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Fukushima NPP Severe Accident Technical Lessons Learned And Somesafetymeasures For The Future

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ABSTRACT: *The accident at the Fukushima-Daichii nuclear plant has generated worldwide debates and deeply raised public concern about the safety of nuclear power plants. The lessons to be drawn from the Fukushima accident are as follows. First, the accident was a result of the worst earthquake and tsunami in Japan's modern history Second, given the extraordinary magnitude of the initiating events (i.e. earthquake was 9.0 vs design 8.2, tsunami wave was 14 m vs design 5.7 m), the Fukushima-Daichii plant has performed relatively well in some respects and so far there is no evidence of major human errors in handling the crisis. It is noted that the containments at Units 1 and 3 have not failed, in spite of the exceptional loads they have been subject to. In fact, no loss of life has occurred as a result of the accident. The Fukushima accident has been rated at the maximum level (Level 7) on the IAEA International Nuclear Event Scale, indicating an accident with large release of radioactivity accompanied by widespread health and environmental effects. It is important to analyze the technical lessons that can be learned from Fukushima, so that the safety of nuclear plants can be further enhanced and the attractiveness of nuclear energy sustained over the long term. An initial attempt to identify the key lessons from the Fukushima accident is presented*

KEYWORDS: *Accident/ Fukushima / Lessons / Earthquake/ Tsunami.*

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I. INTRODUCTION

No doubt that the severe accident at Fukushima Daiichi Nuclear Power Station, triggered by the natural disaster on March 11, 2011, taught Japan and the world many important lessons on nuclear safety and regulatory issues among other things, the issue of the national regulatory frameworks and the national regulatory authorities.Theselessonshave opened many more issues to be learned, especially in newcomer countries embarking on new nuclear power programmers for electricity generation. Following this accident, many regulatory bodies all over the world carried out a complete and intensive review of safety guidelines and regulatory requirements with the aim of formulating a set of new regulations to protect people and the environment. Themain objective of this paper is to highlight the lessons learned to datefrom the Fukushima Daiichi accident that are relevant to strengthening theeffectiveness of national regulatory bodies. Thepaper is focusing and spot lights on the processes and activities undertaken in Egypt for strengthening the nuclear and radiological regulatory effectiveness in the light of thelessons learned from the accident at the Fukushima Daiichi NPP.Among other Arab countries, Egypt is considered as a newcomer country planning to introduce NPPs for electricity generation. One of the apparent actions taken in Egypt,to improve its nuclear safety management and regulatory system, is the activation and re-organizing its newly developed and independent nuclear regulatory body, the Egyptian Nuclear and Radiological Regulation Authority (ENRRA), which is assigned directly to the prime minister[1]. By the end of the year 2011, the executive regulatory requirements for nuclear and radiological activities got into force to direct the processes of learning and acting upon lessons to strengthen nuclear safety, emergency preparedness and radiation protection of people and the environment in Egypt. A complete reorganizing process for ENNRA has been initiated by the separation between the research and the regulatory sectors. Additional activation processes have been achieved to strengthen the practical capabilities of the regulatory sector with emphasis on human resources capacity building, accident management, and on-site and off-site emergency management. Review and assessment as well as regulatory inspection committees in the ENRRA have been activated for the enforcement processes regarding research reactors, fuel manufacturing pilot plant and other radiological activities in the country to update and improve their safety requirements, guides and emergency plans according to the lessons learned after Fukushima accident.

II. OBJECTIVES

This paper presents the implications of Fukushima-Daichii nuclear plant accident for the nuclear industry. This purpose is twofold: we identify and discuss technical issues arising from the accident; and we begin a review of how the lessons learned can be used to improve the safety of current and future plants. The information is organized in six sections: “Emergency Power following Beyond-Design-Basis External Events”,

“Emergency Response to Beyond-Design-Basis External Events”, “Containment”, “Hydrogen Management”, “Spent Fuel Pools”, “Plant Sitting and Site Layout”. For each area, we present key issues observed at Fukushima and corrective actions that should be evaluated for implementation in current and future plants.

