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Findings of Special Safety Inspection on Severe Accident Countermeasures for Operating Plants in the Light of the Fukushima Dai-Ichi Accident

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1. Introduction

Following the Fukushima accident, the Korean government set up a response led by a Prime Ministerial Task Force to precisely assess the safety of operating nuclear power plants (NPPs) against such an event in Japan in March 11th, 2011. KINS organized a targeted Special Safety Inspection (SSI), and a team composed of 37 KINS staffs and 36 external experts stemming from various different organizations was brought together to undertake the mission. The assumed scenario which was investigated mirrored the Fukushima accident. Accordingly, areas for improvement were promptly identified. This paper describes the findings of the SSI and their technical backgrounds, especially on the severe accident countermeasures of operating NPPs.

2. The Special Safety Inspection

2.1 Scope and Results of the SSI

The SSI team undertook an intensive three week inspection, followed by two weeks for review and technical discussion of improvement items between KINS and KHNP. The SSI covered all 21 operating nuclear power plants, the HANARO research reactor and fuel cycle facilities.

Table I: Major Points of SSI

Topic	Major Inspection Points
Extreme natural disasters	- Adequacy of the plant design and facilities against natural hazards - Design against earthquake and seismic capacity - Design against coastal flooding and inundation protection capability
Prevention of severe accidents	- Adequacy of power supply and cooling functions - Power system and emergency power supply - Cooling capability in case of SBO and inundation
Mitigation of severe accidents	- Adequacy of countermeasure capabilities against severe accidents - Facilities, guidelines, and strategies against severe accidents
Emergency response	- Adequacy of emergency response - Emergency response to multi-units accidents - Facilities, systems, and infrastructure for the protection of local residents and workers

The scope of the SSI consisted in the six areas: 1) design against earthquakes and coastal flooding; 2) integrity of systems including electrical power in case of inundation; 3) severe accidents countermeasures; 4) emergency response; 5) old plants; and 6) research reactors and fuel cycle facilities. Major inspection points of SSI are listed in Table I.

A total of 100 items initially suggested by the SSI team were subsequently optimized after the technical information exchange process. As a result of this exchange KINS and MEST, established a list of 50 actions to improve the Korean nuclear safety in the light of the Fukushima accident [1]. After that, MEST notified KHNP and other stakeholders the need to implement relevant improvements according to a two-phased approach; short term (actions should be completed within 2 years) and mid/long-term (5 years) actions.

2.2 Findings on the Severe Accident Countermeasure

Most of the 50 actions concentrate on the prevention as well as the mitigation of a severe accident in the light of the Fukushima accident. Among them, the items directly related to the severe accident management, i.e. Actions 4-1 to 4-6, are listed in Table II. The relevant background of each item and technical concerns of the SSI team are described below.

Table II: Recommended Improvements on Severe Accident Countermeasures

(4.1)	Installation of passive hydrogen removal equipment (PAR)
(4.2)	Installation of filtered vent system or depressurizing facilities in the containment buildings
(4.3)	Installation of reactor injection flow paths for emergency cooling water injection from external sources
(4-4)	Reinforcing education and training for severe accidents
(4-5)	Revision of the Severe Accident Management Guidelines (SAMGs) to enhance effectiveness
(4-6)	Development of Low-Power Shutdown SAMGs

Action 4-1 (Hydrogen Mitigation)

Operating NPPs in Korea have various hydrogen mitigation equipment such as passive autocatalytic recombiner (PAR), electrical hydrogen recombiner (movable or fixed) or hydrogen igniter. During a station blackout (SBO) accident like in the Fukushima Dai-Ichi, all equipment except PAR are inoperable because they work only when the AC power is available. Moreover, the electrical recombiner was designed against a low hydrogen concentration (4% in volume).

Therefore the improvement proposed by the SSI team was that hydrogen shall be removed even under an SBO condition regardless of the AC power. This means that PAR should be installed in the containments of all operating NPPs. In Action 4-1, installation of the hydrogen monitoring system into the NPPs of CANDU and Framatome was also included.

Action 4-2 (CFVS or depressurization)

In SAMGs, containment spray, fan coolers, or purge systems can be used as a strategy for preventing the containment failure. However, since the spray and fan coolers are operated by the AC power, they are not applicable to a severe accident following a SBO event. The containment purge system is not designed to cope with the high pressure of the containment due to steam generation following core meltdown and sequencing late phase phenomena. Therefore, if the purge system is used to depressurize containment, there is a high possibility of large rupture at the containment penetration resulting in a large release of radioactive materials to the environment and the public.

