Assessment of Coping Capability of KORI Unit 1 under Extended Loss AC Power and Loss of Ultimate Heat Sink Initiated by Beyond Design Natural Disaster

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1. Introduction

The safety of the nuclear power plant depends on the availability of the continuous and reliable sources of electric energy and heat sink during all modes operation of the plant. The Fukushima Dai-ichi nuclear power plant accident showed the vulnerability of coping strategy to beyond design natural disaster such as beyond design earthquake and tsunami. In Korea, the government and industry performed comprehensive safety inspection on all domestic nuclear power plants against beyond design basis external events and fifty action items have been issued[1]. In addition to post-Fukushima action items, the stress tests for all domestic nuclear power plants are on the way to enhance the safety of domestic nuclear power plants through finding the vulnerabilities in intentional stress conditions initiated by beyond design natural disaster. Recently, the stress tests for WOLSONG Unit 1[2, 3] and KORI Unit 1[4] have been performed and their assessment results have been reviewed by Korean regulatory body. This paper presents assessment results of coping capability of KORI Unit 1 under the simultaneous Extended Loss of AC Power (ELAP) and Loss of Ultimate Heat Sink (LUHS) which is a representative plant condition initiated by beyond design natural disaster.

2. Methods and Results

2.1 Assessment Scenarios

The assessment has been performed to examine whether the plant still can maintain its capability, in the event of loss of safety functions, to sufficiently cool down the reactor core without fuel damage, to keep pressure boundaries of the Reactor Coolant System (RCS) in transient condition and to control containment pressure and temperature to maintain the integrity of the containment building. A series of accident scenarios under the following conditions have been analyzed to judge the plant's capability to cope with loss of electrical power or/and loss of ultimate heat sink according to the stress test guideline of Nuclear Safety and Security Commission (NSSC) [5]:

(1) Loss of Off-site Power (LOOP)
(2) Station Blackout (SBO)
(3) SBO combined with loss of AAC DG (Extended Loss of AC Power, ELAP)
(4) Loss of Ultimate Heat Sink (LUHS)
(5) LUHS + Alternative Heat Sink
(6) ELAP + LUHS

Based on the scenarios described above, additional scenarios have been considered with natural disasters covering earthquake, flooding, tsunami, etc.:

(7) Earthquake-induced tsunami accompanying ELAP + LUHS
(8) Storm surge/tsunami and precipitation accompanying ELAP + LUHS
(9) Beyond design earthquake (0.3g) accompanying ELAP + LUHS

2.2 Assessment of System and Components Required for Maintaining and Restoring Safety Functions

The analysis on the cliff-edge situations using RELAP/MOD3 thermal hydraulic code [6] has been performed assuming that all electrical AC Power and ultimate heat sinks are lost. The analysis result shows that steam generator inventory would be depleted in about 70 minutes without any manual actions by the operator and the automatic operations of equipment and components except passive components as shown Fig. 1.

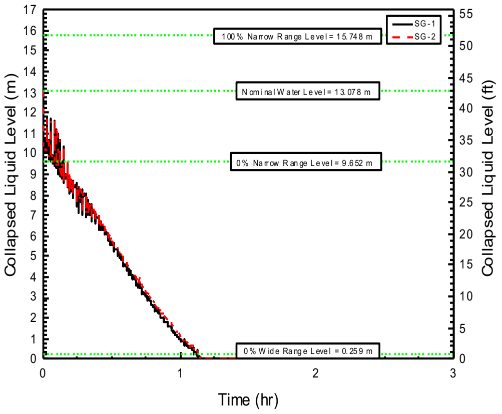

Fig. 1. SG collapsed liquid level when the secondary feed to SG is not credited.