III. EMERGENCY POWER FOLLOWING BEYONDDESIGN BASIS EXTERNAL EVENTSOBSERVATIONS FROM FUKUSHIMA[2]

The loss of offsite power (due to the earthquake) and onsite AC power (due to the tsunami),combined with the rapid discharge of the DC batteries led to a complete station blackout,which in turn led to fuel overheating and damage. Here a key question is arising: How can the station blackout scenario be either prevented or sufficiently mitigated to ensureminimal consequences?

3.1 Possible Corrective Actions for Current Plants [3]

The diesel generators, their fuel, and related switch gear could be housed in rooms atsufficiently high elevation and/or in water-proof rooms to preserve onsite AC power in caseof tsunamis or floods. Note, however, that seismically-induced stresses increase withelevation. Interestingly, due to the concern over typhoons and storm surges, all of theemergency power generation capacity at Korean plants is currently located in water-proofenclosures, including fuel supplies.Utilities and/or FEMA (Federal Emergency Management Agency) could maintain transportable diesel generators or gas-turbinegenerators (i.e. jet engines) that would be rapidly brought to the site (e.g. by air, road orwater) to restore AC power.

3.2 Possible Design Improvements in Future Plants[4]

A mix of passive and active safety systems may be desirable to defeat the station blackoutscenario without relying on external intervention. The right mix should be determinedthrough analysis including risk assessment, taking into account also the possible failuremodes of the passive systems upon occurrence of the initiating external event. A keyquestion here is: should a mix of passive and active safety systems actually be required innew plants?

IV. HYDROGEN MANAGEMENT, OBSERVATIONS FROM FUKUSHIMA[5-7]

Deficient fuel cooling resulted in overheating of the fuel, enabling rapid oxidation andgeneration of large amounts of hydrogen, which ultimately led to the explosion/destruction of the reactor buildings at Units 1 and 3, and possibly fires at Unit 4. However, the exact mechanism of hydrogen accumulation in the reactor buildings has not been ascertained at this time. Here anotherkey questionis arising: How can hydrogen generation and accumulation are reduced?

4.1 Possible Corrective Action at Current and Future Plants:

Venting of pressure vessels should be via strong pipes connected to the stack (this iscurrently a U.S. practice, but it is not clear if it is followed in other countries). Venting shouldbe possible without power.Plants should have the atmospheric in the pool areas more directly connected to the plantstacks. Also, fail-open (on power loss) louvers in the buildings could be used.More hydrogen recombines (passive) and igniters (active) could be considered for smallreleases in the upper regions of a building, where hydrogen may accumulate. Also, catalyticrecombines could be used in the ventilation system and inside the containment where it isnot already done now. Hydrogen flares for massive venting of containment gases could be explored.
Use of materials that generate hydrogen upon oxidation with steam could be reduced oreliminated, e.g., replace Zircaloy cladding with less reactive metals, and ultimately aceramic, such as SiC.

V. CONTAINMENT,OBSERVATIONS FROM FUKUSHIMA [8-9]

Due to the station blackout, the operators had to vent (vs.cool) the containment to prevent containment over-pressurization. Some vented gases leaked into the reactor building,which had no ventilation (again due to the station blackout), resulting in hydrogenaccumulation and ultimately explosion/destruction of the reactor buildings at Units 1 and 3.

Key question:

How can the need for containment venting be eliminated or its consequences mitigated?

5.1 Possible Corrective Actions at Current Plants:

The containment should be vented directly to the stack, when containment cooling is notavailable. A catalytic recombining system that automatically activates upon loss of powercould also be explored.

5.2 Possible Future Improvements:

Use of passive containment cooling could eliminate the need for venting as a means toreduce containment pressure, when AC power is not available. Use of the filtered/vented containment concept (French-Swedish examples) could provide abalanced approach to controlling containment pressure and radioactivity releases to theatmosphere when containment cooling is not available.

VI. SPENT FUEL POOLS, OBSERVATIONS FROMFUKUSHIMA [8-11]

Elevated location of the spent fuel pools exposed them to damage from hydrogen explosions in the reactor buildings at Units 1, 3 and possibly 4. Disablement of spent fuel pool cooling may have caused the pool fire at Unit 4 and forced one-week-long unconventional cooling efforts (e.g. helicopters, water cannons). Earthquake-induced water leakage from the pools (not confirmed at this time) may have aggravated the situation. The largest radioactivity releases from the Fukushima plant may be from the spent fuel pools. **Key questions:**How can the spent fuel pools are better protected from external events? How can reliablecooling of the spent fuel be ensured in case of station blackout? How can the source term ofthe spent fuel pools be reduced?

