Comparative Analysis on the Post-Fukushima Action Items of Key Countries

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1. Introduction

In the wake of the Fukushima Daiichi nuclear power plant accident which occurred on March 11th, 2011, due to a 9.0 magnitude earthquake followed by a tsunami in Japan, every country in the world that operates NPPs, including the Republic of Korea, prepared its follow-up counter-measures, reflecting the lessons of the accident.

The NRC of the United States responded immediately by forming the Near-Term Task force (NTTF) and the Japan Lessons-Learned Project Directorate with the purpose of systematically and methodically reviewing the NRC's processes and regulations, leading the implementation of the associated safety enhancements and preparing the regulatory requirements in light of the Fukushima accident [1].

EU Member States performed "Stress Test" for reevaluation of NPP designs in order to cope with extreme external events for each site characteristic.

The Republic of Korea also immediately formed a safety inspection team consisting of experts from relevant fields and KINS and carried out a safety inspection for domestic nuclear installations. The inspection team identified a total of 50 action items for safety improvement. In 2013, "Stress Test" on relatively aged NPPs was performed for verifying the safety against extreme external events.

Main purpose of this paper is to compare, analyze and update the history, current situation and results of the post-Fukushima action items in Korea with the major countries such as the US and France.

2. Post-Fukushima Action Items

2.1. The United States

2.1.1. Near-term activities

On March 23, 2011, the NRC approved formation of the Near-Term Task Force (NTTF) comprised of senior NRC staff and management, to systematically and methodically review the NRC's processes and regulations. The NTTF concluded there were no imminent safety concerns at American nuclear facilities [1] and made 12 overarching recommendations for the Commission regarding reevaluation of external events, DiD enhancement, severe accident mitigation, etc.

2.1.2. Long-term activities

The NRC also formed the Japan Lessons-Learned Project Directorate (currently called the Japan Lessons Learned Division) to perform a long-term review of the Japanese earthquake and tsunami and lead the implementation of the associated safety enhancements. Initially, this organization reviewed the 12 NTTF recommendations and ultimately agreed with the NTTF's conclusion that the accident did not reveal any imminent risk to public health and safety. The organization then prioritized the 12 NTTF recommendations by tiers and expanded upon the task force recommendations to include proposals from the international community, the U. S. Congress, the NRC's Advisory Committee on Reactor Safeguards, and other stakeholders [1].

2.1.3. Three orders issued for operating reactors

On March 12, 2012, the NRC issued the first regulatory requirements, in the form of orders, for the operating reactors reflecting lessons learned from the accident as follows [1];

(1) Order Modifying Licenses with Regard to Requirements for Mitigation Strategies for Beyond-Design-Basis External Events (EA-12-049)
(2) Order Modifying Licenses with Regard to Reliable Hardened Containment Vents (EA-12-050)
(3) Order Modifying Licenses with Regard to Reliable Spent Fuel Pool Instrumentation (EA-12-051)

The NRC also issued an RFI (Request For Information) requiring each reactor licensee to reevaluate the seismic and flooding hazards at its site using present-day guidance, methods, and information; conduct walk-downs of its facilities ensure protection against the hazards in its current design-basis; and assess its emergency communications systems and staffing levels.

2.1.4. The "FLEX" strategy

Order 1, with regard to mitigation strategies for BDBEE (Beyond-Design-Basis External Events), requires long-term power supply capacity to maintain or restore core cooling, containment and spent fuel pool (SFP) cooling capabilities [2]. The Nuclear Energy Institute (NEI) submitted a guide, titled "Diverse and Flexible coping Strategies (FLEX) Implementation Guide (NEI 12-06)", to the NRC in order to implement the order 1 and the NRC approved this guide in May, 2012 and issued an Interim Staff Guidance (ISG), JLD-ISG-2012-01, endorsing the industry guidance document, NEI 12-06, in August 2012.

The "FLEX" strategy increases DiD for beyond-design-basis scenarios to address an extended loss of alternating current power (ELAP) and loss of normal access to the ultimate heat sink (LUHS) occurring simultaneously at all units on a site [3].