The SSI team strongly recommended to KHNP to insure the containment integrity under such situations by installing the measures reducing containment pressure to prevent the release of the source terms of severe accidents. To fulfill this action, KHNP should consider the containment filtered-vent system (CFVS) as one of corresponding measures.

Action 4-3 (Emergency Cooling Water Injection)

When an accident occurs in a NPP, the most important action of the systems or operators is to protect the reactor core by the continuous removal of decay heat. Korean NPPs, which are different from the BWR, have the secondary loop to remove the energy transported from the primary loop (i.e. reactor coolant system, RCS (PWR) or heat transport system, HTS (CANDU)) through the steam generators. Therefore, maintaining the inventories in the primary and secondary loops is very important. Fortunately, in Korean NPPs, the turbine-operated auxiliary feedwater pumps are available for 2 to 4 hours after the SBO event. However, if the onsite or offsite power could not be recovered within that short period, the heat removal from the core might fail resulting core damage followed by accident progression.

Action 4-3 was made by the SSI team to enhance the core coolability in case of a prolonged SBO accident. Following the Action, KHNP needs to prepare some alternative direct lineups to inject emergency water source to the primary and secondary loops as soon as possible.

Action 4-4 (Education and Training on SAMGs)

Though the systems and procedure (SAMGs) of NPPs are well prepared to cope with severe accidents, if the staffs of the SAMG implementing organization have a low level of the knowledge base about severe accidents and SAMGs, practical effective accident management would fail. This is related to the safety culture of the licensee or corresponding organization. Currently, KHNP assigns 8 hours per 2 years for the education of SAMGs against the staffs. The SSI team judged that it is not enough to well prepare the severe accident scenarios.

The conclusion of the SSI team was that an effective education and training program should be established by increasing current education time to 10 hours every year, which may be helpful to enhance the knowledge base of the members for accident management.

Action 4-5 (Effectiveness of SAMGs)

Action 4-5 is of the overall enhancement of accident management capacity which should be effectively reflected in SAMGs from all related actions proposed by the SSI team.

This item also addressed the survivability of equipment under the severe accident environment in which condition, all essential information about the plant status should be produced. Especially under a prolonged SBO, the electric power supported by batteries will be exhausted after a couple of hours.

Another concern of this item focused on the possibility of the practical protection of the containment in the late phase of severe accident, since the containment is the last physical barrier in the defense-in-depth (DID) philosophy. In the late phase of severe accident, the molten core materials can be relocated to the reactor cavity, which might have a potential to threaten the integrity of containment by overpressurization or basemat erosion on the cavity. To cope with this situation, current SAMGs apply a strategy to flood the cavity with water before the reactor vessel breach for the in-vessel retention of the melt. However, this strategy can bring an unintended steam explosion in flooded cavity when the ex-vessel cooling fails. Moreover, the flow paths for cavity flooding considered in SAMGs of some NPPs came out to be ineffective for the strategy.

The SSI team concluded that SAMGs must be revised to be practically effective even under a prolonged SBO accident. The equipment survivability needs to be re-assessed from the points of the severe accident environment as well as electrical robustness aspects. Additionally, the final barrier of DID should be protected in the late phase of severe accident by using practical measures to flood cavity through reliable assessments.

Action 4-6 (LPSD SAMGs)

Since current SAMGs had been established for the mode of full power condition, it may not be effective for a severe accident at low power or shutdown (LPSD) conditions.

The SSI team, therefore, recommended to establish LPSD SAMGs for all operating NPPs based on the LPSD probabilistic safety assessment (PSA).

3. Conclusions

Following the results obtained from the SSI in the light of the Fukushima accident, KHNP has established the comprehensive action plan and KINS will review the progress report every 6 months. It is believed that the implementation of the Actions will surely enhance the severe accident safety of NPPs for all predictable accident scenarios.

REFERENCES

[1] Ministry of Education, Science and Technology, Draft Results of Safety Inspection on Domestic Operating Nuclear Power Plants (Proposal to the 44th Meeting of the Nuclear Safety Commission), 2011.

[2] IAEA-NSS-IRRS-2011/07, Integrated Regulatory Review Service (IRRS) Mission to the Republic of Korea (Final Draft), 2011.