Incorporation of post-Fukushima Follow-up Actions into Accident Management Regulatory Framework

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1. Introduction

Shortly after the March 2011 Fukushima accident, the government organized a Task Force to conduct a special inspection to ensure safety measures against a possible severe accident at nuclear power plants (NPPs) in the event of a major earthquake or tsunami. As a result, 50 improvement measures have been drawn up, and most of them have been completed until 2016. Some measures of the licensee (Korea hydro and Nuclear Power Co., Ltd: KHNP), including 10 items raised and carried out by KHNP itself, are now under review by the Korea Institute of Nuclear Safety (KINS). These follow-up actions are also confirmed during the KINS' periodic inspections of each nuclear power plant.

Since 2013, as part of the President's pledge, an executive order has been implemented to check the safety of NPPs against extreme natural disasters through the European Union's stress tests on Kori-1 and Wolsong-1. In particular, a technical verification team including a civilian verification team composed of experts from civic groups participated in the KINS verification. This verification was completed for Wolsong-1 and Kori-1 in 2015 and 2016, respectively, and the progress of the safety improvements, as required by the administrative order, has been confirmed twice a year.

Following the earthquake of 5.8 magnitude in the area near Gyeongju in September 2016, and the earthquake of 5.4 magnitude in the area near Pohang in November of 2017 raised the public concern about safety of the NPPs. As a result, the Nuclear Safety and Security Commission (NSSC) prepared a plan for improving the safety of nuclear facilities against a major earthquake, and implemented measures to improve the earthquake response system, to strengthen the seismic capacity of NPPs and to evaluate the seismic capacity. Based on the seismology survey results, KINS plans to reevaluate the seismic design criteria of NPPs.

While these activities have been carried out based on individual administrative orders of the regulatory authority in a relatively short period of time since 2011, the Nuclear Safety Act was revised to provide an additional requirement to submit the Accident Management Plan (AMP) for the Operating License. Accordingly, treatment of the above improvements related to the accident management (AM) in a comprehensive and systematic manner has become necessary when the amended laws and regulations are implemented. Therefore, in this study, we examine the status of the Post-Fukushima actions following the administrative orders of the regulatory body and self-imposed by the licensee by searching mainly the Nuclear Safety Yearbooks [1,2]. Among those actions, we listed up the items that need continuous follow-up. Then we propose a desirable approach to include them in the AMP.

It is very challenging to submit an AMP covering a wide range of design basis accidents, multiple accidents, external hazards, and severe accidents for all operating and new reactors after three years of the preparation period. Similarly, the work of the regulatory body that will review the plan submitted at once should be enormous. Therefore, in this paper, we also tried to present our idea on the schedule for review of the AMP.

2. Post-Fukushima action items relevant to accident management

2.1. The Post-Fukushima regulatory actions

As a result of the special inspection after the Fukushima accident, it was confirmed that the domestic NPPs are designed and operated safely with respect to the maximum earthquake and tsunami scale estimated based on the existing studies. It was reaffirmed that Kori-1, which was operating at that time under the continuous operation approval, had no safety concerns. However, in order to ensure safe operation of NPPs even in the event of a worst natural disaster, a total of 50 safety improvements were identified. The NSSC had the licensees established a plan for implementation of the safety improvement measures. So, it was required to expand the coastal barrier of Kori-1 (7.5 → 10m), enlarged the quantity of the equipment for protection of the residents (60,000 → 480,000 gas masks), and so on. For new reactors, thirty-three items, including the installation of external cooling lines, were required from the stages of design and construction. In addition, KHNP established its own measures of ten items such as provision of mobile diesel driven pump, which are being implemented [3].

2.2. Stress tests for operating plants

Stress test evaluation items for Kori-1 and Wolsong-1 include confirmation of the ability to respond to extreme natural hazards such as earthquakes and tsunamis, i.e., maintaining the integrity of structures, systems, and components, ability to respond to loss of safety functions such as electric power systems, severe accident management capability. In addition, examination of decision-making errors in extreme situations in each of the above areas as well as the capability to operate organization, manpower, and available means were conducted. The verification showed that Wolsong-1 had the capability of responding to most items with the safety margin in its design. For the 19 mid- to long-term safety improvements, follow-up actions are in progress. In the case of Kori-1 which was to be in permanent suspension, measures were taken to enhance facilities such as spent fuel storage that require substantial period of operation even after permanent suspension, and to enhance operational capability during the remaining operational period. Among the total of 14 safety improvements provided by the KINS verification team, 11 items have been applied to all domestic NPPs and the validity of the results will be confirmed during the successive stress tests for them. In fact, when the NSSC closed the stress tests for those two plants in September 2015, it endorsed "The current status and future plan for the stress tests for operational plants" which expands the test to all NPPs to confirm their safety against extreme natural disasters. They will be conducted by 2020 [4].

