Lessons Learned from Fukushima Daiichi Nuclear Power Station Accident and Consequent Safety Improvements

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OVERVIEW: In March 2011, an accident occurred at the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Co., Inc. in Japan. The accident came at a time when international demand for the construction of nuclear power plants appeared to be growing against a background of concerns about the security of fossil fuel supplies, which include oil and coal, and because of nuclear power's effectiveness as a means for countering global warming. While reactions to the accident in nuclear power markets outside Japan varied from country to country, many countries in regions such as Asia and the Middle East, where there are plans to construct new plants, have announced their intention to continue with policies that promote nuclear power, with the provision that necessary countermeasures will be adopted based on a close investigation of what happened at Fukushima. Hitachi intends to contribute to safer and more reliable plant operation and construction by incorporating the lessons learned from the accident at the Fukushima Daiichi Nuclear Power Station into its nearly 40 years of experience in the construction of nuclear power plants so that it can supply ABWRs with even higher levels of safety, and also to consider how these lessons can be applied in existing plants.

INTRODUCTION

THE Great East Japan Earthquake that struck in March 2011 and the resulting accident at Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Co., Inc. brought enormous damage to Japan.

Fully recognizing the seriousness of this accident, Hitachi has been cooperating wholeheartedly in the recovery and reconstruction of the affected regions and Fukushima Daiichi Nuclear Power Station, while also working to restore faith in nuclear power generation.

Over the nearly 40 years since it participated in the construction of Japan's first boiling water reactor (BWR), Hitachi has been striving to improve their reliability, safety, and economics. During that time, Hitachi has been involved in the construction of more than 20 such reactors. Hitachi has also been involved in the joint development of the advanced boiling water reactor (ABWR) in collaboration with power companies that operate BWRs, General Electric Company, and Toshiba Corporation. The ABWR is a generation III+ reactor design (as defined by the U.S. Department of Energy), and is the only reactor of this generation to be in actual use. Hitachi was involved in the construction of all four ABWRs currently in commercial operation and is responsible for major components in ABWRs currently being built. Also, in July 2011, Hitachi was selected as a strategic investor (SI) in the Visaginas Nuclear Power Plant Project in the Republic of Lithuania, and is currently proposing an ABWR design with enhanced safety, including measures adopted in response to the accident at Fukushima Daiichi Nuclear Power Station.

This article gives an overview of the basic strategy for enhancements to safety based on the lessons learned from the accident at Fukushima Daiichi Nuclear Power Station, summarizes the specific equipment countermeasures applicable to the ABWR, and describes policies for the deployment of safety enhancements at existing plants in Japan.

LESSONS LEARNED FROM FUKUSHIMA DAIICHI NUCLEAR POWER STATION ACCIDENT

This section reviews the situation at the Fukushima Daiichi Nuclear Power Station following the accident and describes the lessons learned.

Situation at Plant after Fukushima Daiichi Nuclear Power Station Accident

Responding to seismic acceleration, Fukushima Daiichi Nuclear Power Station went into automatic shutdown (a large scram) at approximately 2:46 PM on March 11, 2011. With external power having been lost due to the earthquake, the backup diesel generators

(DGs) started automatically to provide emergency power. Subsequently, at approximately 3:35 PM, the power station was struck by the tsunami, resulting in the inundation of water supply equipment, including the emergency seawater system, and the flooding of the yards around the buildings. Water also entered the buildings causing some basement equipment to become submerged.

This unavailability of the emergency seawater system left the plant without any way of shedding heat, a situation called “loss of ultimate heat sink” (LUHS). The loss of the emergency seawater system also prevented the backup diesel generators from running and caused a “station blackout” (SBO) in which all alternating current (AC) power was lost. The inundation of the building also left some switchboards out of action, including a loss of direct current (DC) power due to the resulting unavailability of DC power infrastructure. This loss of control power and plant status monitoring functions greatly impeded the plant’s management of the accident.

Fig. 1 shows the sequence of events during the Fukushima Daiichi Nuclear Power Station accident (using the example of Unit 1), and their relationships to the lessons learned.

Lessons from Accident[2]

This section describes seven lessons learned from an analysis of the sequence of events during the accident at the Fukushima Daiichi Nuclear Power Station, using Unit 1 as an example. Although the sequences of events at Units 2 and 3 were different, the lessons are believed to be the same.

