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ROOT CAUSES OF THE FUKUSHIMA DAI-ICHI NUCLEAR PLANT ACCIDENCTS AND STUDY OF ITS CLIFF-EDGE

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ABSTRACT: The Fukushima Daiichi Nuclear Power Plant has been stupendously affected by the massive earthquake and tsunami of the Great East Japan Earthquake occurred on March 11, 2011, where the cooling system for reactors and spent fuel storage pools became uncontrollable. As a result, reactor cores were damaged at unit 1-3. Furthermore, the cooling function of the spent fuel storage pools of unit 1-4 were also lost, and some fuels may have been damaged. The “Cliff Edge” factors are DC power loss, the loss of cooling system, and the loss of the ultimate heat sink.

Key Words: Nuclear Power Plant, East Japan earthquake, tsunami engineering, cliff-edge, nuclear safety

INTRODUCTION

Since Japan is a highly earthquake-prone country, many years have been spent considering how to ensure integrity of the nuclear facility against earthquakes, and particularly the maintenance of three reactor safety functions: containing nuclear reaction, assuring cooling of the fuels, and containing radioactive materials. As a result, the methodology for seismic assessment was established and used to create the currently effective codes and standards. Based on these codes and standards, concrete measures have been adopted by all Japanese Nuclear Power Plants. Therefore, the operating units in Fukushima Dai-ichi even after being hit by the Tohoku-Pacific Ocean Earthquake were successfully shut down and maintained cooling until Tsunami came, as designed. This means the safety functions successfully worked and were protected against the earthquake.

The direct causes of the accident at Fukushima Dai-chi Nuclear Power Plant arise from the loss of multiple safety functions of systems/components vital to safety; the quake-hit plant was no longer able to withstand further crisis beyond design basis. The height of tsunami triggered by the Tohoku Pacific Ocean Earthquake yielded no allowance. Why, then, the progress of the event led to a nuclear crisis? Various factors cross our minds, such as the way each cause influenced one another. What can we do to prevent the recurrence of a similar accident? Contemplating when to expect the unimaginable natural disaster leads us to our utmost concern: prevention of a similar accident , with the right focus. The following is a summary of the accident, with the content limited to tsunami-related technical issues. It is based on the extent of disaster damage and handling of the crisis.

NORMAL SHUTDOWN PROCEDURE

Reactor will automatically shut down normally under an earthquake;, the automatic isolation valve containment will close, followed by depressurization and cooling, and flooding of the fuel will be maintained..

In this case, if all of the equipments are operating properly, the reactor will reach a cold shutdown through the following procedure. (reference to Fig.1)

・Reactor cooling water is injected into the reactor by Isolation Cooling (IC) system or Reactor Core Isolation Cooling (RCIC) system, thereby maintaining reactor water level.

・Reactor cooling water is injected into the reactor by Emergency Core Cooling System (ECCS), there by maintaining reactor water level.

・(Ensuring the heat sink) continuing nuclear reactor cooling by (RHR) Residual Heat Removal system.

・If the above-mentioned equipment and /or the system is dysfunctional, alternative water injection measure should be taken to inject water, continue cool down, and maintain stable water level..

There is hardly an alternative for a seawater pump motor lost by the tsunami. The dysfunctional heat removal system impacted greatly on the progress of the accident.. , The core meltdown was due to lack of water required to cool the reactor core, and the water level response to ensure the furnace is important.

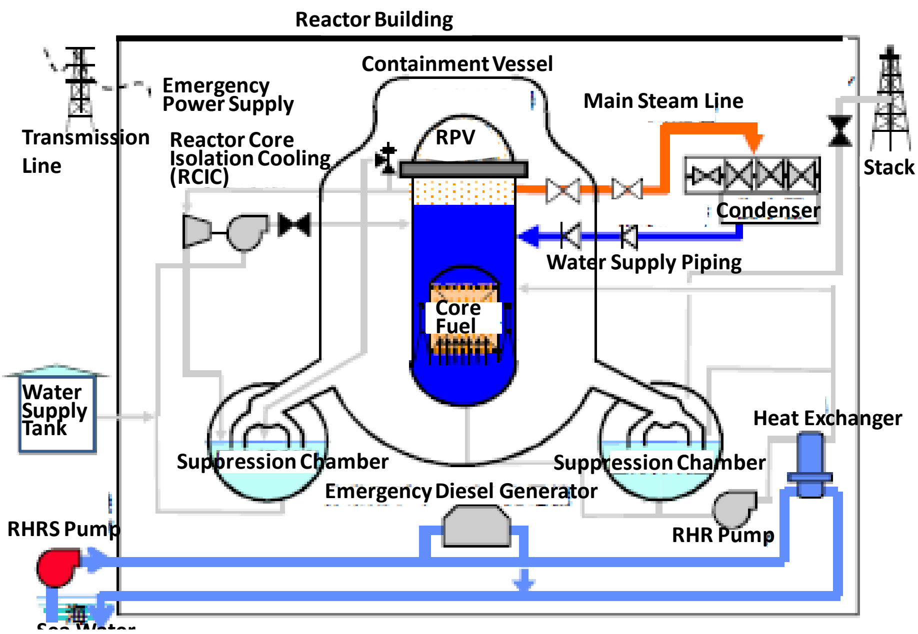

Fig. 1 Nuclear Power Plant System (BWR)