2.3. Follow-up actions of large-scale earthquakes

For about 81 days from the day of the earthquake, September 12, 2016, the NSSC carried out an inspection on the followings: 1) evaluation of the appropriateness of the earthquake measurement results, 2) evaluation of the adequacy of operation and responses following the earthquake, and 3) Safety assessment through checking the plant's operational parameters, 4) checking on the integrity of the plant structures, systems, and components, and 5) checking on the abnormal operation of the equipment including occurrences of the abnormality alarms. The NSSC confirmed that there was no impact of the earthquake on the safe operation of Wolsong Units 1 through 4. However, in order to strengthen the capacity of the domestic NPPs against large earthquakes, it provided the following safety improvement plan for the nuclear facilities;

(1) Improvement of the earthquake response system
- Strengthening management of earthquake monitoring facilities
- Establishment of the rapid reporting and action system
- Transparent release of information in the event of an earthquake

(2) Seismic reinforcement of the NPPs and detailed evaluation of seismic capability
- Reinforcement of seismic performance
- Accurate re-evaluation of actual seismic capability of critical facilities

(3) Improving safety of the medium- and low-level waste disposal site in Gyeongju in response to an earthquake

(4) Precise geological survey in the 9.12 earthquake area and re-evaluation of the design basis

(5) Securing the emergency response base that is safe from earthquakes

(6) Strengthening emergency response capabilities against earthquakes

2.4. The AM-relevant items that need continuous follow -up

In the new legal system under the revised Nuclear Safety Act [5-7], the scope of the accidents that are the objects of the accident management covers not only the design basis accident that is within the existing regulatory framework but also those related to prevention - multiple events, natural and man-made extreme hazards - and mitigation of a severe accident. Evaluation of the AM capability includes determination of the capability of the severe accident prevention and mitigation, accident consequence evaluation, and probabilistic safety assessment. Through these evaluations and comparison with the safety goal, the achievement of the accident management is to be confirmed. Among the items associated with the above three administrative orders of the regulatory body and the licensee's own action, those which are considered directly linked with AM and need continuous management are presented in Table 1. They could be reorganized in a simpler way under the AMP framework, considering the actual contents of follow-up actions.

Table I: Selected Post-Fukushima Action Items That Need Continuous Management in Terms of Accident Management

Action Item	Remarks
1. Fukushima follow-up	
(3-1) Provision of mobile power generation vehicles and batteries	
(3-2) Improvement of the design criteria for Alternative Emergency Diesel Generators	
(3-5) Provision of measures against	

loss of cooling function of the spent fuel pool	
(4-1) Provision of the hydrogen control facilities during a severe accident	
(4-2) Installation of containment venting or depressurizing facility	
(4-3) Installation of the external emergency cooling water injection lines	
(4-4) Strengthening training for severe accidents	
(4-5) Revision of SAMGs[1)] for enhancement of the effectiveness of AM strategies	Needs to be linked with equipment survivability
(4-6) Development of SAMGs for shutdown / low power operation	
Development of EDMGs[2)]	KHNP's own action
Development of EOP[3)]-SAMG interconnection guidelines	KHNP's own action
Hardware reinforcement to cope with beyond design basis hazards	Additional safety measures
Provision of emergency response base equipped with seismic function	Additional safety measures
Strengthening emergency response capabilities	Additional safety measures
2. Stress Test Verification Task for operational NPPs	
F1. Improved protection of safety functions against earthquakes - Safety of the Wolsong site against natural disaster and reactor containment integrity - Strengthening the ability to respond to earthquake induced fires in the critical response areas	
F3. Enhanced capability to prevent severe accidents to respond to loss of safety functions - Improved capability to cope with simultaneous accidents at multiple units and complex accidents - Evaluation with consideration of simultaneous accidents at multiple units and finding safety improvements	
F4. Strengthened ability to mitigate and manage severe accidents - Preparation of measures for reducing the possibility of containment bypass and responding to it - Equipment reinforcement through stress testing	
3. Measures to improve safety of nuclear facilities against large-scale earthquakes	
Enhancement of seismic performance of NPPs and detailed evaluation of their seismic capacity - Reinforcing the seismic performance of Safe Shutdown Systems up to 0.3g-level - Detailed reevaluation of actual seismic capacity of critical facilities of NPPs and confirmation of the seismic capability for major functions	