The main equipment and components for maintaining safety features under the simultaneous ELAP and

LUHS has been identified as batteries, Turbine Driven Auxiliary Feed Water Pump (TD-AFWP), Pressurizer Safety Valves (PSV), reactor coolant gas vent valves, Main Steam Safety Valves (MSSV), Steam Generator Power Operated Relief Valves (SG-PORV), Safety Injection Tanks (SIT), Charging Pumps (CHP), Containment Spray Pumps (CSP), Refueling Water Storage Tank (RWST), and Condensate Storage Tank (CST). These critical equipment and components and their auxiliary systems have been assessed to be available for a certain period time.

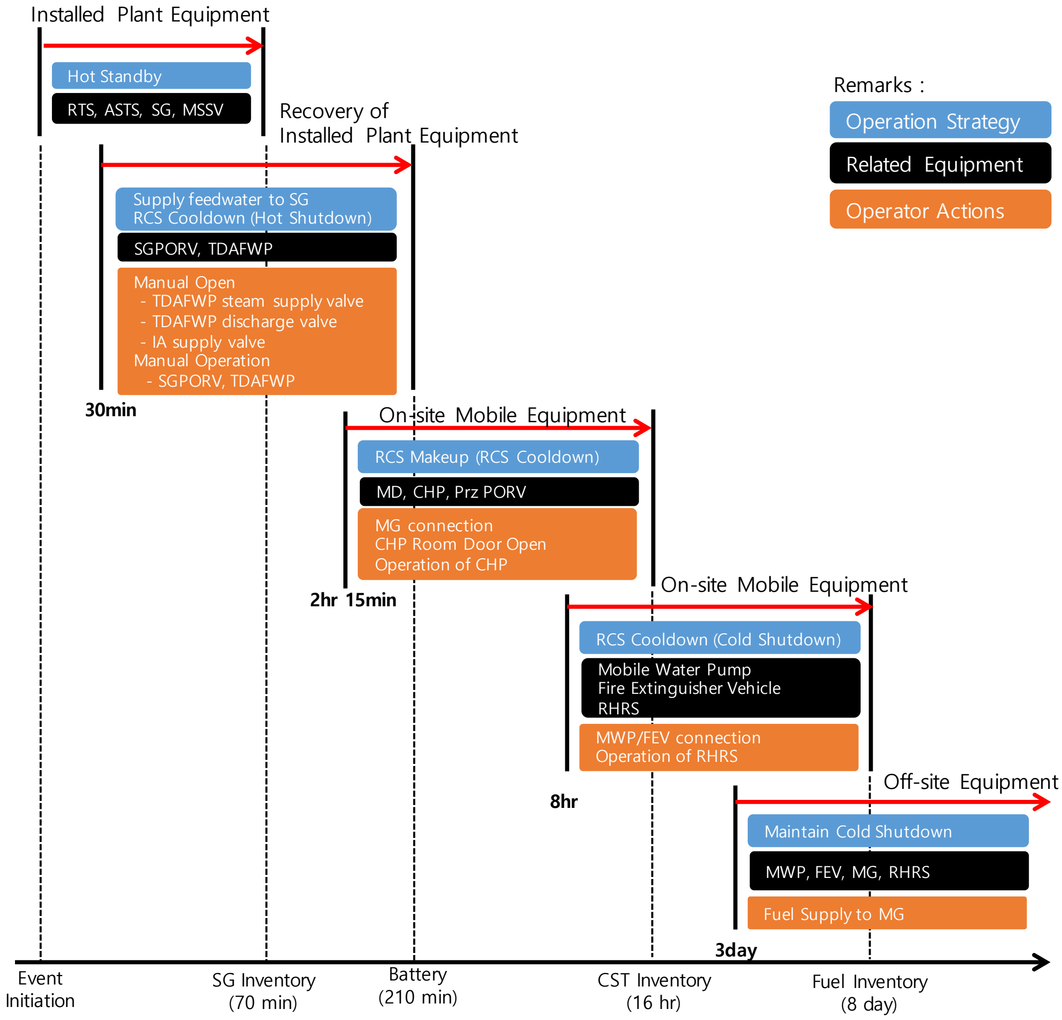

Fig. 2 Plant Coping Strategy for Beyond Design Earthquake accompanying ELAP and LUHS.

