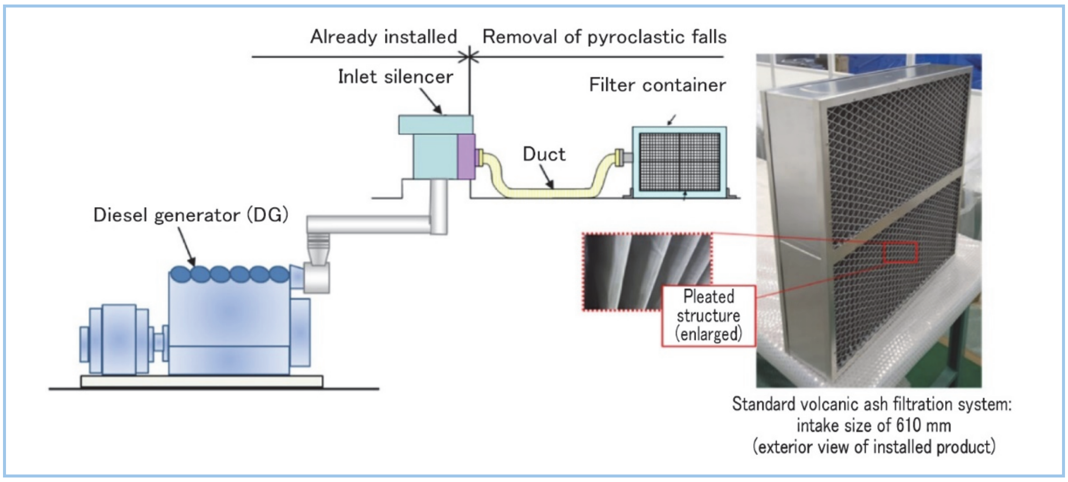

Figure 5 Overview of high-performance volcanic ash filtration system

In BWR plants, air intake for both EDG and building air conditioning is through the same line, as shown in **Figure 6**. Therefore, some plants need to treat a large volume of air (i.e., collection of volcanic ash). In such plants, a fiber mesh filter (bag filter) is already installed in the air inlet for building air conditioning (and EDC) to remove dust and other foreign matter. However, if volcanic ash enters in large quantities, the collected amount will soon exceed the filter capacity. The weight of the collected volcanic ash may damage the fiber filter. We therefore investigated out a new method in which volcanic ash is collected according to the particle size, and as a result, we established a system able to operate in the volcanic ash fall environment particular to BWR plants. Specifically, this system has a hybrid configuration of the high-performance volcanic ash filter and the already-installed fiber mesh filter (bag filter). The former collects large ash particles, which account for most of the weight of volcanic ash, while the latter, which is positioned downstream of the former, traps small ash particles. We will further work on the high-performance volcanic ash filtration system for its more flexible applications to various facilities and structures of BWR plants, such as the development and installation of volcanic ash filter attachments for movable generator carriers.

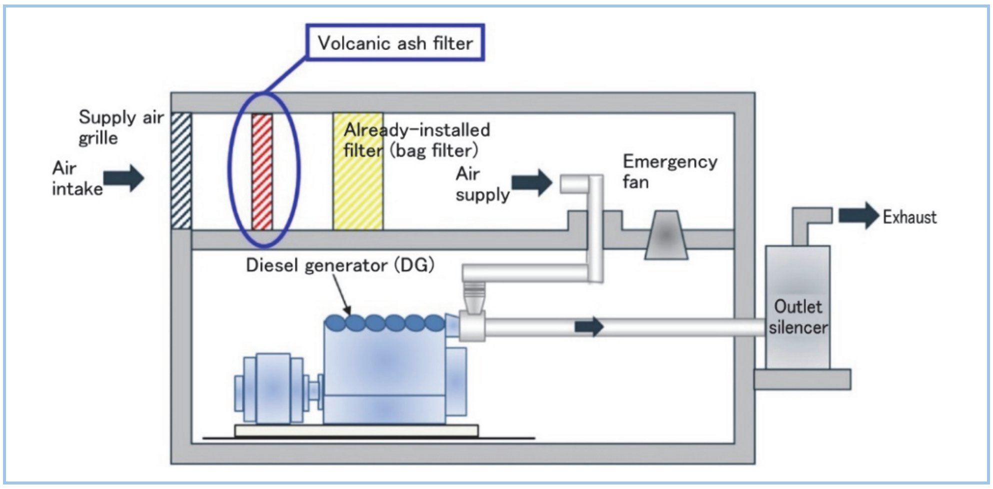

Figure 6 Bird's-eye view of BWR building

2.5 Air-cooled power supply system

The new regulatory requirements necessitate making diverse and independent (decentralized) backup power supplies available, in addition to the conventional emergency power supply systems in nuclear power plants. We have therefore developed an emergency power supply that adopts an air-cooling system, which is different from the conventional DGs of nuclear power plants. The system does not require a seawater cooling system and can be installed on a hill high enough to remain unaffected by tsunamis.

