

Analysis of Feedwater Line Break Accident to Improve the Diagnostic Actions in Emergency Operating Guidelines for APR1400

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1. Introduction

The Emergency Operating Guidelines (EOGs) provide the technical background for development of plant-specific Emergency Operating Procedures (EOPs) [1]. They are technical guidance documents that specify the actions and associated technical background required to mitigate emergency events during operating Modes 1, 2, and 3, as well as during Mode 4 when the shutdown cooling system is not in operation. The Diagnostic Actions (DA) guideline facilitates the identification of the type of accident that has occurred. Based on the diagnostic result, either the Optimal Recovery Guideline (ORG) or the Functional Recovery Guideline (FRG) is selected.

A feedwater Line break (FLB) is one of the Design-Basis Accidents (DBAs) [2]. When an FLB occurs, the inventory is continuously discharged through the broken line in affected Steam Generator(SG), reactor will trip by reaching the low SG water level trip setpoint [3]. Furthermore, secondary-side inventory of the SG decreased. Thereby reducing heat transfer from the primary side to the secondary side. Consequently, the reactor coolant system (RCS) temperature increases, lead to the pressurizer pressure increases. Once the affected SG is depleted, its heat-transfer capability is completely lost. However, core decay heat can be stably removed through the intact SG.

However, DA of an FLB indicated that the accident could be diagnosed into the FRG rather than the appropriate ORG depending on the break size. Therefore, an FLB analysis was performed to evaluate the necessity of supplementing the DA process in the EOGs, ensuring an accurate diagnosis into the Excess Steam Demand Event(ESDE) Guideline.

2. Analysis Model for an FLB Accident

2.1. Initial Conditions and Major Assumptions

This FLB analysis was performed using the RELAP5/MOD3.3 code based on the best-estimate(BE) methodology for APR 1400 Pressurized water reactor (SAEUL NPP Units 1&2). Fig. 1 presents the Nodalization model developed for the FLB accident analysis the accident was assumed to occur under operating conditions established using nominal design values at 100% core power as the initial conditions.

The break area was varied in increments of 0.1 ft² up

to a maximum break area of 0.761 ft² for the Economizer(EC) line and up to 0.448 ft² for the Downcomer(DC) line. The plant control system including the Pressurizer Pressure Control System(PPCS), Pressurizer Level Control System(PLCS), Feedwater Control System(FWCS), Steam Bypass Control System(SBCS) are included for the BE analysis.

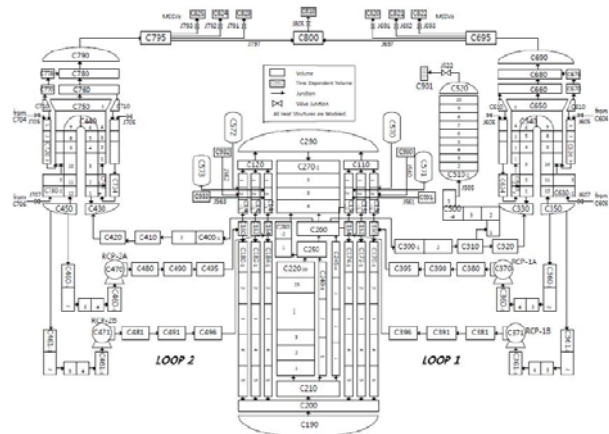


Fig. 1. RELAP5 Nodalization

2.2. Results of the FLB Accident Analysis

The results of FLB analysis are presented in Table 1 and Figs. 2 through 6.

Table 1. Sequence of Events by Break Location (EC and DC)

Time(s)		Sequence of Events
EC (0.761 ft ²)	DC (0.448 ft ²)	
0.00	0.00	Occurrence of a FLB
16.4	29.4	Reactor trip on low SG water level
19.9	38.5	Initiation of auxiliary Feedwater injection to the affected SG
53.4	110.2	Generation of the main steam isolation signal(low SG pressure)
58.4	115.2	Closure of the main steam isolation valves
63.4	120.2	Closure of the main feedwater isolation valves
65.7	107.0	Initiation of auxiliary Feedwater injection to the intact SG
69.1	103.7	Safety Injection Actuation Signal setpoint reached (low pressurizer pressure)
-	144.0	Initiation of safety injection
552.0	606.0	Termination of auxiliary feedwater injection to the intact SG

As shown in Table 1 and Fig. 2, following a Maximum-size (0.761 ft²) FLB, the water level in the affected SG decreases rapidly, leading to a reactor trip. Although auxiliary feedwater is subsequently injected, the affected SG continues to be depleted.

As shown in Fig. 3, the affected SG is depleted by mass discharge through the break line and its pressure does not recover. Thereafter, the feedwater and main steam lines are isolated, and the pressure increases as the RCS temperature rises.

As shown in Figs. 4 and 5, during an EC line break, the pressurizer pressure reaches the Safety Injection Actuation Signal (SIAS) setpoint however, actual safety injection (SI) is not initiated because of the subsequent increase in RCS temperature and pressure. During a DC line break, the low pressurizer pressure SIAS setpoint is reached. Because the heat removal through the break is greater than that for the EC line break, the pressurizer pressure decreases below the SI shutoff head, thereby initiating SI. However SI is terminated as the RCS temperature and pressure increase. The pressurizer level decreases during the early phase of the accident due to coolant contraction caused by the decrease in RCS temperature, however it is gradually recovered as the RCS temperature increases due to reduced primary-to-secondary heat transfer and PLCS operation.