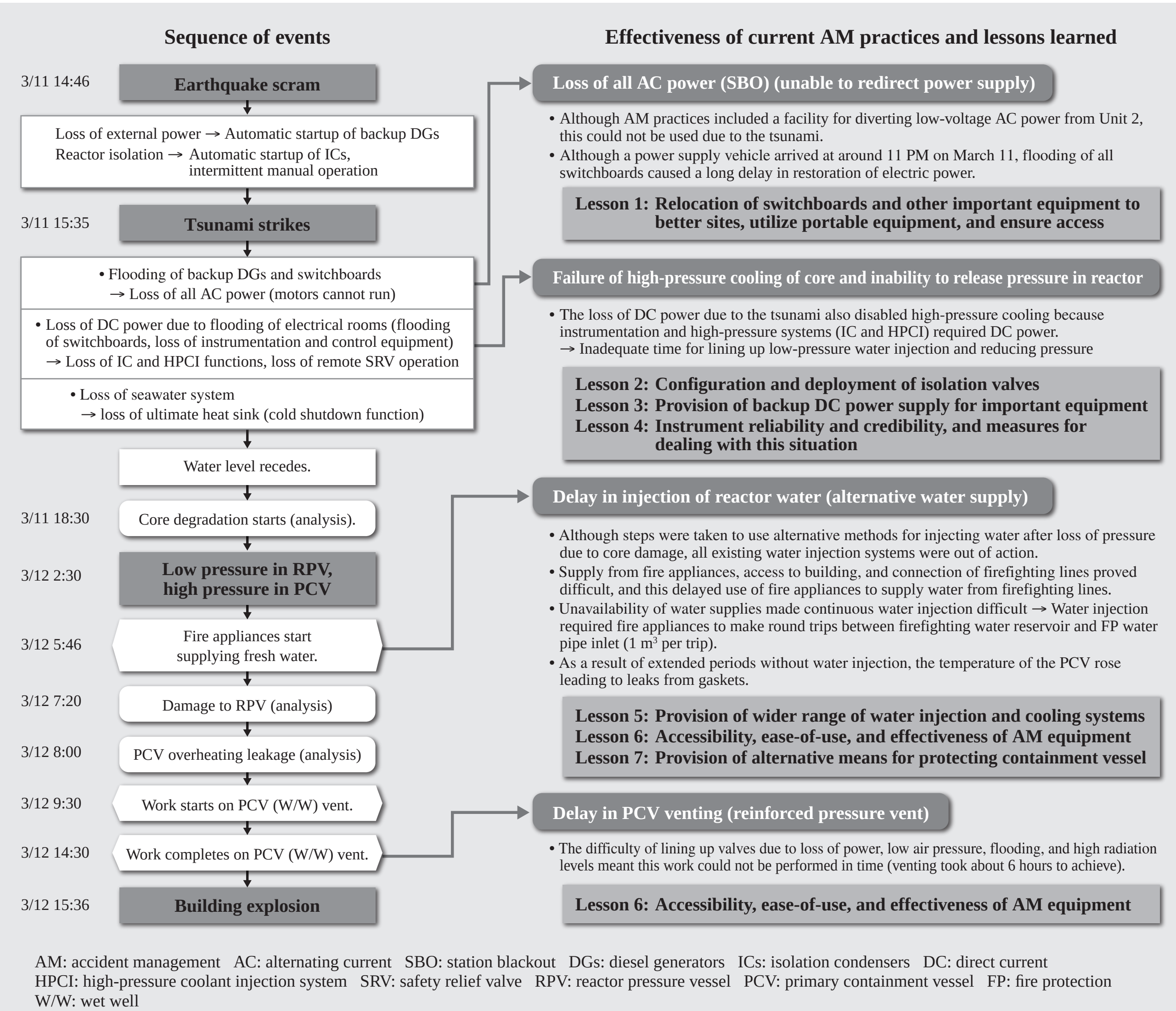

Fig. 1—Sequence of Events and Lessons Learned from Effectiveness of Current AM Equipment[1].
The figure shows how the lessons learned relate to the functional status of the current AM equipment during the sequence of events at the Fukushima Daiichi Nuclear Power Station (using the example of Unit 1).

