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A Brief Comparative Study on Stress Tests Specifications of the EU and Korea

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1. Introduction

Stress tests on Nuclear Power Plants (NPPs) in Korea are currently underway. After Fukushima accident, stress tests are considered as an important evaluation method for ensuring the safety of NPPs under extreme natural disasters beyond Design Basis Accident (DBA) together with post-Fukushima action items and the development of Accident Management Plans (AMPs). Successful implementation of stress tests will ensure nuclear safety on extreme conditions and improve public acceptance.

Following the Fukushima accident, Korea Hydro & Nuclear Power (KHNP) conducted stress tests based on EU methodology to confirm the safety of Kori unit 1 and Wolsong unit 1, the two oldest Korean NPPs, in accordance with the pledge of the former president. Stress tests of the two NPPs were also a prerequisite for the extended operations of the two plants. Stress tests have been carried out in accordance with the specifications provided by the Nuclear Safety and Security Commission (NSSC). As a result of the stress tests, 14 and 19 action items were derived for Kori unit 1 and Wolsong unit 1, respectively and implementation action items have been conducted. In 2016, the NSSC decided to apply the stress tests to all operating NPPs in Korea.

The stress tests in Korea are based on the evaluation method of the stress tests conducted by the European Union (EU) after the Fukushima accident. However, it requires stronger safety by reflecting safety measures adopted by the International Atomic Energy Agency (IAEA), Japan and the United States, and also opinions of international environmental groups. In this paper, the stress tests specifications of the EU and Korea were compared and analyzed.

2. Comparative Analysis of the stress tests methodologies between the EU and Korea

2.1 Stress Tests Specifications of the EU and Korea

Following the Fukushima accident, Western European Nuclear Regulators' Association (WENRA) developed specifications for the EU stress tests at the request of the European Commission. The specifications cover three technical scopes and assessment methodologies are provided for each in the specifications.

In Korea, stress tests specifications for Kori unit 1 and Wolsong unit 1 were developed by NSSC/KINS in 2013 based on the EU specifications, and the specifications were revised in 2016 as the stress tests were extended to all other operating NPPs in Korea.

The revised specifications for all other operating NPPs provide a strategy of performing the evaluations in two consecutive steps. In the first stage, 4 representative NPPs are evaluated considering the reactor type for each site. For the second stage, gap analysis is performed to analyze common and unique items between representative NPPs and remaining NPPs. In the second stage, common items of the same reactor type apply in common, and only the unique features of the site are further evaluated

2.2 Comparative Analysis

2.2.1. Assessment Areas [1-3]

The technical scope of the EU stress test is divided into three areas: initiating events, loss of safety functions, and severe accident management. Earthquake and flooding were presented as initiating events.

On the other hand, Korea's stress tests specifications deal not only with earthquake and earthquake-induced floods but also with earthquake-induced fires. Furthermore, various natural disasters beyond DBA such as strong wind, low water level, and water temperature rise is extensively analyzed to confirm the robustness of NPPs against those disasters. In fact, the EU stress tests have also been conducted on other extreme weather conditions besides earthquake and flooding. However, ENSREG stated in the peer review report that the result was not satisfactory because there was little evidence of assessing margins beyond design basis [5].

Loss of safety function is evaluated by considering loss of electrical power, Loss of Ultimate Heat Sink (LUHS), and a combination of both. In this sense, the EU and Korea show similar evaluation methods. However, stress tests in Korea additionally reassessed the capability of NPPs to respond to the loss of safety functions due to extreme natural disasters assuming that all reactors on the same site are equally damaged. By assuming the extreme conditions, safety functions can be evaluated more conservatively.

In the area of severe accident management, both Korea and the EU deal with three aspects: means to protect from and to manage core cooling function, means to protect from and to manage loss of cooling function in the fuel storage pool, means to protect from and to manage loss of containment integrity. However, the stress tests in Korea further evaluates the factors to undermine severe accident management taking into account extreme natural disasters. This assessment ensures that NPPs can cope with severe accidents even in extreme conditions.