1) SAMGs: Severe Accident Management Guidelines
2) EDMGs: Extensive Damage Mitigation Guidelines
3) EOPs: Emergency Operating Guidelines

4. Follow-up of the action items under the AMP framework

3.1. Feedback of Post-Fukushima actions to the AMP

The actions described above have been carried out by individual administrative orders of the regulatory body with independent needs. However, since they started from the common motivation for coping with a Fukushima-like accident, they inevitably have similarities in the final aim at prevention and mitigation of severe accidents at NPPs. Owing to the technological deepening in the course of implementation of each measure, they have contributed greatly to the effective severe accident management and enhancement of emergency response capability. Nevertheless, we might ask whether there could be a more comprehensive and systematic approach with the viewpoint of the mid- and long-term to be more effective in terms of spending the limited resources in order of priority.

Whereas, the revised Nuclear Safety Act deals with overall aspects to ensure the capabilities of severe accident prevention and mitigation. Therefore, it is expected that it will play a role of synthesizing and organizing those activities carried out by individual administrative order with respect to prevention and mitigation of a severe accident. For example, the strategy of injection of external cooling water to the primary and the secondary systems were adopted as a Fukushima follow-up action. It could be a useful

strategy to limit significant core damage when it is applied with on-site installation of mobile pumps, even immediately after the entrance criteria for initiation of SAMGs are met. Since the Fukushima action has the objective only to install an external injection lines, limited assessments including containment pressure estimation were performed. However, if it is considered credible, it could be used in the AMPs in evaluation of the severe accident prevention capability against beyond design basis accidents.

Even though the deadline for submission of the AMP is several months ahead, it is recommended that a framework to reflect the results of the overall improvement activities related to the items presented in Table 1 in the AMP be established. Then the capability of severe accident prevention and mitigation may be effectively evaluated and confirmed. It is also desirable to establish an administrative system such that follow-up actions related to the AMP will be integrated and managed continuously in a harmonious manner with the preceding follow-up actions, through changes to the license, periodic safety review and periodic inspections.

3.2. Step-by-step review of the AMP

Until now the licensee has selected the representative NPPs of the types of OPR, APR, WH-2, WH-3, FRA, and CANDU reactors and is proceeding 1) analysis of the accident consequence, 2) development of procedures for emergency operating guidelines, multiple defensive operating guidelines, extensive damage mitigation guidelines, and severe accident mitigation guidelines, 3) development of plans for testing, surveillance, inspection and maintenance of facilities, 4) PSA, and 5) evaluation of equipment survivability [8]. Then they are expanding these activities to 18 subject NPPs. The KHNP plan is such that the AMPs for the representative plants will be completed by the end of 2018, and those for the expanded NPPs are under development from July 2018 to June 2019.

Currently, it seems that the licensee is struggling to resolve the delay in contracting the relevant tasks, the difference in timing between the AMP submission and the licensing/tests of the facilities, and to keep the consistency of PSA [8]. Therefore, it could be a challenge for the licensee to ensure high quality of the AMPs, which could also give difficulties to the reviewer afterwards.

Considering that there will be 18 AMPs with the large amount of documentation submitted at a time, the KINS' review period is uncertain at this time. In general, a typical review includes quite a few activities. Furthermore, review of the AMP may be not easy because there are several areas where the new regulatory requirements are applied for the first time. So, it is expected that drawing up technical issues and reviewing their solutions will take time. Therefore, for the efficient review work, we propose the following step-by-step approach similar to that of the licensee.

1. Review of four or five representative NPPs' AMP (expected to take at least 2-2.5 yrs.) including pre-compliance review, main review, derivation of technical issues, and imposing safety improvements or operating conditions
2. Review of the expanded NPPs' AMPs (expected to take at least 1-2 yrs.) including the licensee's action to reflect main results from the review of the representative NPP in the corresponding AMPs during the process of Step 1, main review, and preparation of safety enhancements or operating condition

4. Conclusion

The revised Nuclear Safety Act requires submission of an AMP which can demonstrate the severe accident prevention and mitigation capability. It is anticipated that the AMP will play a role to synthesize and systematize the individual activities aimed to confirm the ability through Fukushima follow-up, stress tests, and safety improvements against largescale earthquakes. For instance, installation of the equipment or evaluation results from the Fukushima actions should be appropriately reflected in the AMP. Among those follow-up items, we listed up those which are related to the AM and need follow-up under the AMP framework. While it is expected that preparation and review of the AMPs require much efforts, we propose a step-by-step review approach similar to that of the licensee.

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