The FLEX comprehensively addresses the NRC's Tier 1 recommendations. The FLEX, reflecting various recommendations, suggests mitigation strategies for BDBEE by providing power and water supply means that support the essential safety functions.

Table 1. Major factors of FLEX [3]

Elements	
·	Portable equipment that provides means of obtaining power and water to maintain or restore key safety functions for all reactors at a site
·	Reasonable staging and protection of portable equipment from BDBEEs applicable to a site
·	Procedures and guidance to implement FLEX strategies
·	Programmatic controls that assure the continued viability and reliability of the FLEX strategies
3-Phase approach	
i.	Initially cope by relying on installed plant equipment
ii.	Transition from installed plant equipment to on-site FLEX equipment
iii.	Obtain additional capability and redundancy from off-site equipment until power, water, and coolant injection systems are restored or commissioned
Boundary Conditions	
·	Beyond-design-basis external event occurs impacting all units at site.
·	All reactors on-site initially operating at power, unless site has procedural direction to shut down due to the impending event.
·	Each reactor is successfully shut down when required (i.e., all rods inserted, no ATWS).
·	On-site staff are at site administrative minimum shift staffing levels.
·	No independent, concurrent events, e.g., no active security threat.
·	All personnel on-site are available to support site response.
·	Spent fuel in dry storage is outside the scope of FLEX.

2.2. France

2.2.1. Stress Test

In France, 2-level Stress Test was performed as a post-Fukushima action plan [4].

Initially, according to the requests of the European Council, the stress test within a European framework was performed by 17 European countries on Nov. 24~25, 2011. It consisted of contents confirming the safety of nuclear power plants in exceptional circumstances like the Fukushima nuclear power plant accident.

Secondly, within a national framework, a safety inspection was performed by the instructions of French Prime Minister. This national study was conducted in compliance with the ENSREG specifications but with two extensions [4]:

(1) the study carried out in France concerned all nuclear facilities (including research and fuel processing facilities);
(2) the specifications were supplemented by points concerning the use of subcontracting.

The European level stress test was examined by a peer review under the supervision of the ENSREG in April, 2012 and 32 resolutions were adopted by ASN.

As result of these stress tests, ASN considered that the nuclear facilities examined displayed a sufficient level of safety not to require the immediate shutdown of any one of them but issued a series of resolutions dated 26 June 2012 requiring EDF to set up firstly [4]:

(1) a hardened safety core of material and organizational provisions aiming at:
  · preventing an accident with fuel melt, or limiting its progression;
  · limiting large-scale radioactive releases;
  · enabling the licensee to perform its emergency management duties.
(2) a local emergency centre allowing emergency management of the nuclear site as a whole in the event of an extreme external hazard;
(3) a nuclear rapid intervention force (FARN) which, using mobile means external to the site, can intervene on a nuclear site in a pre-accident or accident situation.

2.2.2. Hardened Safety Core

The aim of the Hardened Safety Core (HSC) is to secure and maintain essential response functions to prevent severe accidents even in extreme situations, and to limit the outflow of radioactive materials. In order to address this aim, the HSC has to be able to withstand earthquakes and floods much severe than the conditions considered in nuclear design and be protected from on-site and off-site hazards such as weight falls, effects of other component/structures, fire, explosion, etc.

EDF decided to arrange emergency diesel generators, emergency water supply systems and emergency management centers protected by a bunker so that they can withstand large-scale external events that simultaneously affect multi-units.

2.2.3. FARN

The Nuclear Rapid Intervention Force (FARN) is a national response system to support operators' response when a severe accident occurs, and consists of specialized personnel and equipment for replacing operators of NPPs.

If a severe accident occurs, the corresponding team first arrives at the NPP site, initiates countermeasures using HSC, and then necessary equipment and corresponding staffs arrive in stages.