Lesson 1: Relocation of switchboards and other important equipment to better sites, utilize portable equipment, and ensure access

Waterproofing important equipment and installing it at as elevated a location as possible is an effective countermeasure against tsunamis. However, given that the large impact force of water and the presence of air inlets and outlets make it difficult to provide full protection, provide attachments for the emergency connection of portable equipment and have heavy machinery available for establishing access routes.

Lesson 2: Configuration and deployment of isolation valves

It was reported that isolation valves could not be opened during the accident. While keeping isolation as the top priority, provide ways of opening the most important isolation valves remotely or manually (by locating isolation valves outside the containment vessel and providing backups including for electric power and pneumatics).

Lesson 3: Provision of backup DC power supply for important equipment

Determining the status of plant was made difficult by the loss of instrumentation functions due to the lack of a DC power supply, there was insufficient time to line up the low-pressure water injection system due to the loss of high-pressure functions [isolation condenser (IC) and high-pressure coolant injection system (HPCI)] that require a DC power supply, and reducing pressure via the safety relief valves was delayed. Accordingly, provide portable or backup DC power supplies for this important equipment.

Lesson 4: Instrument reliability and credibility, and measures for dealing with this situation

For those plant monitoring items that are critical to accident management (AM), review the environmental conditions for instruments (considering the harsh conditions that occur during an accident), provide alternative means for verifying the credibility of instrument readings, and provide measures for dealing with the situation when the plant status cannot be monitored due to lack of faith in these readings.

Lesson 5: Provision of wider range of water injection and cooling systems

There is a need for greater diversity in the ways of dealing with a loss of functionality in excess of the design assumptions (including the provision of a long-term water source), including with regard to the response and assistance from off-plant. In addition to providing greater protection through measures such as improving the water tightness of key on-site equipment and building layout, there is a need to ensure the flexibility to deal with a wide range of scenarios though greater diversity, including portable equipment.

Lesson 6: Accessibility, ease-of-use, and effectiveness of AM equipment

In response to problems such as the valves required to operate AM equipment being difficult to approach because they were located close to the containment vessel, and system line up being delayed by the difficulty of connecting external water supply equipment, make improvements to the accessibility, ease-of-use, and other practical aspects of AM equipment.

Lesson 7: Provision of alternative means for protecting containment vessel

It is possible that the interior of the containment vessel overheated due to insufficient core cooling, causing degradation of non-metallic components and the potential release of radioactive material. Accordingly, while keeping core cooling as the top priority, there is a need to protect the containment vessel by cooling it on the inside and by providing cooling from outside the containment vessel.

BASIC STRATEGY FOR SAFETY MEASURES

A review of experience from the accident at Fukushima Daiichi Nuclear Power Station and the lessons learned indicates that there is a need to consider the potential for site-wide damage that exceeds equipment operating conditions as a result of wide-scale external events such as earthquakes and tsunamis. This means that flexible equipment is important for dealing with situations that exceed assumptions, while also reviewing protective equipment based on specified design standards, and there is a need to consider factors such as access to ensure the practicality of this equipment. The following section describes the basic strategy for safety measures based on the above considerations.

The first is to protect important safety equipment from design loads caused by external events. Examples include embankments, measures for making buildings watertight, and relocation of equipment for dealing with a complete loss of AC power.

The second is the use of portable equipment in the event that the protection for safety equipment fails, and the preparation of flexible responses (responses to external events that exceed design conditions). Improving the durability of the containment vessel with respect to leaks of radioactive material is also important.

The third is to provide measures based on the use of flexible and portable equipment and to make response procedures as simple as possible to ensure that coordination can proceed smoothly in the event of a major external event leading to major damage across the entire site and a need for off-site assistance.