In supporting the restart of PWRs, we have newly designed and produced the onboard/stationary air-cooled DG and gas turbine generator (hereinafter referred to as GTG), whose earthquake resistance and reliability were verified as suitable for use in nuclear power plants before the approval by NRA was obtained. Further expansion of the power supply system line-up and provision of support for BWRs based on these experience are ongoing. This report summarizes MHI's air-cooled backup power supply system.

The air-cooled DG is a power generation system in which the engine, generator and auxiliary equipment are air-cooled by a large radiator. Although the capacity as a power source is smaller than the already-installed water-cooled DG, the air-cooled DG can also serve as a movable power supply system in the event of an accident by making its packaged unit transportable by trailer truck (**Figure 7**). This air-cooling system can be placed anywhere, in contrast to the existing water-cooled DG whose place of installation is limited because of the use of seawater as a coolant. The earthquake resistance specified by the new regulatory requirements is unprecedentedly high when compared with the general performance of trailer truck onboard equipment. Therefore, MHI carried out a seismic test including the trailer truck equipped with DG. The following test-operation of the trailer truck and DG confirmed their unaffected functionality, thereby demonstrating sufficient earthquake resistance. After the verification, a total of more than 50 units of the air-cooled DGs (either onboard or stationary) have been delivered to PWR plants. Over 10 units will be delivered to BWR plants as well.

The air-cooled GTG is a power generation system in which the equipment is air-cooled while air is taken in the enclosure for both combustion and cooling purposes (**Figure 8**). Operating on a different internal-combustion engine principle from the water-cooled DG and having an air-cooling system, the air-cooled GTG is advantageous in terms of system diversity because it prevents the entire plant from crippling if one mechanism fails. Although the introduction of GTG to nuclear power plants involves verifying the satisfactory earthquake resistance based on the new regulatory requirements, an assessment method has yet to be established as none of the GTGs across the world have been tested to verify the earthquake resistance for use in nuclear power plants. Then we used the finite element method (FEM) for analysis, by which GTG behavior during an earthquake was reproduced to confirm the health of the major engine parts such as the turbine rotor. Moreover, the reliability test based on the U.S. standard criteria IEEE-387 for DGs was conducted using an actual unit to demonstrate the robust operational functionality. The outcome is the approval by NRA. We have delivered 14 units to PWR plants and 3 units to BWR plants. More units will be delivered to

BWR plants.

Figure 7 Structure of onboard air-cooled DG

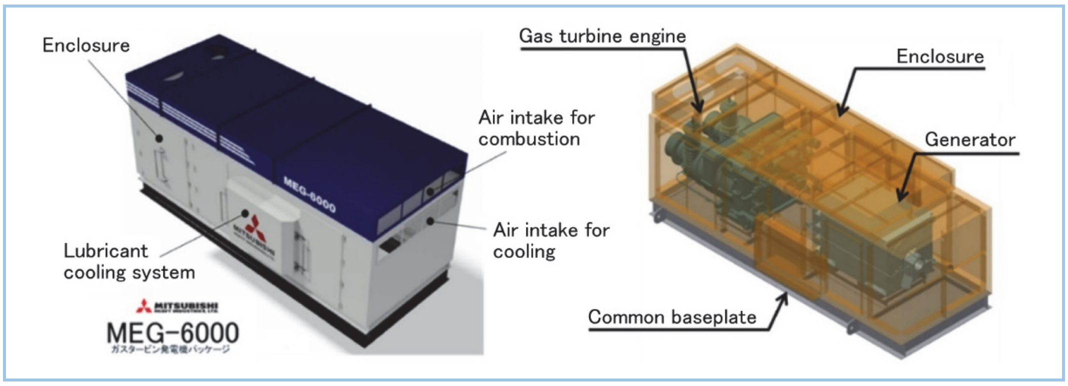

Figure 8 Structure of air-cooled GTG

While enhancing the reliability of backup power supplies through producing and delivering the generator systems compliant with the new regulatory requirements, MHI takes advantage of its rich line-up of power supply systems including the air-cooled DG/GTG and develops a system design adaptable to various plant specifications whether it be PWR or BWR, to meet the needs for electricity. In this way, we continue helping to restart more nuclear power plants.

3. Conclusion

MHI has contributed to the restart realization of 12 PWR plants by the sure execution of the safety measures construction after the Fukushima Daiichi Accident. Based on our holistic capabilities and knowledge acquired through past restart projects, we are now helping with BWR plants for their restarting and installation of specialized safety facilities. Through the continued provision of solid support for BWR plants in this matter, MHI helps to further restore public confidence in nuclear power generation and realize safe and stable operation of nuclear power plants (both PWR and BWR) with the aim of achieving a 20-22% share of Japan's energy mix with nuclear power, which is considered as a precondition for a 46% reduction in greenhouse gas emissions by 2030.