CONSIDERATION OF THE "CLIFF EDGE" FACTOR DETERMINING STABILITY AND ACCIDENT

What factors determine the equipment and/or structure damage – the loss of function or keeping performance - under an earthquake? It is possible to evaluate fragility of the system under hazard situation with this assessment. With the tsunami case, , the equipment is subject to a serious situation as losing all functions under certain conditions, the so-called “Cliff edge” effect - factors which lead to a disastrous accident. Therefore, identifying the “Cliff Edge” factors of the event is very important..

Evaluation of Spacing

As shown below, to evaluate the tsunami reached if the range in power plant has been expanded gradually. In other words, the system lists affected by the tsunami, the equipment, at each stage of the tsunami reached, to assess the extent to which function can be maintained. (reference to Fig.2)
① Assuming the damage of the intake facility with submerged intake facilities.
② Assuming the outdoor installation of equipment damage by power plant site flooding.
③ Assuming equipment damage in the turbine building.
④ Assuming the damage of equipment in the service building auxiliary facilities have been installed.
⑤ Assuming the damage in the reactor building equipment.

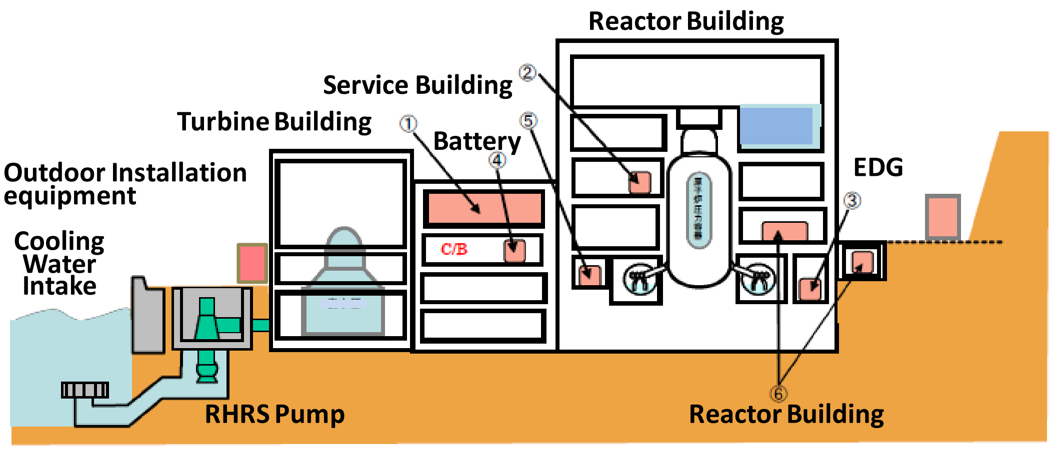

Fig. 2 Evaluation the Elevation of Equipment BWR Nuclear Power Plant System (for example)

Evaluation of Event Sequence

Assessment at each stage of the progress of the sequence of events triggered by large tsunami,
As shown in the following examples, the assessment is conducted step-by-step for the sequence of events triggered by large tsunami. The affected systems and the equipment are listed, and their functions are evaluated in each step.

[BWR] (reference to Fig.3)

a) Step 1: Earthquake occurrence
(The assumed result is a loss of off-site power, **EDG startup**.)
b) Step 2: **Large tsunami event**
(The assumed result is a loss of function for all equipment in the intake, flooding of power supply in the turbine building.)
c) Step 3: **SBO**, which is a loss of off-site power, **EDG operation failure**
(The assumed results is a loss of the cooling systems.)
d) Step 4: **Loss of ultimate heat sink**
(The assumed result is temperature increase of water in the suppression chamber, failure of PCV venting)
e) Step 5: Loss of fresh water source, seawater injection
(The assumed result is **dry out of the reactor/ fuel damaged**)
f) Step 6: Insufficient injection of seawater
(The assumed result is **further fuel damaged**, **hydrogen generation**, and then hydrogen venting for avoiding explosions)

[PWR]

a) Step 1: Earthquake occurrence (The assumed result is a loss of off-site power, EDG startup)
b) Step 2: Large tsunami event (The assumed result is a loss of function of all equipment in the intake,

flooding of power supply in the turbine building)

c) Step 3: SBO, which is a loss of off-site power, EDG startup failure (The assumed result is a loss of the cooling systems/ loss of heat removal by the steam generators.)

d) Step 4: Loss of fresh water source, seawater injection (The assumed result is temperature increase of water in the reactor/fuel damaged.)

e) Step 5: Insufficient injection of seawater (The assumed result is further fuel damaged, hydrogen generation.)