OVERVIEW OF SAFETY EQUIPMENT

Overview of ABWR Safety Equipment

Nuclear power plants are built on the principle of defense in depth with designs that ensure safety through redundancy and diverse methods. Design of safety equipment establishes design conditions with enough of a safety margin to deal with a wide range of different accident scenarios, and then designs equipment that can function reliably under these conditions. In addition, to reduce risk and deal with events that fall outside the accident scenarios considered in the design, AM equipment is provided to manage operations such as the use of equipment other than safety equipment to inject water into the reactor or remove the heat generated in the reactor. Fig. 2 shows stochastic assessments of the safety with respect to on-site accidents of typical light water reactors and third-generation reactors, including the ABWR. The graph shows the ABWR as having the world's highest level of safety.

BWRs have a simple direct-cycle configuration in which the generated steam is supplied to the turbine directly. The ABWR, which was developed primarily in Japan and the USA, represents the culmination of this type of reactor. This use of a direct-cycle configuration allows highly efficient generation of electric power at a low operating pressure. Specifically, the operating pressure of the reactor is less than half that of a pressurized water reactor (PWR), another type of light water reactor. The features of the BWR power generation system are utilized in the design of the safety equipment. That is, because the BWR uses direct-cycle operation at low pressure, it is easy to inject water directly into the reactor, and therefore the basic approach to achieving safety is to provide a number of different alternative methods for water injection.

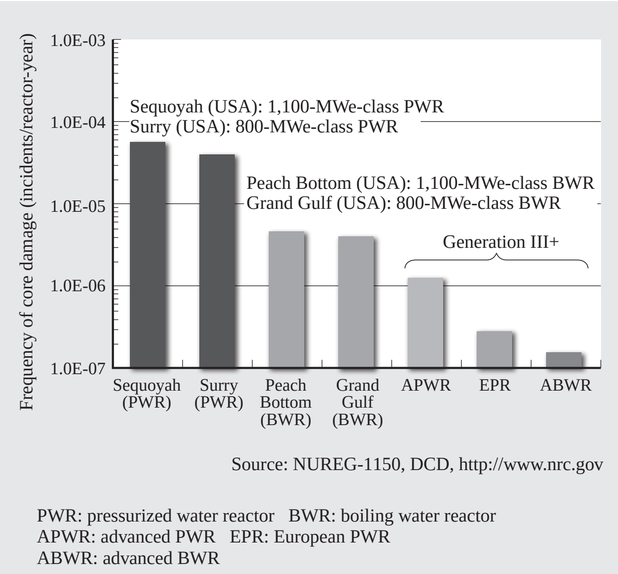

Fig. 2—Comparative Safety Assessments of ABWR and Other Light Water Reactors from Around the World.
The graph shows stochastic assessments of safety with respect to on-site accidents of example light water reactors (BWRs and PWRs) and of ABWRs and other third-generation reactors.

The section below describes specific equipment-related responses. Based on the basic strategy for safety measures described above, these responses are built on safety policies that take advantage of the features of the BWR. In this case, the explanation focuses on measures that relate to the second of the basic strategies, which affects power plant equipment.

(1) Because of the likelihood of confusion in the initial response to major external events, depending on the level of damage, it was decided to make available portable equipment as a way of providing more options for injecting water into the core. This is a simple measure that takes advantage of the features of BWRs. Because this is a simple strategy, it should also be an effective way of cooperating with off-site assistance teams during times of confusion, as described for the third of the basic strategies for safety measures.

(2) Connections from the outside and on-site operations performed in close proximity are important considerations when using portable equipment. Accordingly, the installation of a number of external connection points at different locations was considered to ensure flexibility.

(3) In addition to adding alternative ways to inject water into the containment vessel, a facility for injecting water to the top head of the containment vessel was fitted to improve the durability of the vessel's non-metallic components.

(4) Also under study in addition to the above measures is the concept of a backup building equipped with an alternative power supply and a reactor water injection function for use in events that are bigger than expected. The concept involves a facility, located separately from the reactor building, that is kept sealed off during routine operation and only opened at times of emergency so that the facilities it provides will be able to function during events that are bigger than expected. Locating the in-place water injection equipment away from the reactor building allows water injection to be performed quickly. It should also be useful for functions such as providing