2.2.4. Implementation Plan

EDF has an implementation plan of the resolutions in three phases [4]:

(1) Phase 1 (2012-2015) : implementation of temporary or mobile measures to enhance protection against the main situations of total loss of the heat sink or the electrical power supplies

(2) Phase 2 (2015-until about 2020) : implementation of definitive design and organizational means that are robust to extreme hazards, such as the fundamental elements of the hardened safety core designed to respond to the main situations of total loss of the heat sink or electrical power supplies beyond the baseline safety requirements in force
(3) Phase 3 (as from 2019) : this phase supplements phase 2, in particular to improve the level of coverage of the potential accident scenarios considered. EDF indicates that these means have also been defined with a view to continuing operation of the reactors beyond forty years

2.3. Republic of Korea

2.3.1. Post-Fukushima Action Items

Since the accident in Fukushima, the Korean government decided to conduct an overall safety inspection of domestic nuclear facilities on March 21, 2011 and formed the inspection team comprised of 73 experts in the areas of earthquakes, tsunamis, power supply, fire, reactor cooling, severe accidents, etc. Domestic nuclear facilities, were inspected from March 21st to April 30, 2011.

As a result of the inspection, the inspection team confirmed that domestic nuclear power plants were safely designed and operated to withstand the largest scale of earthquakes and tsunamis predicted through existing survey and research.

However, in light of the Fukushima nuclear power plan accident, in order to further strengthen and secure the safety of domestic NPPs even if the worst natural disaster occurs, the Korea Hydro & Nuclear Power Co., Ltd. (KHNP) identified a total of 50 action items for safety improvement in May 2011 and the Nuclear Safety and Security Commission (NSSC) identified 3 additional supplementary items in April 2014 based on regulatory experience and overseas case studies.

As of the end of 2016, the KHNP completed the measures for 44 items, 42 of which were reviewed by KINS and two are ongoing review.

2.3.2. Stress Test

On the 30th of April 2013, the NSSC issued an administrative order to KHNP to perform stress test on the relatively aged Kori Unit 1 and Wolsong Unit 1 in order to confirm their safety against extreme natural disasters. The stress test performed by KHNP reflects EU Stress Test specifications, assessment criteria partially applied by the IAEA, USA, and Japan and Green Peace recommendations.

The results of the stress test performed by the KHNP were submitted to the NSSC in 2013. Subsequently, the Korea Institute of Nuclear Safety (KINS), entrusted by the NSSC, organized a technical verification team which includes a civic review team and proceeded with technical verification. Through decision and reporting during NSSC Meetings, the verifications on the stress test results of Wolsong Unit 1 and Kori Unit 1 were respectively completed in February 2015 and in January 2016.

It was confirmed that the two nuclear power plants generally had response capabilities against extreme natural disasters and ongoing measures are taken for the safety improvements identified by the verification team.

In September 2015, the NSSC decided to perform stress test on all operating domestic nuclear power plants so as to verify the safety of nuclear power plants against extreme natural disasters. The detailed performance procedures and guideline (proposal) were reported and finalized during the NSSC General Meeting on October 27th, 2016 and stress test on all operating domestic nuclear power plants is expected to be completed by 2020.

3. Analysis

3.1. Initial Response of US, France and Korea

In the US, recommendations were identified promptly by the NTTF. In addition to this, the fact that regulatory requirements for enhancing safety were prepared in form of orders by the Japan Lessons-Learned Project Directorate is a characteristic matter.

Considering the NTTF recommendations and the regulatory requirements made by the Japan Lessons-learned Project Directorate, there was focus on reevaluation of the response to external events and the following ELAP/LUHS, as well as conduct of walk-down on nuclear facilities. This is considered as a strategy of reviewing rationality, validity and effectiveness by conducting walk-down and reevaluating external events and preparing the necessary measures and equipment. This strategy is different from the immediate action focusing safety enhancement measures and equipment in Korea.

Since the US operates various types of nuclear reactors and has various site environments, analyses to identify evaluation factors such as boundary conditions are performed preferentially, rather than taking immediate action as in the Republic of Korea. Regulatory requirements based on clear standards were completed and it was possible to reflect them directly on nuclear safety regulations.