In Korea, meanwhile, the specification for Wolsong unit 1 and Kori unit 1 added the new field of 'emergency preparedness'. This sector assesses emergency response capabilities, the ability to make appropriate emergency response decisions, and the availability of emergency response facilities to evaluate resident protection ability.

The revised specifications for all other operating NPPs added additional assessment area which is 'operational management capability'. This field validates the adequacy and practical feasibility of accident response operational activities. Table I shows the comparison of assessment areas between the EU and Korea stress tests specifications.

Table I: Assessment Areas Comparison [1-3]

Specifications		Assessment Areas
EU		**1. Initiating events** A. Earthquake B. Flooding **2. Loss of safety functions** A. Loss of electrical power including SBO[1)] B. LUHS C. Combination of both **3. Severe accident management** A. Loss of core cooling function B. Loss of cooling function in the fuel storage pool C. Loss of containment integrity
Korea	Rev. 0 (`13.4)	**1. Integrity of SSCs[2)] against earthquake** A. Evaluation of DBE[3)] B. Plant protection against DBE C. Indirect impact by earthquake D. Range of earthquake severity for loss of safety functions/fuel damage E. Range of earthquake severity for containment integrity damage F. DBE-induced Flooding G. DBE-induced Fire **2. Integrity of SSCs against Tsunami and other natural disasters** A. DBF[4)] B. Plant protection against DBF C. Range of flooding severity for loss of safety functions/fuel damage **3. Loss of safety functions** A. Equipment for safety functions B. Plant response capability for loss of power and LUHS C. Plant response capability in extreme natural disasters **4. Severe accident management** A. Core cooling function B. Containment integrity C. SFP[4)] cooling function D. Components and equipment for severe accident management E. Factors to undermine severe accident management considering extreme natural disasters **5. Emergency preparedness** A. Emergency response B. Decision making adequacy C. Habitability of emergency facilities
Korea	Rev.1 (`16.10)	**1. Characteristics of extreme natural disaster beyond DBA** A. Earthquake B. Flooding and other natural disasters **2. Integrity of SSCs against extreme natural disasters** A. Integrity of SSCs against earthquake B. Integrity of SSCs against earthquake-induced flooding C. Integrity of SSCs against earthquake-induced fire D. Integrity of SSCs against flooding and other natural disasters **3. Loss of safety functions** A. Equipment for safety functions B. Plant response capability for loss of power and LUHS C. Plant response capability in extreme natural disasters **4. Severe accident management** A. Core cooling function B. Containment integrity C. SFP[5)] cooling function D. Components and equipment for severe accident management E. Factors to undermine severe accident management considering extreme natural disasters **5. Emergency preparedness** A. Emergency response B. Decision making adequacy C. Habitability of emergency facilities **6. Operational management capability** A. Adequacy of accident response strategy B. Adequacy of operators actions C. Adequacy of main resources D. Effectiveness of human engineering E. Ability to cope with simultaneous accidents of multiple reactors

1) SBO : Station Blackout
2) SSCs : Structures, Systems, and Components
3) DBE : Design Basis Earthquake
4) DBF : Design Basis Flooding
5) SFP : Spent Fuel Pool

2.2.2. Review Process

Since the EU carried out stress tests on 165 units in 17 countries, each licensee performed an assessment according to the same specifications as presented in WENRA. The assessment results were reviewed by the national regulatory bodies in each country. In order to enhance the credibility and accountability of the process, the results were then mutually reviewed by peer review teams composed of members from the EU member states participating in the stress tests.

In Korea, KHNP performed a primary assessment of the stress tests because KHNP is the only licensee operating NPPs. At the review stage, the Korea Institute of Nuclear Safety (KINS) review team and civil expert review team performed independent review of the compliance with the specifications. As the tests expanded to all operating NPPs, two review teams were unified into the KINS review team for consistency and efficiency. Civil experts were included in the KINS review team to provide technical support.