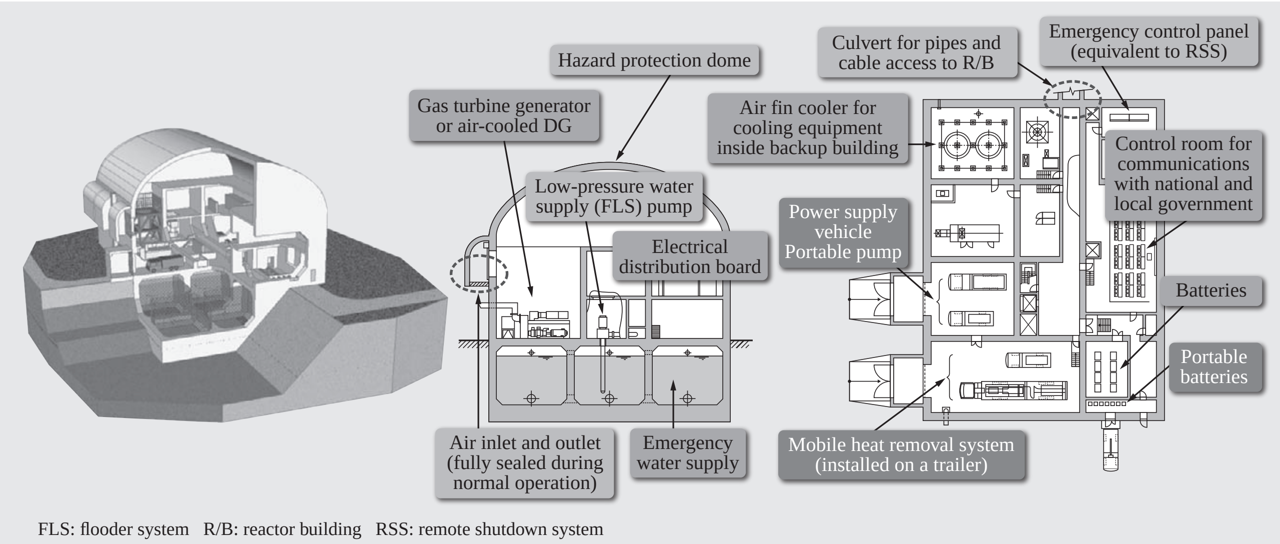

Fig. 3—Sketch of Backup Building and Concept behind Alternative Power Supply and Reactor Water Injection Function.
Hitachi has developed the concept of a backup building to provide power, portable equipment, and other resources, maintaining equipment functions in case of large external hazards so that water can be injected into the core quickly from a separately located building.

a frontline base during emergencies or a storage facility for AM spare parts and other material. Fig. 3 shows an outline of this facility and Fig. 4 shows an overview of the ABWR safety equipment.

Strategy for Deployment of Safety Measures to Existing Plants in Japan

In July 2011, the Nuclear and Industrial Safety Agency instructed electric power companies to

