An Evaluation of Time Requirements to Restore the off-site Power in a SBO for OPR1000

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1. Introduction

When all emergency diesel generators and alternate alternating current diesel generator fail to operate under loss of off-site power, operators should restore the power supply to engineered safety features to mitigate the event. Failure of this action leads to core damage according to PSA [1].

In the previous PSA, the time requirement to restore the off-site power was calculated by the MAAP4 code which was designed to simulate a severe accident analysis. However, to meet the requirements of the ASME PRA standard [2], a thermal hydraulic analysis based on the best-estimate code such as RELAP/MOD3.3, MARS is required.

In this paper, the time requirement to restore the power in a station blackout by the MARS code and impact on the PSA are assessed.

2. Analysis and Results

2.1 Identification of Event Sequence

The event tree for a station blackout (SBO) contains three cases to lead core damage, as shown in Fig. 1.

In the Case 1 sequence, turbine-driven auxiliary feed water pump (TD-AFWP) is successfully actuated and operated for 4 hours based on capacity of its battery after the SBO occurs. Then, steam release by the atmospheric dump valve (ADV) is performed. In the Case 2 sequence, secondary heat removal by the TD-AFWP and main steam safety valves (MSSV) is performed. Case 3 sequence has no recovery action.

After the off-site power is restored thoroughly, additional recovery action such as shutdown cooling, secondary heat removal, and feed and bleed operation is required to prevent core damage.

2.2 Modeling Assumption

The criterion for core damage is 2200˚F(1477K) for the MARS code.

The time requirement to restore the off-site power is considered as the time from when the SBO occurs to the time before the core is uncovered.

The following assumptions related to an accident mitigation system are used to the select sequences.

- A TD-AFWP is actuated and delivers auxiliary feedwater flow to one SG when the SG narrow-range level is decreased to the low-low level, i.e., 23.6%.

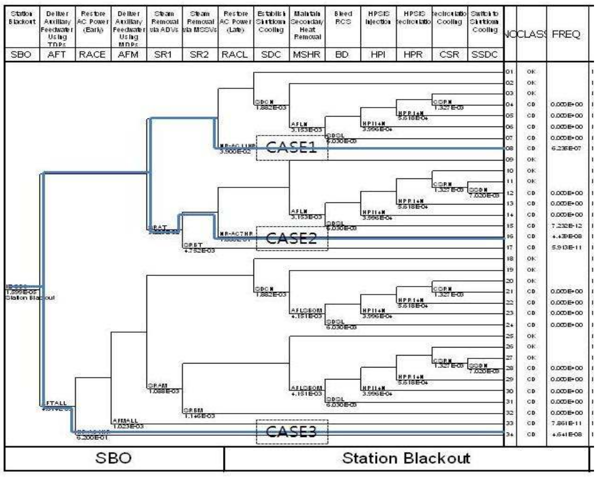

Fig.1. Three cases (sequence no. 8, 16, 34) are related to the time requirement to restore off-site power in the SBO event tree.

- A TD-AFWP which is powered by safety class batteries operates to supply water into the SG for four hours.
- After power is recovered, MD-AFWP is actuated and delivers the flow to one SG.
- CST dries out at 12 hours after the SBO occurs.
- For feed and bleed operation, when the wide range level of two SGs is less than 2%, the operator should stop all RCPs and manually open two safety depressurization system (SDS) [3].
- When the temperature of the SI flow is constant, it is assumed that high pressure recirculation and recirculation cooling of the SI flow are successfully performed.

2.3 Analysis Results

According to the TD-AFWP operation at the beginning of the accident, the time requirements to restore the off-site power are shown in Table I. In the case of steam release by means of the atmospheric dump valve (ADV), the time requirement to restore the off-site power is regarded as approximately 10 hours. In the case of using MSSV, the time requirement for power recovery is considered as nearly 5 hours. When the TD-AFWP fails to operate, the time requirement to recover the power is defined as 1 hour before the core is uncovered.

Table I: MARS analysis results considering no power recovery after SBO occurs

Event/Time(min)	Case 1	Case 2	Case 3
Event begins, Reactor trip	0.0	0.0	0.0
TD-AFWP starts	1.0 (ADV)	1.0 (MSSV)	-
TD-AFWP stops	241.0	241.0	-
T_{CET*}>662°F	594.4	320.2	41.6
PSV open	597.1	320.2	42.9
Core uncover	**660.1**	**386.9**	**90.3**
T_{CET*} > 1200°F	671.9	395.9	97.0
PCT > 2200°F	676.8	400.2	100.0
END	676.8	400.2	100.0

CET* : Core Exit Temperature
PCT : Peak Cladding Temperature

Based on the time requirements to restore the off-site power from the Table I, sequences including feed and bleed operation are evaluated by the MARS code for verification. The MARS results show that the time requirements to restore the off-site power are appropriately evaluated for feed and bleed operation as shown in Table II.

Table II: MARS analysis results considering power recovery and feed and bleed operation after SBO occurs

Event/Time(min)	Sequence No. 3	Sequence No. 10	Sequence No. 26
Event begins	0.0	0.0	0.0
TD-AFWP starts	1.0	1.0	-
TD-AFWP stops	241.0	241.0	-
Power recovery	600.0	300.0	60.0
MD-AFWP starts	-	-	60.0
CST dry out MD-AFWP stops	-	-	720.0
T_{CET*}>662°F	596.7	321.3	853.5
PSV open	597.2	321.3	853.3
Bleed operation	630.2	330.2	870.0
Core uncover	650.2	358.5	895.2
HPSI injection	656.5	358.0	897.5
Core covered	696.3	408.3	970.7
T_{CET} > 1200°F	661.0	-	-
PCT > 2200°F	-	-	-
END	1000.0	1000.0	1000.0

Table III shows that the MARS analyses provide smaller time windows compared to the MAAP4 analyses. The characteristics of the two codes results in different time windows.

Table III: Comparison of time requirements to restore the power with various conditions between the MARS analysis and the MAAP4 analysis

Conditions	MARS	MAAP4
TD-AFWP with ADV	10 hours	11 hours
TD-AFWP with MSSV	5 hours	6 hours
No TD-AFWP	1 hour	1 hour

2.4 PSA Effects

This section assessed the impact of time requirements to recover the off-site power for a SBO on the PSA. Table IV shows the re-estimated recovery failure probability [4] and the core damage frequency (CDF) change rate based on the MARS analysis and the MAAP4 analysis. The recovery failure probabilities were increased from 25.6% to 40.0% compared to those of the MAAP4 analysis. The change in the CDF was increased by 3.3%.

Table IV: Re-estimated recovery failure probability and CDF compared to the previous results

Operation Conditions	Recovery failure probability		CDF	
	MARS	MAAP4	MARS	MAAP4
TD-AFWP with ADV	4.9E-2	3.9E-2	+3.3%	0.0
TD-AFWP with MSSV	1.0E-1	1.4E-1		

3. Conclusions

We assessed the time requirements to restore the off-site power in a SBO using the MARS code and the impact on PSA. The results show that those of the MARS analyses provide smaller time requirements than those of the MAAP4 analyses and increase the CDF by 3.3%.

In the previous PSA, the time requirements was considered as the time before the core was uncovered and was not evaluated with consideration of the subsequent actions such as actuation of MD-AFWP and feed and bleed operation. But, for a more realistic and accurate PSA, this study shows that the time requirements calculation for power recovery in a SBO should be analyzed by considering the subsequent operator's actions after power recovery additionally.

REFERENCES

[1] KHNP, "Probabilistic Safety Assessment for Ulchin unit 3&4, November, 2004.
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