NSSC/KINS also plans to carry out IAEA peer review on Hanul unit 3 as a third-party review and apply the review results and recommendations for improvements to the remaining NPPs. The IAEA peer review will ensure that NPPs in Korea are more stringent in safety by using IAEA safety guides which are independent of the EU specifications. Figure 1 and Figure 2 shows review processes of the EU and Korea respectively.

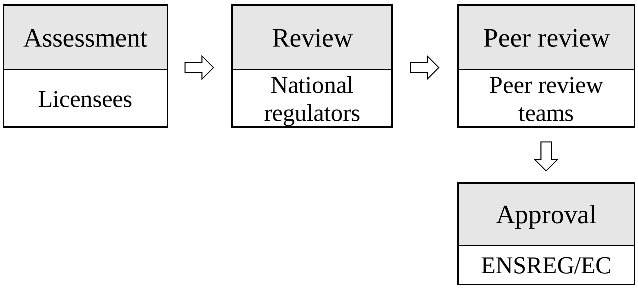
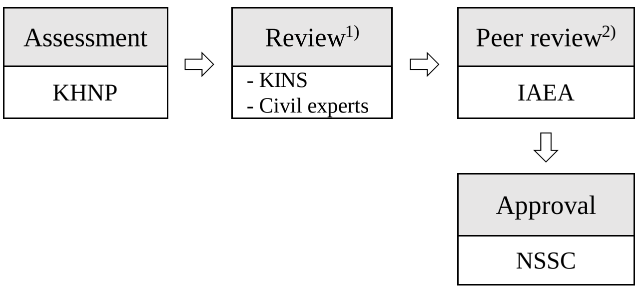


Fig.1. Review Process of the stress tests in the EU



1) Integrated into KINS review team from the stress tests on all operating NPPs
2) Applied from the stress tests on all operating NPPs

Fig.2. Review Process of the stress tests in Korea

2.2.3. Action Plans

After the final report was approved by European Nuclear Safety Regulators Group (ENSREG) and the European Council (EC), an ENSREG action plan was developed to track implementation of the recommendations [4]. After that, each national regulator generated a country-specific action plan as part of the ENSREG action plan. ENSREG prepared a consistent compilation of peer review recommendations and suggestions to assist the preparation of national action plans by national regulators.

In Korea, action items for Kori unit 1 and Wolsong unit 1 were derived from the result of assessment by KHNP and review by KINS review team. Table Ⅱ shows 33 action items for Kori unit 1(14) and Wolsong unit 1(19). These 33 action items are again divided into 71 detailed implementation plans.

From the stress tests on all operating NPPs, the result of the peer review by IAEA will be also included in the action items so that more objective action items can be derived. In addition, KHNP plans to improve the safety of NPPs widely by establishing a comprehensive safety improvement plan that encompasses not only the action items derived from the stress tests but also action items that meet the legal safety requirements set forth in AMP.

Table Ⅱ: Action Items for Kori #1 and Wolsong #1

Unit	Area	Action Items
Kori #1 (14)	Ⅰ. Earthquake, Fire, other natural disasters	1. Review seismic performance of SFP cooling system equipment
		2. Enhance ability to respond to earthquake-induced fires
	Ⅱ. Loss of safety functions	3. Secure stable performance of mobile generator for SBO
		4. Improve battery power supply time
		5. Secure coping facilities for simultaneous multiple accidents
	Ⅲ. Severe accident management	6. Secure communication facilities between MCR[1)] and local operators
	Ⅳ. Emergency preparedness	7. Specify radiation emergency plan
		8. Train and protect ERO[2)]
		9. Improve UPS[3)] of ERMS[4)]
		10. Improve habitability of emergency response facility
	Ⅴ. Operational management capability	11. Improve operational ability of mobile generator
		12. Verify operator's ability to respond to steam emission using PORV[5)]
		13. Reevaluate operational response capability and human performance
	Ⅵ. Permanent shutdown	14. Reevaluate the response capability of extreme natural disasters during the permanent shutdown
Wolsong #1 (19)	Ⅰ. Earthquake, Fire, other natural disasters	1. Confirm the safety of Wolsong site and the integrity of RCB[6)] by natural disasters
		2. Enhance earthquake-induced fire response capability
		3. Inspect the impervious layer of emergency water supply reservoir periodically
	Ⅱ. Loss of safety functions	4. Install earthquake-resistant battery
		5. Secure essential coping functions
		6. Ensure early and long-term core cooling
	Ⅲ. Severe accident management	7. Assess appropriateness of coping ability of severe accident by extreme disasters
		8. Install external injection line of reactors
		9. Adjust CFVS[7)] open pressure /Install RMS