A Characteristic of stress test, which is the initial response of European Countries, is that after operators of NPPs thoroughly had inspected the safety of nuclear facilities in each country. A peer review team was established and the team reviewed the results of stress test and identified resolutions. Due to this process, the application of regulatory requirements to each country was somewhat late compared to the US case. However, considering the geographical situation of Europe in which many countries are gathered together and public reliability on neighboring countries for each country's

nuclear safety stemming from such geographical circumstance, it is evaluated that this method and process was appropriate. Conducting the peer review will have allowed them to improve their nuclear safety and gather many ideas from each country's experts to refer to in preparing necessary regulatory requirements.

Korea is characterized by taking immediate and active measures for the integrity of nuclear facilities and defense in depth against external disasters at an early stage, assuming scenarios of severe accidents caused by extreme natural disasters that occurred in Fukushima. Taking into account public concern on the Republic of Korea being closest to Japan, it is commendable that follow-up measures were taken early after the accident, but there are some opinions that the scientific evaluation, such as in-depth analysis of the site characteristics, design of NPPs and external events, etc., were somewhat insufficient in comparison with other countries.

3.2. Accident Mitigation Strategy of US and France

The 3-phase approach of FLEX, which is the severe accident mitigation strategy of the US, prioritizes the use of installed plant equipment and afterwards, on-site FLEX equipment are used to ultimately secure off-site equipment, which differs from the French EPR equipment, HSC.

The FLEX is evaluated to comprehensively address the NRC's Tier 1 recommendations, reflect various requirements. However, considering simultaneous occurrence of independent events is excluded in the boundary conditions applied to the FLEX, it is appraised that improvement is needed for FLEX in addressing the possibility of complex accidents as situations outside of ELAP/LUHS such as reactor shutdown function are regarded as normal states.

A characteristic of HSC, which is the severe accident mitigation strategy of France, is that the dedicated equipment, HSC, is protected by a 'bunker' from external hazards. Unlike the US case in which the stepwise use of equipment is considered, the French approach is a "bunker concept" that enables dedicated equipment to ensure normal functions even under extreme accident conditions.

It is a characteristic different from the US in the sense that specialized experts and equipment of FARN enter sites from off-site locations in emergency conditions to execute emergency response measures.

3.3. Safety Inspection Program of Korea and EU

The stress test performed by the Republic of Korea is based on its own standard consisting of the EU stress test specifications along with the addition of a guide that takes into account emergency response and human factors. The results were reviewed by a technical verification team including a civic review team, intending to improve public acceptance, unlike the European stress test, which was reviewed through peer review.

However, the Korean stress test was mainly aimed at verifying the safety of aging NPPs, whereas the EU stress test verified safety against extreme external events immediately after the occurrence of the severe accident in Japan. Furthermore, the fact that the preparation of regulatory requirements was later than the US has been pointed out as a flaw.

4. Conclusion

The accident at the Fukushima NPPs in Japan occurred because no one presumed that such a large-scale natural disaster would occur, which is reflected in NPP design standards being set without any prediction of large-scaled natural disasters and operators and regulators not questioning the possibility of such natural disasters.

The case of the accident at the Fukushima NPPs brings about many challenges to nuclear power operating countries around the world about the design of NPPs considering BDBEE, and the prevention and mitigation strategy of severe accidents, which have been key themes of global nuclear safety.

As far as nuclear safety is concerned, no country should be complacent.

Through comparing the process, approach method and key concept of post-Fukushima action items in the US and France, which represent nuclear developed countries, with those of Korea, this paper intends to promote an open attitude of continuously raising questions about nuclear safety and maintaining a learning attitude. This paper also can provide updated information that will be helpful to future implementation of post-Fukushima action items.

REFERENCES

[1] U.S.NRC, The United States of America Seventh National Report for the Convention on Nuclear Safety, 2016
[2] U.S.NRC, Issuance of Order to Modify Licenses with regard to Requirements for Mitigation Strategies for Beyond-Design-Basis External Events , 2012.
[3] Nuclear Energy Institute, Diverse and Flexible Coping Strategies (FLEX) Implementation Guide, Rev.2, 2015
[4] France, Seventh French Report under the CNS, 2016