Analysis of Golden Time for Recovering the Safety Injection System in BDBA

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1. Introduction

The Fukushima accident gave great fear and also, many Koreans recognized the importance of golden time at the ferry Sewol accident. Design basis accidents (DBAs) such as loss-of-coolant accident (LOCA) in nuclear power plants (NPPs) may lead to serious accidents that exceed the DBAs due to failure of safety systems [1]. We predicted the golden time for safety injection system (SIS) recovery that can accomplish a reactor cold-shutdown and prevent core uncovery or RV failure when the SIS was not operated normally [2].

In this study, the core uncovery and RV failure according to event types were analyzed by using the MAAP code when SIS was not operating normally. The parameters of the MAAP simulation are based on the optimized power rector 1000 (OPR1000). If the plant operator knows the golden time, it is expected that they can better organize their recovery and mitigation actions.

2. The definition of simulation events

Reactor core damage was defined as follows: (ASME PRA Standard [3])

(1) The maximum temperature of the fuel claddings exceeds the 982℃.
(2) The core exit temperature (CET) exceeds the 649℃ for more than 30minutes.
(3) The piping in the reactor coolant system (RCS) is broken, and proper core cooling is not performed.
(4) The core temperature is not reduced and the long term residual heat is not removed for a certain period of time.

The end of the accident and the criteria were defined as follows [4]:

(1) Neither the operator action nor the system was required in order to mitigate accident.
(2) The core stays the subcritical within 24 hours of the accident. And it is continuously cooling without core damage.

Table I shows core damage frequency in the Shin Kori 1, 2 units PSA report. The MAAP simulations include several major initial events that contribute largely to CDF. Also, the MAAP simulation will be extended continuously to include more initial events. Simulations were conducted according to event case (Table II). It was assumed that there were a variety of situations for SIS failure. It is assumed that passive systems were operated in the simulations.

Table I: Core damage frequency (CDF)

Event		Initiating Events Frequencies (/year)	CDF (/year)	CDF (%)
LOCA	LBLOCA	1.70E-04	6.52E-07	9.4
	MBLOCA	1.70E-04	5.10E-07	7.4
	SBLOCA	3.00E-03	1.66E-06	23.9
	SGTR	4.50E-03	4.22E-07	6.1
	ISLOCA	1.77E-09	1.77E-09	0.0
	RV failure	2.66E-07	266E-07	3.8
	All LOCA		3.51E-06	50.6
Anticipated transients	LSSB	1.50E-03	1.08E-08	0.2
	LOFW	5.50E-01	1.05E-06	15.1
	LOCV	2.30E-01	3.64E-07	0.5
	LOCCW	7.30E-02	2.47E-07	3.6
	LOKV	1.75E-03	3.34E-09	0.1
	LODC	3.50E-03	1.97E-07	2.8
	LOOP	3.19E-02	8.09E-07	11.7
	SBO	5.34E-06	2.31E-07	3.3
	GTRN	3.40E+00	5.65E-07	8.1
	ATWS	2.18E-05	2.80E-07	4.0
	All anticipated transient		3.43E-06	49.4
All transient			6.94E-06	100

Table II: Simulation event cases

SIS	LOCA			SGTR	MSLB	LOFW	SBO
	SB	MB	LB				
HPI	Delay Inj	Delay Inj	Delay Inj	Delay Inj	Delay Inj	Delay Inj	Delay Inj
LPI	Inj	N/A	N/A	N/A	N/A	N/A	N/A
AFW	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CSS	Inj & Rec	N/A	N/A	N/A	N/A	N/A	Delay Inj & Rec
FAN	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CHP	N/A	N/A	N/A	N/A	N/A	N/A	N/A
PZR V/V	N/A	N/A	Delay Inj	Delay Inj	Delay Inj	Delay Inj	Delay Inj
REC ON	Delay Inj & Rec	Delay Inj & Rec	Inj & Rec	Inj & Rec	Inj & Rec	Inj & Rec	Inj & Rec
AC power	ON	ON	ON	ON	ON	ON	Delay ON
DC power	ON	ON	ON	ON	ON	ON	OFF
MFW	Inj	Inj	Inj	Inj	Inj	N/A	Inj

2.1 LOCA

The LOCA simulations were conducted according to break size (large, medium and small) relative to the double ended guillotine break (DEGB) of the cold-leg (30 inch). The LOCA is a one of DBAs, if not managed effectively, the results of a LOCA could result in core damage.

(1) LBLOCA
The LBLOCA simulation is conducted for the break size of 6 inches in diameter. The analysis result of the MAAP simulation shows that the core uncovery time and RV failure time are 17 and 5,477 seconds when SIS was not operating normally.

(2) MBLOCA
The MBLOCA simulation is conducted for the break size of 4 inches in diameter. The analysis result of the MAAP simulation shows that the core uncovery time and RV failure time are 1,113 and 8,175 seconds when SIS was not operating normally.

