ANALYSIS OF OPERATIONAL EFFECTS OF EXTERNAL WATER INJECTION DURING EXTENDED LOSS OF AC POWER UNDER HAZARD CONDITIONS

Wook-Cheol, Seol[1], Ji-yong Oh[2*], Yong-soo Kim[3]

[1,2,3] Central Research Institute of Korea Hydro & Nuclear Power, Ltd. Yuseong-Gu, Daejeon, Korea, 305-343,
[*]Corresponding author: jiyong.oh@khnp.co.kr

EXTENDED ABSTRACT

The Fukushima accident demonstrated that the flexible and diverse mitigation strategies are needed to cope with a variety of unforeseen accident conditions. These mitigation strategies will be typically implemented in Phase 2 or 3 when the evolving accident cannot be properly coped with by the use of fixed equipment alone [1]. There has been world-wide effort to implement the accident mitigation strategies at nuclear power plants to further strengthen defense in depth [2]. In the USA, the portable equipment that will be used to implement the mitigation strategies is called FLEX (Diverse and Flexible Coping Strategies) equipment. In Korea, the accident mitigation strategies will be carried out by so-called MACST (Multi-barrier Accident Coping Strategy) equipment, consisting of mobile diesel generators, mobile pumps, and so on. MACST is the strategy and equipment that KHNP (Korea Hydro & Nuclear Power) developed to cope with severe accident such as Fukushima Daiichi nuclear accident [3]. Since sufficient water sources are required to use these strategies, various water sources are currently being considered for nuclear power plants. However, these water sources cannot provide an infinite supply of coolant, and non-seismically designed water sources cannot be used during seismic-induced accidents. Therefore, in such limited situations, it will be difficult to expect proper cooling if an accident proceeds for days or more. In order to address this issue, it is necessary to develop response strategies that can utilize limited water sources effectively.

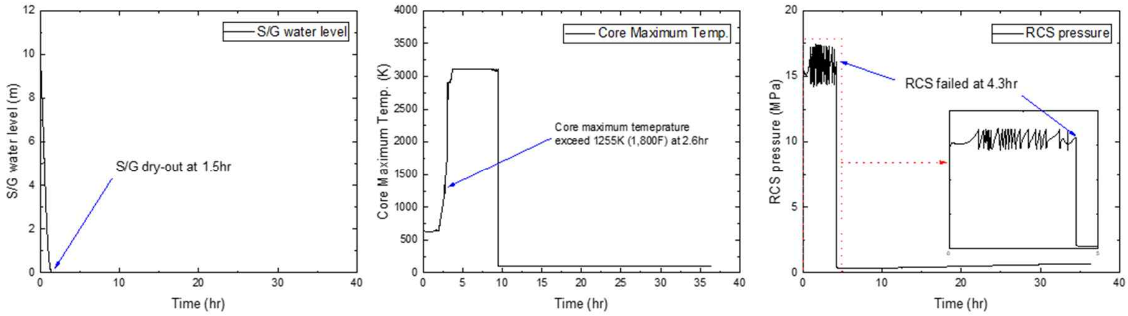
This analysis was therefore performed in consideration of operational parameters so that limited water sources and mobile pumps could be used during long-term accidents such as Fukushima. To analyze the effect of operational parameters on accident progression, the behaviors of the reactor coolant system, steam generator, and containment were considered. The present study is carried out for a nuclear power plant featuring a pressurized light water reactor with a thermal power rating of 3,000 MW. The base accident scenario is an extended loss of AC power (ELAP), which is a long-term loss of internal and external power in nuclear power plants. For evaluating the effectiveness of mobile pump operation in a severe accident after core damage, the applied accident scenario assumes that the core is damaged due to the absence of any safety actions. In the case of external power recovery after core damage, it is assumed that power is recovered by a mobile diesel generator before reactor vessel failure.

TABLE I. SCENARIO CASES

Case ID	Bleed	Feed	Injection Type	Set Points
Base Case	-	-	-	-
Case 1-1	ADV	Mobile Pump	Continuous	S/G water level
Case 1-2			Intermittent	

The base case is a scenario in which core damage occurs due to the loss of AC power without any safety measures such as depressurization or safety injection. Case 1 considers steam generator (S/G) depressurization through opening the ADV and on-site water(such as water tank or pond) injection into the secondary side using a mobile pump. Specifically, a comparative analysis was performed by dividing the cases into continuous injection using the mobile pump (Case 1-1) and injection operation adjusted according to the water level of the steam generator (Case 1-2).

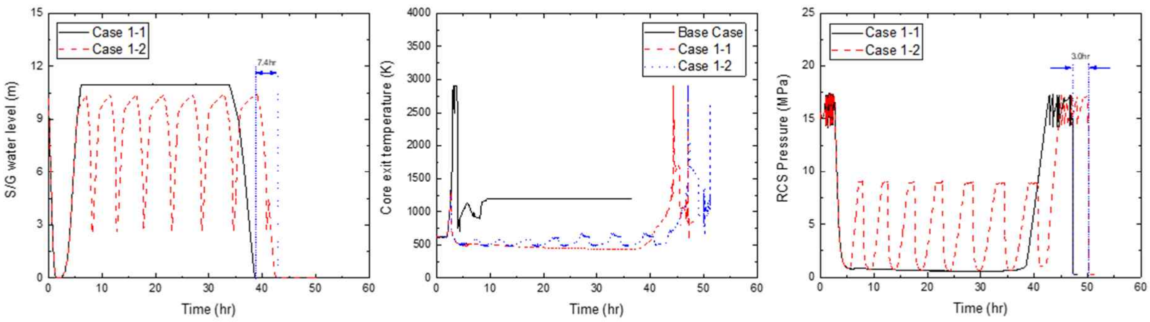
The steam generator dries out in about 1.5 hours after station blackout occurs in the base case. Subsequently, it was analyzed that the core becomes uncovered at 2 hours due to the loss of all coolant in the primary system, and that the maximum core temperature exceeds 1,255 K (1,800°F) at 2.6 hours, resulting in core damage. After that, since no action is taken to cool the core, the core melts and relocates to the reactor vessel lower head. The reactor vessel is continuously heated by the corium and eventually ruptures (FIGURE 1).



<S/G water level> <Core maximum Temp.> <RCS Pressure>

FIGURE 1. RESULTS OF BASE CASE

In Case 1-1, as shown in FIGURE 2, the water level is recovered due to external water injection starting at 2.6 hours after the accident occurs. The core exit temperature of the primary system decreases due to secondary heat removal. However, the temperature rises sharply again after the external water source is depleted. The core is heated up to melting temperature again, resulting in core melt and relocation to the lower head. The reactor vessel is continuously heated by the corium and eventually ruptures. In Case 1-2, when the timing of external water source depletion is delayed, corium relocation and reactor vessel failure timing are also delayed by approximately 3 hours each. As the external water depletion progresses, the time to vessel failure is delayed because the mobile pump is operated according to the secondary water level.



<S/G water level> <Core Exit Temp.> <RCS Pressure>

FIGURE 2. RESULTS OF CASE 1-1 AND 1-2

It was analyzed that performing secondary system heat removal through external water injection provides a time margin of approximately 40 hours before reactor vessel failure occurs. Furthermore, if the external water injection operation is appropriately adjusted based on the secondary system water level, an additional time margin of about 3 hours can be secured.

REFERENCES

[1] Nuclear Energy Institute, “Diverse and Flexible Coping Strategies (FLEX) Implementation Guide,” NEI-12-06 (2012).
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