6.1 Possible Corrective Measures at Current Plants and Possible Future Improvements:

Spent fuel assemblies could be moved to dry storage as quickly as possible. Could redesigndry casks with a “top hat” chimney to enhance air cooling for the hotter fuelassemblies. However, (i) one must ensure the casks do not tip over due to an earthquakeor hurricane/typhoon, (ii) if the casks are breached, radioactivity release is un-mitigated(unlike in pools where water provides some scrubbing effect), (iii) the decay heat in pools isdominated by recently-discharged fuel, so moving the older fuel to dry casks may not havethat significant an impact on pool heat-up time in the event of an accident. Theseuncertainties make it unclear whether accelerated dry storage is actually preferable to otheroptions, such as on-site spent fuel pools or centralized interim storage.Current spent fuel pools could be retrofitted with a passive cooling system that can survivethe initiating external event.The policy on full core unloading into the pools during refueling shutdowns and spent fuelpool packing may have to be reviewed.Spent fuel pools could be housed in containment-like structures separate from the reactorbuilding. Note that some PWR plants have spent fuel pools inside the actual containment.Regional or national consolidated spent fuel interim storage facilities could be built. Thiswould reduce the spent fuel inventory at the plant, which in turn would reduce the sourceterm in case of spent fuel pool accidents. Interestingly, Japan has recently completed areprocessing plant at Rokkasho and in 10-15 years it is likely that all their spent fuel will beshipped there rather than stay at reactor sites for long periods of time.A national spent fuel repository could be created. The large inventories of spent fuel in U.S.reactor pools are a consequence of delays of the U.S. repository program that was to haveinitiated spent fuel removal from reactor sites by 1998. The U.S. has an operatinggeological repository for plutonium wastes generated from defense activities near Carlsbad,New Mexico, because of a broad national consensus that such a repository was required. Asimilar consensus is required for a second repository for spent nuclear fuel.

VII.PLANT SITTING AND SITE LAYOUT OBSERVATIONS FROMFUKUSHIMA [1-12-13]

Due to this site’s compact layout, problems at one unit created negative safety-relatedsituations at adjacent units. For example, the hydrogen explosion at Unit 3 disabled somefire pumps used for seawater injection at Unit 2. Also, it has been suggested that thefire explosion at Unit 4 was caused by leakage of hydrogen released from Unit 3 throughshared duct-work with Unit 4. Units 5 and 6, which are far from Units 1-4, were unaffected by the hydrogen explosions at Units 1 and 3.

A single external event (the tsunami) disabled all 13 diesel generators at the stationsimultaneously. The Fukushima-Daichii and Onagawa plants, both in the vicinity of Fukushima-Daichii,survived the earthquake and tsunami without major damage.

Key question:How can common cause failure and unit-to-unit contagion are prevented?

7.1 Possible Corrective Actions for Current Plants:

Layout diversity and separation at multi-unit sites could be enhanced. For example, at leastone diesel generator room could be placed sufficiently above grade (for protection againsttsunamis), and one below grade (for protection against plane crashes). Also, in futureplants the administrative buildings and parking lots could be located between units toenhance physical separation between those units.

7.2 Possible Future Improvements:

An obvious approach for future plants would be to choose sites away from highly seismic areas and coasts, to greatly reduce (and perhaps eliminate) the possibility of damage due to massive earthquakes, tsunamis and floods. It is noted that people tend to congregate near coasts and faults (river valleys); therefore, there are strong synergies between minimizing the probability of an adverse external event and maximizing the distance from densely populated areas. Notable exceptions are the plants in Japan, Taiwan and California; however, the large seismic challenge (ie. Higher expected ground motions) in these regions is currently overcome by a more stringent seismic design of the plants located in these regions.The strategic question here is: should there be arequirement to avoid identified vulnerabilities or should plants be allowed to design againstthem?
The number of allowable units at a single plant site could be determined based on ananalysis which accounts for the following, often conflicting, factors: (i) reduction of commoncause vulnerabilities, (ii) availability of an obvious approach for future plants would be to choose sites away from highly seismic areas and coasts, to greatly reduce (and perhaps eliminate) the possibility of damage due to massive earthquakes, tsunamis and floods. It is noted that people tend to congregate near coasts and faults (river valleys); therefore, there are strong synergies between minimizing the probability of an adverse external event and maximizing the distance from densely populated areas. The vast majority of nuclear plants worldwide are already located away from highly seismic areas. Notable exceptions are the plants in Japan, Taiwan and California; however, the larger seismic challenge (i.e. higher expected ground motions) in these regions is currently overcome by a more stringent seismic design of the plants located in these regions. The strategic question staff and resources to address a severe accidentimpacting all units simultaneously, (iii) reduction of potential source terms, (iv) highstandardization (shared learning), (v) shared equipment (with implications on botheconomics and safety), and (vi) low environmental impact of multi-unit cooling.