(3) SBLOCA
The SBLOCA simulation is conducted for the break size of 2 inches in diameter. The analysis result of the MAAP simulation shows that the core uncovery time and RV failure time are 3,369 and 12,225 seconds when SIS was not operating normally.

2.2 Steam generator tube rupture (SGTR)

The SGTR simulation is conducted for the break of the tube inside the steam generator. The analysis result of the MAAP simulation shows that the core uncovery time and RV failure time are 5,426 and 15,051 seconds when SIS was not operating normally.

2.3 Main steam line break (MSLB)

MSLB is a large secondary steam line break outside or inside the containment. The MSLB simulation was conducted for DEGB of the main steam line. The analysis result of the MAAP simulation shows that the core uncovery time and RV failure time are 2,325 and 8,489 seconds when SIS was not operating normally.

2.4 Loss of feed water (LOFW)

The LOFW includes the failures of the main feed water system and the relevant system. The analysis result of the MAAP simulation shows that the core uncovery time and RV failure time are 2,362 and 8,391 seconds when safety SIS was not operating normally.

2.5 SBO

The SBO corresponds to a total loss of all alternate current (AC) power as a result of complete failure of both offsite and onsite AC power sources including emergency diesel generator. The analysis result of the MAAP simulation shows that the core uncovery time and RV failure time are 33,447 and 45,009 seconds when SIS was not operating normally.

3. Analysis results of golden time

Table III shows the core uncovery time, RV failure time, golden time of the event.

Table III: Golden time of event type

Event	Golden time		Failed time	
	Core uncovery	RV failure	Core uncovery	RV failure
LBLOCA	-	4,010	17	5,477
MBLOCA	-	7,210	1,113	8,175
SBLOCA	1,920	11,880	3,369	12,225
SGTR	2,520	14,030	5,426	15,051
MSLB	550	8,190	2,325	8,489
LOFW	470	8,030	2,362	8,391
SBO	17,920	30,090	33,447	45,009

3.1 Golden time of LOCA

(1) LBLOCA
The analysis result of the golden time shows that the golden time for preventing RV failure is 4,010 seconds. In LBLOCA, there is no way to prevent the core uncovery. Fig. 1 shows the CET when SIS is activated before the golden time.

(2) MBLOCA
The analysis result of the golden time shows that the golden time for preventing RV failure is 7,210 seconds. In MBLOCA, there is no way to prevent the core uncovery. Fig. 2 shows the CET when SIS is activated before the golden time.

(3) SBLOCA
The analysis result of the golden time shows that the golden times for preventing core uncovery and RV failure are 1,920 and 11,880 seconds. Fig. 3 shows the CET when SIS is activated before the golden time.

3.2 Golden time of SGTR

The analysis result of the golden time shows that the golden times for preventing core uncovery and RV failure are 2,520 and 14,030 seconds. Fig. 4 shows the CET when SIS is activated before the golden time.

3.3 Golden time of MSLB

The analysis result of the golden time shows that the golden times for preventing core uncovery and RV failure are 550 and 8,190 seconds. Fig. 5 shows the CET when SIS is activated before the golden time.

3.4 Golden time of LOFW

The analysis result of the golden time shows that the golden times for preventing core uncovery and RV failure are 470 and 8,030 seconds. Fig. 6 shows the CET when SIS is activated before the golden time.

3.5 Golden time of SBO

The analysis result of the golden time shows that the golden times for preventing core uncovery and RV failure are 17,920 and 30,090 seconds. Fig. 7 shows the CET when SIS is activated before the golden time.

4. Conclusions

When an event occurred, the normal operation of SIS is very important in maintaining the integrity of NPPs [1]. Each event has different activities to perform within golden time. If the recovery time of SIS for accident recovery is predicted, the core will not be exposed through appropriate action. Also, the RV failure will be prevented by the cooling water injection even if the reactor core is exposed [5].

In this study, we concluded that the CET is one of the most important factors to analyze the degree of core damage. The research on the golden time will be possible to more efficiently manage accidents beyond design basis for accident recovery. And it is expected to contribute to the safety improvement of NPPs.