Wolsung #1 (19)	Ⅲ. Severe accident management	10. Review the need to install hydrogen igniter
		11.Reinforce equipment and prepare strategy for SFP crack or damage
		12. Reduce possibility of bypassing RCB
		13. Radioactive waste management during severe accident
	Ⅳ. Emergency preparedness	14. Develop dose assessment program considering simultaneous multiple accidents
		15. Secure additional emergency response centers considering simultaneous multiple accidents
	Ⅴ. Operational management capability	16. Reinforce measuring equipment and continuous monitoring plan
		17. Ensure accessibility considering extreme disasters
		18. Secure personnel and organizations to cope with extreme disasters
		19. Enhance ability to respond to accidents through training

1) MCR : Main Control Room
2) ERO : Emergency Response Organization
3) UPS : Uninterruptible Power Supply
4) ERMS : Environmental Radiation Monitoring System
5) PORV : Power-Operated Relief Valve
6) RCB : Reactor Containment Building
7) CFVS : Containment Filtered Venting System

2.2.4. Openness & Transparency

ENSREG applied the principles for openness and transparency to EU stress tests and conducted inter-country peer reviews as part of this principle [3]. All results of stress tests were also made available to the public and discussed in national and European public seminars.

In Korea, as an effort for transparency and openness, KINS has composed a civil expert as an independent review team in the review process for the stress tests on Kori unit 1 and Wolsong unit 1. As the stress tests are expanded to all operating NPPs, KINS established a pool of civil experts to provide technical advice in the KINS review team and proceeds third party review of IAEA. Stress tests information including test results is disclosed on the Internet homepage. In addition, the stress test review plan is explained to the local residents, and outside through various activities such as explain sessions, conferences and forums.

3. Conclusions

Stress test is one of the KHNP's implementation of post-Fukushima actions. KHNP aims to verify and reinforce the safety margins of all operating NPPs in Korea against extreme disasters exceeding DBA through the tests. Stress tests in Korea are based on the EU case. However, NSSC have developed more enhanced specifications. Major improvements are as follows.

First, the scope of the evaluation was further diversified. Unlike the EU specifications that only assumed earthquakes and flooding in initiating events, KHNP evaluated various natural disasters such as fire, strong winds and rising water temperature. In the areas of 'loss of safety function' and 'severe accident management', more conservative and strengthened safety are pursued by assuming simultaneous accidents of multiple reactors on the same site by extreme natural disasters. In addition, emergency preparedness area has been newly added to evaluate the resident protection measures. Operational management capability area was also introduced to improve the reliability of verification.

Second, Korea pursued the objectivity and reliability of review by including civil experts as well as the regulatory body in the review process. Third-party review through IAEA is also part of the efforts to secure the reliability of review process.

Third, Korea plans to establish comprehensive action plans that enhance safety by linking action plans with safety requirements of AMP.

Fourth, Korea has made various efforts to ensure the transparency of review such as public disclosure of the tests results on the homepage, local resident explanation sessions at the plant sites, external information sharing through conferences and forums.

These improved specifications in Korea have provided more strict safety standards. Stress tests currently being conducted in Korea will further enhance the robustness of NPPs against extreme disasters and contribute to safer nuclear operation.

REFERENCES

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