VIII. RESPONSE OFTHEENRRA EMERGENCY CENTRE TO FUKUSHIMA ACCIDENT, TECHNICAL SAFETY MEASURES

An intensive capacity building training programs in cooperation with the IAEA, the EC and R.ofS. Korea have been initiated to improve the regulatory capabilities of ENRRA (Egyptian Nuclear and Radiological Authority) man power especially in the fields of review and assessment and regulatory inspection for NPPs. Agreements with other TSOs in the universities and nuclear centers have been activated to enhance safety culture and strengthen the technical capabilities of workforce in the nuclear field. Regarding accident management and emergency management tasks, a complete reorganizing process of the emergency management center of the ENRRA has been achieved with emphasis to training capabilities of the human resource in this center. Participation in several IAEA workshops and Exercises or drills on the international levels has been successfully implemented.

IX. EMERGENCYRESPONSE TO THE FUKUSHIMA DAIICHI ACCIDENT [14]

The emergency response to the Fukushima Daiichi accident was greatly affected by the severe and widespread damage caused by the external event manifested in earthquake and tsunami. Although Japan is known to be well prepared for natural hazards; however, the earthquake and tsunami caused devastation on a scale beyond what was expected and prepared for. The investigations revealed some findings:

The Fukushima Daiichi accident revealed vulnerabilities in Japan's offsite emergency management. The competing demands of the earthquake and tsunami diminished the available response capacity for the accident. was overwhelmed by The extreme natural events, producing damaging effects on communications, electrical power, and other critical infrastructure over an extended period of time caused serious bad effects on the implementation of existing nuclear emergency plans. Additionally:

- Inadequacy of emergency management plans in Japan at the time of the Fukushima Daiichi accident to deal with the magnitude of the accident, requiring emergency responders to improvise.
- Decision-making processes by government and industry officials were challenged by the lack of reliable, real-time information on the status of the plant, offsite releases, accident progression, and projected doses to nearby populations.
- Coordination among the central and local governments was hampered by limited and poor communications.

- Protective actions were improvised and uncoordinated, particularly when evacuating vulnerable populations (e.g., the elderly and sick) and providing potassium iodide.
- Different and revised radiation standards and changes in decontamination criteria and policies added to the public's confusion and distrust of the Japanese government.
- Cleanup of contaminated areas and possible resettlement of populations are ongoing efforts 3 years after the accident with uncertain completion time lines and outcomes.
- Failure to prepare and implement an effective strategy for communication during the emergency contributed to the erosion of trust among the public for Japan's government, regulatory agencies, and the nuclear industry.

  The accident raises the question of whether a severe nuclear accident such as occurred at the Fukushima Daiichi plant would challenge emergency response capabilities in other countries because of its severity, duration, and association with a regional-scale natural disaster. The natural disaster damaged critical infrastructure and diverted emergency response resources.

  Recommendation 1: The nuclear industry and organizations with emergency management responsibilities should assess their preparedness for severe nuclear accidents associated with offsite regional-scale disasters. Emergency response plans, including plans for communicating with affected populations, should be revised or supplemented as necessary to ensure that there are scalable and effective strategies, well-trained personnel, and adequate resources for responding to long-duration accident and/or disaster scenarios involving:
- Widespread loss of offsite electrical power and severe damage to other critical offsite infrastructure, for example, communications, transportation, and emergency response infrastructure;
- Lack of real-time information about conditions at nuclear plants, particularly with respect to releases of radioactive material from reactors and/or spent fuel pools; and
- Dispersion of radioactive materials beyond the 10-mile emergency planning zones for nuclear plants that could result in doses exceeding one or more of the protective action guidelines.