2.3 Assessment Results with Scenario 9 (Beyond Design Earth Earthquake (0.3g) Accompanying ELAP + LUHS)

In the event of beyond design earthquake (0.3g) accompanying ELAP and LUHS, the reactor will shut down safely through automatic operation of Reactor Trip System (RTS) and Automatic Seismic Trip System (ASTS). The situation of plant and coping strategy in this scenario are summarized in Fig. 2. The critical equipment and components such as Charging Pumps (CHP), Component Cooling Pumps (CCWP) and Component Cooling Sea Water Pumps (CCSWP) are not operated due to ELAP and LUHS. The loss of feed water supply to SG takes places with the stop of main feed water system. Without any operator actions, the cliff edge times for loss of SG inventory and the supply of electric power through DC batteries have been estimated as 70 minutes and 210 minutes, respectively.

The operator will initiate the manual operation of Turbine-Driven Auxiliary Feedwater Pump (TD-AFWP) and the feed water is supplied to SG through seismically designed Condensate Storage Tank (CST) within 30 minutes after the diagnosis of the event. The decay heat is removed by natural circulation cool down with the operation of SG PORV that operates with battery and safety grade Instrument Air (IA) system. With these operator actions, the cliff-edge times for SG inventory and the core uncover due to RCP seal leakage are increased to 16 hours and 18 hours, respectively.

The assessment on the capacity of safety equipment of KORI Unit 1 has shown that class 1E battery has a capacity of 3.5 hours with load shedding. Therefore, within 3.5 hours, the plant should connect the Mobile Generator (MG) to activate charging pumps to restore RCS inventory. Once the MG connection is succeeded, RCS cooling is initiated by increasing steam relief through SG PORVs. In this case, void generation in the RCS by RCP seal leak is inevitable, therefore, rapid cooling at a rate 100^{o}F/hr should be performed. With this operator action the cliff edge time for electricity supply is increased to 8 days because the MG can run for about 8 days with its own fuels and EDG fuels.

For LUHS, sea water can be supplied to the secondary side of CCW heat exchanger by mobile water pumps and fire extinguisher vehicles within 8 hours. Afterwards, the plant will be cooled down by RHRS operation and can maintain the cold shutdown state within 15 hours. Through the operation of RHRS, the cliff edge times for SG depletion and core uncover are no more concerns. The electricity supply to essential components can be maintained because the continuous supply of fuels to MG is possible from off-site.

2.4 Safety Improvement Items

Through an assessment of KORI Unit 1 for the coping capability to beyond design natural disaster, the following safety improvement items are drawn:

(a) Increase of battery capacity up to at least 8 hours to cope with uncertainties of mobile generator availability under beyond design natural disaster
(b) Additional securement of mobile generator to cope with multi-unit accidents (N+1 per site)
(c) Securement of mobile seawater pumps (mobile water pumps and fire extinguisher vehicles will play the role of mobile seawater pump in case of KORI Unit 1)
(d) Communication tools between field operators and main control room or remote shutdown panel
(e) Updating emergency operating procedures and guideline
(f) Plant operating guideline on emergency back-up equipment

3. Conclusions

The assessment of the coping capability of KORI Unit 1 has been performed under simultaneous the extended loss of AC power and loss of ultimate heat sink initiated by beyond design natural disaster. It is concluded that KORI Unit 1 has the capability, in the event of loss of safety functions by beyond design natural disaster, to sufficiently cool down the reactor core without fuel damage, to keep pressure boundaries of the reactor coolant system in transient condition and to control containment and temperature to maintain the integrity of the containment buildings. The several additional items for safety improvement has been drawn to enhance the coping capability for loss of safety functions under beyond design natural disaster in addition to post Fukushima action items.

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