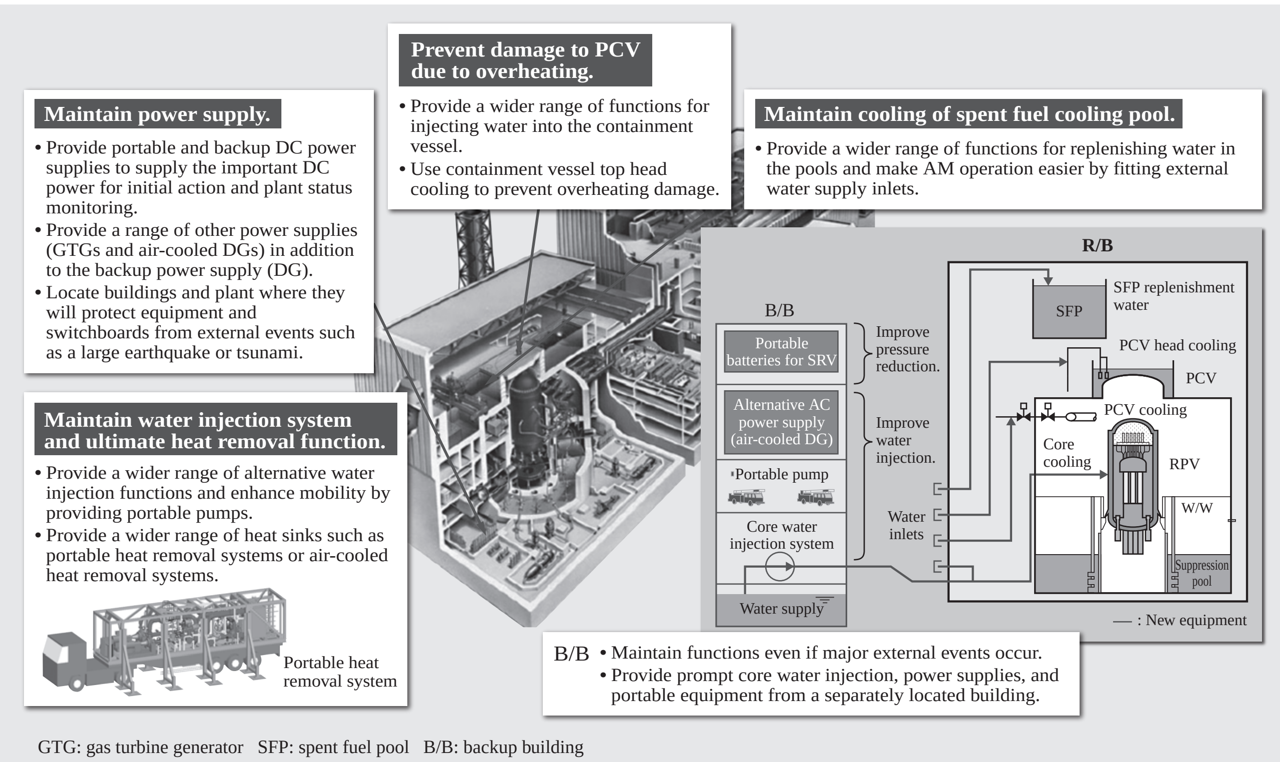

Fig. 4—Overview of ABWR Safety Equipment.
Based on experience from the accident at Fukushima Daiichi Nuclear Power Station and the lessons learned, important safety equipment is protected from the impact of wide-scale external events such as earthquakes and tsunamis, and safety equipment is built that allows flexible measures to be taken, using portable equipment for example, in the event that this protection fails.

conduct stress tests to comprehensively assess the safety of existing nuclear power facilities in the light of the accident at Fukushima Daiichi Nuclear Power Station. Hitachi's involvement included work on improving the water tightness of pipe entry locations and the earthquake resistance of firefighting water pipes that provide a greater safety margin by offering an alternative method of cooling the reactor, and also "cliff edge" assessments for preventing reactor core damage in the event of an earthquake or tsunami. The purposes of the stress tests were to identify what measures were needed to equip nuclear power plants to cope with events that exceed design assumptions, and to make ongoing improvements. Assessments conducted to date have found the safety measures put in place in response to the recent accident to be effective. Hitachi intends to continue to study and propose measures for further improving safety margins based on a series of assessments.

Meanwhile, the "Technical Findings on the Accident at Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Co., Inc." published by the Nuclear and Industrial Safety Agency in March 2012 identified 30 items to be incorporated into future regulations. The basic safety philosophy is the same as the basic strategy for safety measures described above. Hitachi has presented safety measure concepts that include air-cooled DG systems and portable heat removal systems, and is currently working on specific investigations.

In this way, it is considered to be necessary to provide existing plants in Japan with greater safety margins by formulating and implementing optimal safety margin improvement measures that are based on the basic safety philosophy referred to above and that also take into account the individual circumstances of each plant, to use stress tests and other measures to conduct quantitative assessments of their effectiveness, and to make ongoing improvements to safety margins in the areas identified as requiring measures to be taken. Hitachi intends to continue to make maximum use of its know-how and experience in its ongoing activities.

CONCLUSIONS

This article has given an overview of the basic strategy for enhancements to safety based on the lessons learned from the accident at Fukushima Daiichi Nuclear Power Station, summarized the specific equipment countermeasures applicable to the ABWR, and described policies for the deployment of safety enhancements at existing plants in Japan.

A lesson from the recent accident is that safety improvements must be unremitting. To this end, Hitachi intends not only to draw on the lessons from the accident at Fukushima Daiichi Nuclear Power Station to supply nuclear power plants with further safety improvements, but also to contribute to safer and more reliable plant operation and construction through the deployment of these improvements to existing plants.

REFERENCES

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