  Recommendation 2: The nuclear industry and organizations with emergency management responsibilities should assess the balance of protective actions (e.g., sheltering in place, evacuation, relocation, and distribution of potassium iodide) for offsite populations affected by severe nuclear accidents and revise the guidelines as appropriate. Particular attention should be given to the following issues:
- Protective actions for special populations (children, ill, elderly) and their caregivers;
- Long-term impacts of sheltering in place, evacuation and/or relocation, including social, psychological and economic impacts; and
- Decision making for resettlement of evacuated populations in areas contaminated by radioactive material releases from nuclear plant accidents.

X. CONCLUSIONS

From this study it can be concluded:

1. Site selection standards for a nuclear power plant shall be modified and be more conservation with a factor of safety higher than the currently used.
2. The number of units in one site should be determined based on risk calculations taking into consideration the feedback from the relevant studies of accidents like that of Fukushima.
3. Emergency power supply to power plants should address the situations arising from sever external hazards to assure the continuity under beyond design basis conditions.
4. Dealing with generated hydrogen during an accident should be taken into consideration in the design phase and for conditions more severe than those for the present plants. Venting of containment and passive containment cooling should be considered.
5. Spent fuel storage and management should be revised. Passive for the spent fuel storage pool are options to be studied and scrutinized.
6. Enhance the capacity building of the regulatory bodies to address the challenges imposed by the nuclear accidents and making use of the lessons learned to avoid such accidents.

REFERENCES

[1]. Low No 7 on Nuclear Activities Regulation, 2010.

[2]. JCINI. Japanese earthquake and tsunami: Implications for the Nuclear Industry, office of Nuclear Regulation, 2011.

[3]. Charles Miller et al., Recommendations for Enhancing Reactor safety in the 21thCentury, the Near Term Task Force, Review of Insights from the FukushimaDai-IchiAccident, US. NRC, 12 July 2011.

[4]. Lesson from Fukushima Nuclear Accident for Improving Safety of U.S. Nuclear Plants, Nuclear and Radiation Studies Board, July 2014.

[5]. Lesson from Fukushima, Reducing Risks and Protecting Communities from Nuclear Disasters Fukushima Booklet Committee.

[6]. Five Years the Fukushima Daiichi Accident: Nuclear Safety Improvement and Lessons Learnt, DECD 2016, NEA No 7284 Nuclear Energy Agency OrganizationforCo-Operation and Development.

[7]. Preliminary Lessons Learned from theFukushima Daiichi Accident for Advanced, Nuclear Power Plant Technology Development IAEA Preliminary Report,2010.

[8]. Nuclear Systems Enhanced Performance Program, Technical Lessons Learned from the Fukushima Daichii Accident and Possible Corrective Actions for the Nuclear Industry: An Initial Evaluation, MIT-NSP-TR-025, May2011.

[9]. Lessons Learned From the Nuclear Accident at the Fukushima Daiichi Nuclear Power Station INPO 11-005 Addendum August 2012.

[10]. Lessons Learned from the Nuclear Accident at the Fukushima Daiichi Nuclear Power Station, ISBN 978-0-309-27253-7, Committee on Lessons Learned from the Fukushima Nuclear Accident for improving Safety and Security of U.S Nuclear Plants. Nuclear and Radiation Studies: Division on Earth and Life Studies: National Research Council.

[11]. Lessons Learned from the Fukushima Accident and Challenge for Nuclear Reform, NAS Meeting, Tokyo Akira Kawano, Tokyo Electric Power Company, November 26, 2012.

[12]. Lessons from Fukushima, Executive Summary, Green Peace, 2012.

[13]. IAEA, International Atomic Energy Agency, Atoms for Peace, Fukushima Daiichistatus Report, 27 Oct. 2011, 2 November 2011, 13 Feb. 2012, 30 March 2012, 27April 2011, 2 May 2012.

[14]. A Report to the Secretary of Energy of Requirements and Capabilities for Analyzing and Responding to Beyond Basis Events of Nuclear Safety office of Health, and Security U.S. Department of Energy 2011, Safety Bulletin Report.

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