In this assessment, a comparison can be made between the assessment results before and after the countermeasures. This comparison clarifies the effectiveness of these countermeasures.

Fig.3 Progress of Event after SBO at the Seismic and Tsunami-Hit Plants – Cliff Edge Points

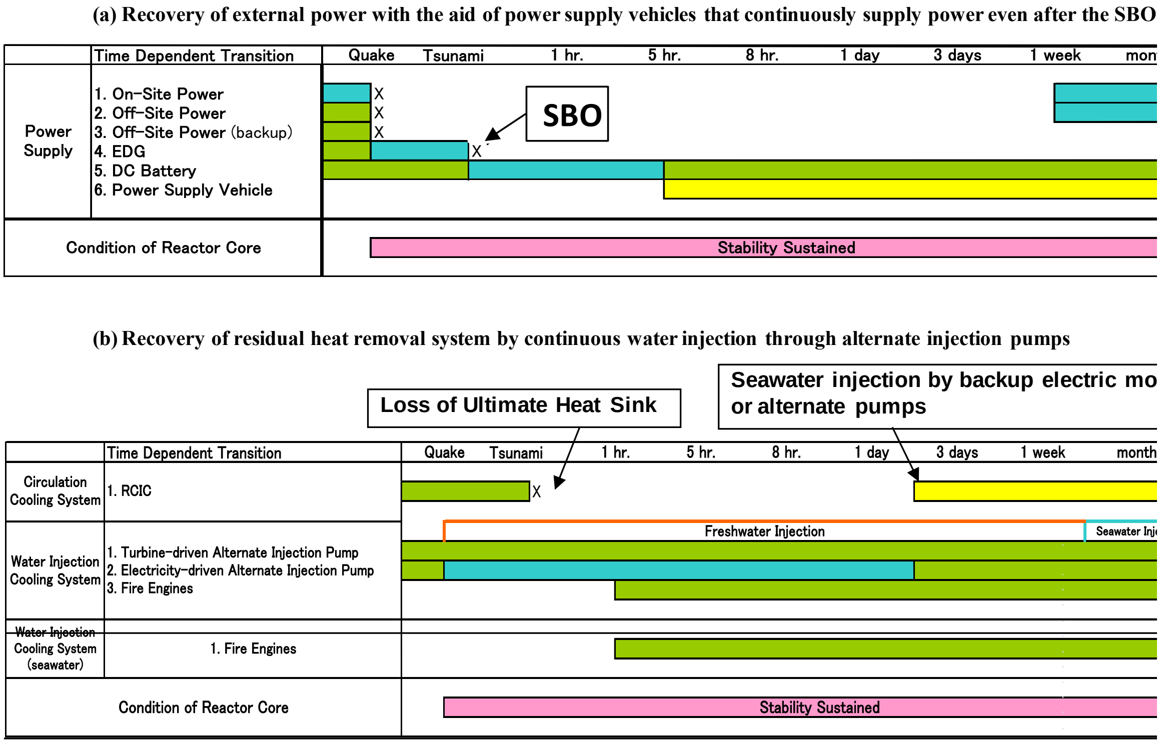

Fig.4 Progress of Event after SBO at the Seismic and Tsunami-Hit Plants (after countermeasure)

Study

In the event of a SBO that does not directly lead to core melt, the loss of DC power supply and EDG are important "Cliff Edge" factors . Depending on external events, "Cliff Edge" effects are important factors and branching points that determine an accident or maintenance of stability. .

Core damage may still be prevented with continuous cooling by power supply vehicles as a countermeasure. On the other hand, even where the power is supplied, the loss of circulating cooling system as the ultimate heat sink would lead to the core damage. Yet, it can be easily prevented by injection of fresh water and sea water by fire engines. This means that the fundamentally important “Cliff-Edge” factors are power loss, the loss of cooling system, and the loss of the ultimate heat sink as shown in Fig.3. Evaluation of these factors and accident countermeasures of the plant may be judgmental criteria for the assessment of the plant’s tolerance against external events, on whether it will remain stable or strained by a crisis, or not. .
By securing the battery, the core cooling system such as IC or RCIC is activated as shown in Fig.4. And then, it is necessary to continue the cooling of the reactor core cooling system by securing on an ongoing basis, an alternative pump or fire-engine. Finally, as the ultimate heat sink, an alternative heat exchanger, filtered venting system, or a portable pump and etc., will be prepared.

CONCLUSIONS

If the Nuclear Power Plant is met by major natural disasters such as the tsunami, in order to ensure safety of nuclear power plants, “Cliff Edge” must be eliminated. There are three magor “Cliff Edge”. One is the DC power loss, one is the loss of cooling system, and the other is the loss of the ultimate heat sink.

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