The Effects of Mitigative Strategies on SBO Severe Accidents in the KSNP

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1. Introduction

The purpose of this analysis is to evaluate the effects of safety systems or mitigative strategies on the progression of severe accidents. The Korean standard nuclear power plant (KSNP) has been selected as a reference plant, and the eight station blackout sequences, which are the most likely scenarios based on the probabilistic safety analysis of the KSNP[1], have been determined as base cases. These eight sequences account for 99 percent of the occurrence frequency of a total of 197 station blackout accident scenarios. Furthermore, an additional evaluation for the strategy of a primary feed & bleed strategy has been performed as sensitivity cases. Thermal hydraulic analyses have been done by using MAAP version 4.06.

2. Analysis and Results

2.1 Characteristics of Base Sequences

The eight base sequences are classified as to whether they are successful operations for a secondary heat removal, primary safety injection, or containment spray injection as mitigative strategies. Table 1 represents the analyzed cases and the evaluated strategies. The secondary heat can be removed via an auxiliary feedwater system (AFW), and atmospheric dump valves (ADV) or main steam safety valves (MSSV). Turbine driven auxiliary feedwater pumps are designed to supply feedwater into the steam generators for about 4 hours without a AC power supply.

Table 1. Mitigative Strategies Applied to Each Calculation Case

Sequence	Secondary Heat Removal	HPSIS Operation	CSS Operation	AC Power Restoring
SBO-33	AFW+ADV	Success	Success	Before RV fail
SBO-41	AFW+ADV	Fail	Success	After RV fail
SBO-45	AFW+ADV	Fail	Fail	No Restoring
SBO-78	AFW+MSSV	Success	Success	Before RV fail
SBO-86	AFW+MSSV	Fail	Success	After RV fail
SBO-90	AFW+MSSV	Fail	Fail	No Restoring
SBO1-90	Fail	Fail	Success	After RV fail
SBO1-94	Fail	Fail	Fail	No Restoring

The AC power is restored before a reactor vessel failure in SBO-33 and 78 sequences, thus high pressure safety injection systems (HPSIS) and containment spray systems (CSS) can be operated. For the SBO-41, 86 and SBO1-90 sequences, the CSS is operable only after a reactor vessel failure due to a late power recovery.

2.2 Results of Base Sequences

Without the secondary heat removal (SBO1-90, 94), a core uncovery and ae reactor vessel failure occur at 6,980 and 15,030 seconds, respectively. Meanwhile the core uncovery and the reactor vessel failure are delayed by 23,640 (6.6 hours) and about 27,080 seconds (7.5 hours) for the secondary heat removal by using the AFW pump and MSSV (SBO-78, 86, 90). When the decay heat is removed by using the AFW pump and the ADV (SBO-33, 41, 45), they are delayed by 54,260 (15.1 hours) and about 64,570 seconds (17.9 hours), respectively.

Even if the HPSI pump can work before a vessel failure following a power recovery (SBO-33, 78), a cooling water can not be injected into the vessel due to a high system pressure. Instead, it minimizes the concrete erosion in the reactor cavity where water is available as soon as a vessel failure occurs.

The containment spray system has been assumed to be powered at before a vessel failure for SBO-33, 78 and at 48 hours after an accident initiation for SBO-41,86, SBO1-90. There are considerable decreases in the containment peak pressure and the concrete erosion. The calculation results are summarized in Table 2.

Table 2. Event Summary for Base Sequences

Sequence	Core Uncovery Time (second)	Reactor Vessel Failure Time (second)	Containment Peak Pressure (MPa)	Concrete Erosion Depth in Cavity (m)
SBO-33	61,240	79,270	0.47	Negligible
SBO-41	61,240	79,600	0.91	Negligible
SBO-45	61,240	79,600	1.13	0.89
SBO-78	30,620	41,900	0.42	Negligible
SBO-86	30.620	42,110	1.05	0.41
SBO-90	30,620	42,110	1.27	1.56
SBO1-90	6,980	15,030	0.99	Negligible
SBO1-94	6,980	15,030	1.34	2.32

2.3 Analisis of Sensitivity Cases

An additional evaluation for the strategy of a primary feed & bleed strategy has been performed as a sensitivity case. The sensitivity parameters are the number of feed (high pressure injection, low pressure injection) and bleed (safety depressurization system, SDS) systems, and the bleed time. The considered cases, which are summarized in Table 3, are expanded from SBO-33 in the previous Section.

Based on the MAAP calculations, the feed and bleed strategy using 1 SDS and 1 HPSI train at the time of a PSV (pressurizer safety valve) first opening (SB033AH1) could prevent a core uncovery. When the 2 SDS and 2 LPSI are available at this time (SB033AL2) the corium does not relocated into the lower plenum even though the core has been uncovered. In the case that the depressurization initiated at a core uncovery, the corium relocation could be prevented with the cases of SB033BL2, SB033BH1, and SB033BH2. Moreover, a relocation does not occur by using the HPSI system as long as the strategy is initiated within 2 hours of a core uncovery.

3. Summary

The effects on the mitigation measures for an secondary heat removal, a containment spray , and a primary feed & bleed are evaluated for the SBO sequences of the KSNP. A core uncovery and a reactor vessel failure are delayed by 23,640 and 27,080 seconds for the secondary heat removal by using the AFW pump and the MSSV. They are delayed by 54,260 and 64,570 seconds, respectively, when the AFW pump and the ADV are used. A core uncovery or corium relocation is likely prevented by a feed and bleed operation even though it depends on the number of systems and the depressurization times.

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REFERENCES

[1] KEPCO,"Ulchin 3&4 Final Probabilistic Safety Assessment Report"

Table 3. Accident Progression Summary for the Sensitivity Cases

Sequence	Sensitivity Parameter (Input)		Event Time (Calculation Result)			
	RCS Bleed Time (second)	Feed & Bleed System	Core Uncovery (second)	HPSI Injection (second)	LPSI Injection (second)	Corium Relocation into Lower Vessel (second)
SBO-33	N/A	N/A	61,240	N/A	N/A	78,030
SB033CH1	at core uncovery + 2 hours	1 SDS & 1 HPSI	61,240	68,700		No Relocation
SB033CH2		2 SDS & 2 HPSI		68,610		
SB033BL1	at core uncovery	1 SDS & 1 LPSI	61,240		after RV Fail	80,870
SB033BL2		2 SDS & 2 LPSI			65,090	No Relocation
SB033BH1		1 SDS & 1 HPSI		61,650		
SB033BH2		2 SDS & 2 HPSI		61,460		
SB033AL1	at PSV first open (28,500 seconds)	1 SDS & 1 LPSI	37,110		63,230	57,480
SB033AL2		2 SDS & 2 LPSI	36,100		37,270	No Relocation
SB033AH1		1 SDS & 1 HPSI	No Uncovery	32,180		