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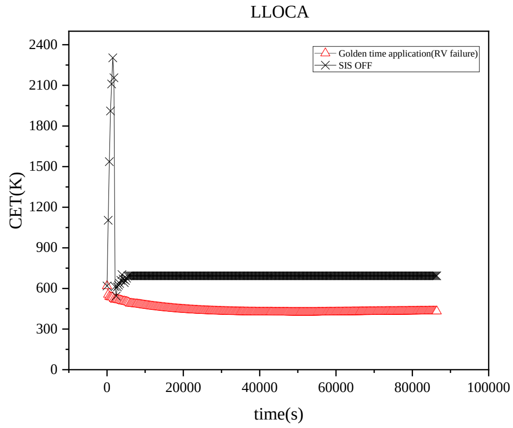

Fig. 1. CET of LBLOCA

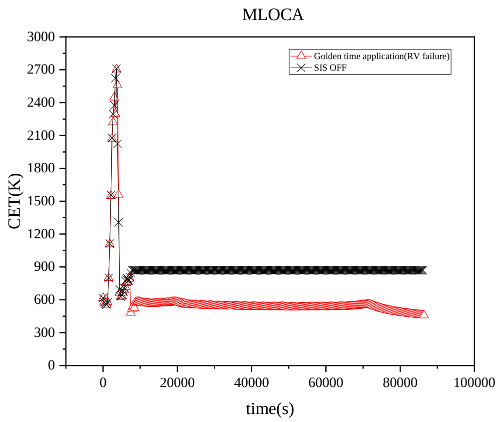

Fig. 2. CET of MBLOCA

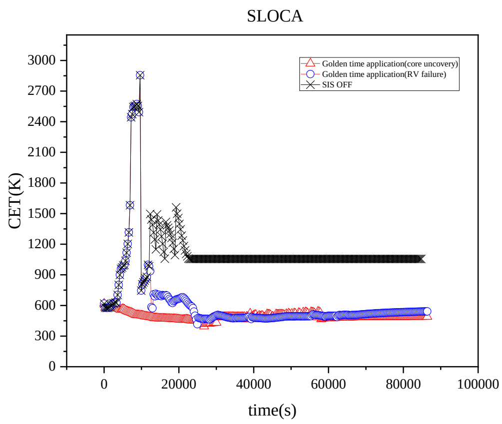

Fig. 3. CET of SBLOCA

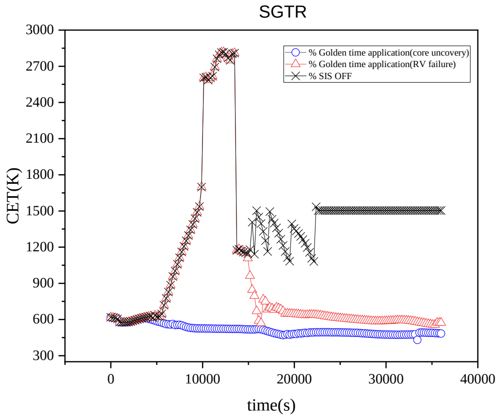

Fig. 4. CET of SGTR

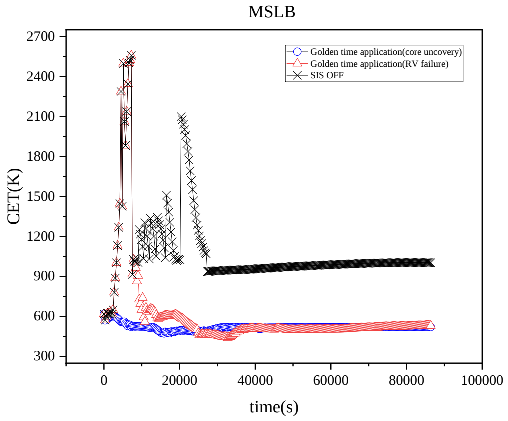

Fig. 5. CET of MSLB

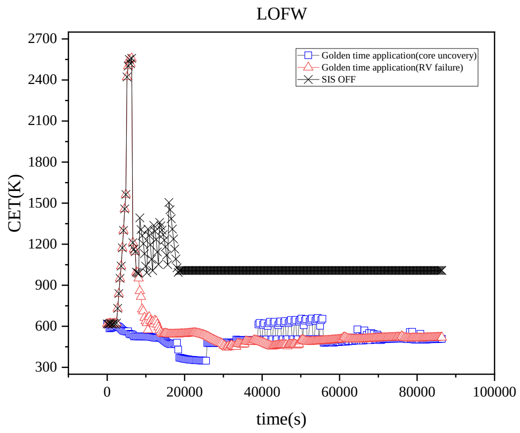

Fig. 6. CET of LOFW

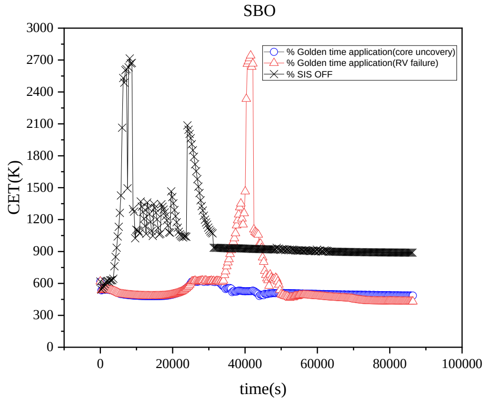

Fig. 7. CET of SBO