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SEVERE ACCIDENT ISSUES RAISED BY THE FUKUSHIMA ACCIDENT AND IMPROVEMENTS SUGGESTED

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This paper revisits the Fukushima accident to draw lessons in the aspect of nuclear safety considering the fact that the Fukushima accident resulted in core damage for three nuclear power plants simultaneously and that there is a high possibility of a failure of the integrity of reactor vessel and primary containment vessel.

A brief review on the accident progression at Fukushima nuclear power plants is discussed to highlight the nature and characteristic of the event. As the severe accident management measures at the Fukushima Daiich nuclear power plants seem to be not fully effective, limitations of current severe accident management strategy are discussed to identify the areas for the potential improvements including core cooling strategy, containment venting, hydrogen control, depressurization of primary system, and proper indication of event progression. The gap between the Fukushima accident event progression and current understanding of severe accident phenomenology including the core damage, reactor vessel failure, containment failure, and hydrogen explosion are discussed.

Adequacy of current safety goals are also discussed in view of the socio-economic impact of the Fukushima accident. As a conclusion, it is suggested that an investigation on a coherent integrated safety principle for the severe accident and development of innovative mitigation features is necessary for robust and resilient nuclear power system.

KEYWORDS : Fukushima Accident, Severe Accident, Severe Accident Management, Severe Accident Phenomenology, Boling Water Reactor

1. NATURE OF THE FUKUSHIMA ACCIDENT

The accidents at Fukushima Daiichi nuclear power plants are striking as they not only resulted in simultaneous core damage in multiple units, but also there was a high possibility of failure of the reactor vessels and primary containment vessels in all three reactors. Though the radiological release is estimated to be about 10% of the Chernobyl accident [1, 2], the severity of the accident in terms of scale and number of units involved is unprecedented. The accident was classified as International Nuclear Events Scale (INES) level 7 accident [1].

The accident progression, including the cause of the accident, the response of the reactor and safety system, recovery actions, and core damage progression leading to a release of radioactive material, were investigated and reported by the Japanese Government [1], TEPCO [2] and international experts [3]. However, the status of the damaged reactor vessel, and damage to the primary containment vessel are still under investigation.

Though the occurrence of severe accidents were evidenced in the Three Mile Island (TMI) and Chernobyl accident, the measures for the prevention and mitigation of a severe accident were not strictly regulated. In most countries, severe accident prevention and mitigation measures were recommended only for new builds, as voluntary actions to enhance the safety, while provision of severe accident management guidelines were recommended for operating reactors. It is stated in reference 1 that “While the Japanese National Government recognized that further safety regulations were unnecessary as the safety of nuclear power plant in Japan was fully ensured by the present safety measures, it recommended that electric utilities should perform self-disciplined safety efforts in order to reduce a risk of accident and to further enhance safety.”

The severe accidents at Fukushima Daiichi nuclear power plants happened unexpectedly. The event occurred due to a combination of an earthquake and tsunami in an unprecedented scale. The question is “Was it possible to predict and be prepared for this kind of accident?” Certainly, it seems to not be.

Though external events are considered in the design of the nuclear power plant, as recommended in safety guide IAEA-NS-G-1.5 [4], the Fukushima accident suggests that the very low probability of extreme external events can be overlooked, which can lead to catastrophic consequences. Different perspectives of external hazards, such as an impact of simultaneous occurrence of external events, the need for the provision of a long term electricity backup capacity, and a potential impact of terror, have to be investigated. The Fukushima accident is like a “Black Swan” [5], as it lay outside the realm of regular expectations. It came with catastrophic consequences and we were able to explain it only after the fact. Therefore, it might be wise to focus on how we can be prepared for this kind of severe accident in the future, rather than focus on the reasons for this particular accident happening.

The nuclear industry tended to be confident that nuclear power plants were safe, and there was very little chance of severe accidents like TMI or Chernobyl. This overconfidence could be one of the reasons why we were not able to predict the Fukushima accident, and why the defense-in-depth implemented, including the support system and emergency preparedness in the plant, was not robust enough to avoid the substantial release of radioactive material.

The nature of a low probability severe accident has often led to quite different views for the implementation of preventive and mitigation features among countries. The range of views has been wide, between pessimistic and optimistic. The gap should be narrowed to be properly prepared for the highly improbable event of a severe accident .

2. ACCIDENT PROGRESSION AT FUKUSHIMA DAIICH NUCLEAR POWER PLANTS

This section provides an overview of the chronology from the occurrence of the accident to the emergency measures taken at Fukushima Daiichi Nuclear Power station. In addition, highlights of the event progression, including plant response, operator recovery and unresolved issues, are discussed.

2.1 Plant Configuration and Event Progression for Each Unit

The event progression and plant specification discussed here are excerpts taken from Reference 1, 2 and 3. Major design parameters for the Fukushima Daiichi Units 1 through 4 are summarized in Table 1.

The earthquake which occurred at 14:46 on March 11, 2011 brought Fukushima Daiichi Units 1 through 3, which were in operation, to a reactor trip, due to the high earthquake acceleration. Unit 4 was under outage for periodic inspection when the earthquake occurred. All fuel had been removed from the reactor and transferred to the Spent Fuel Pool (SFP). Units 5 and 6 were under outage for periodic inspection, with all fuel in the reactors and all control rods inserted.

After the automatic shutdown of the reactors, the station power supply was switched to offsite power. However, the power plants were unable to receive electricity from the offsite power transmission lines, because some of the transmission towers had collapsed due to the earthquake. For this reason, the emergency Diesel Generators (DGs) for each Unit were automatically started to maintain cooling of the reactors and the spent fuel pools.

Later, all the emergency DGs, except at Unit 6, stopped, because their seawater cooling systems and metal-clad switchgears were submerged due to the tsunami that followed the earthquake. The result was that all AC power

Table 1. Major Design Parameters of Fukushima Daiichi Units 1 through 4

	Unit 1	Unit 2	Unit 3	Unit 4
Commercial Operation	1971	1974	1976	1978
Reactor Design	BWR-3	BWR-4	BWR-4	BWR-4
Rated Power (MWe)	460	784	784	784
Thermal Power (MWt)	1,380	2,381	2,381	2,381
Isolation Cooling System	IC	RCIC	RCIC	RCIC
ECCS Configuration	HPCI (1) ADS CS (4)	HPCI (1) ADS CS (2) LPCI (2)	HPCI (1) ADS CS (2) LPCI (2)	HPCI (1) ADS CS (2) LPCI (2)
Primary Containment Vessel	Mark-I	Mark-I	Mark-I	Mark-I

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