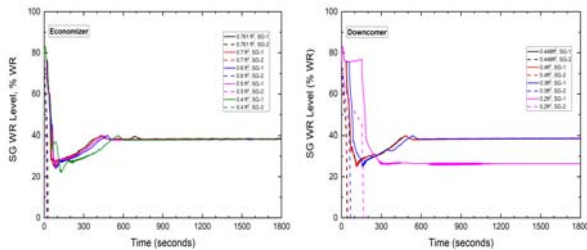


Fig. 2. SG Water Level (EC and DC)

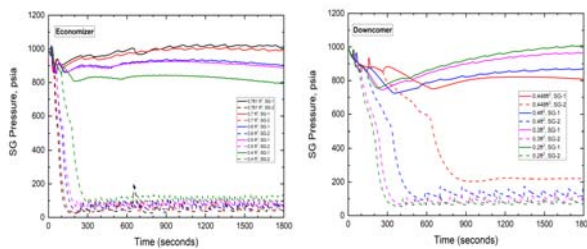


Fig. 3. SG Pressure (EC and DC)

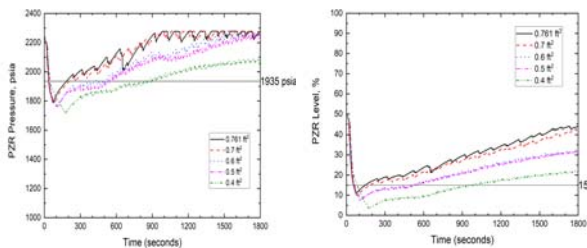


Fig. 4. Pressurizer Pressure and Level (EC)

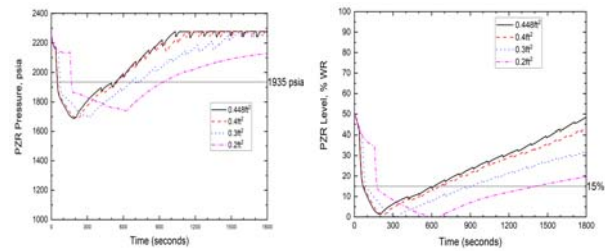


Fig. 5. Pressurizer Pressure and Level (DC)

3. Review of the Diagnostic Actions Process

3.1. Diagnostic Actions Process Strategy Approach

DA for the FLB accident was performed in accordance with the process shown in Fig. 7. In this process, Step 7 verifies whether the pressurizer pressure exceeds the lower limit of the [post-trip pressurizer pressure range] and is stable or increasing. Step 8 verifies whether the pressurizer level exceeds the lower limit of the [post-trip pressurizer level range] and is stable or increasing. As indicated by the results in Figs. 4 and 5, whether these criteria are satisfied depends on the break size. For small break sizes, the criteria of Steps 7 and 8 are not satisfied, and the process proceeds to Step 9.

As shown in Fig. 6, the criterion of Step 9 that the RCS subcooling margin is [less than the minimum RCS subcooling margin] is not satisfied, and the process leads to the ESDE Guideline. In contrast, for large break sizes, the criteria of Steps 7 and 8 are satisfied, resulting in transition into the FRG. Therefore, clarification of the process is required to ensure that the ESDE Guideline is accurately performed in all FLB accident cases.

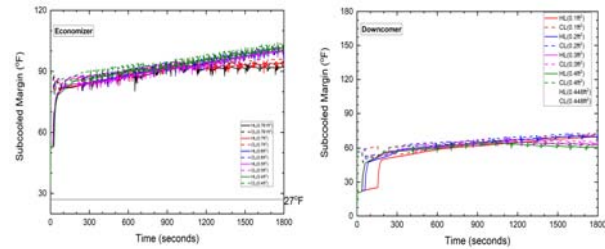


Fig. 6. Subcooling Margin (EC and DC)

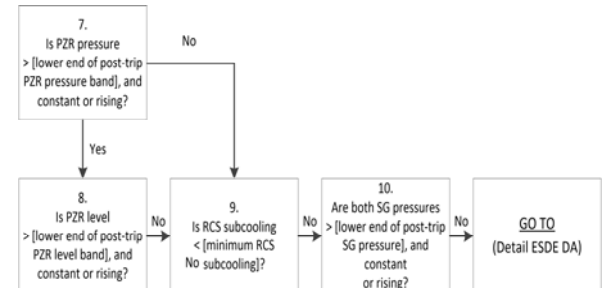


Fig. 7. Current Diagnostic Actions Process

3.2. Proposed Diagnostic Actions Process

As shown in Section 3.1, the current DA path diverges to either the ESDE guideline or the FRG depending on the break size. Therefore, the DA process was improved to ensure a consistent diagnosis framework during a FLB regardless of the break line size. To reflect the distinct SG level drop characteristics during an FLB, a new step was added to the existing DA, as shown in Fig. 8. This step 9 determines whether all SG levels exceed the [post-trip SG level lower limit] and are stable or increasing. This additional step 9 enables an accurate transition to the ESDE guideline, thereby securing the consistency and reliability of accident management.

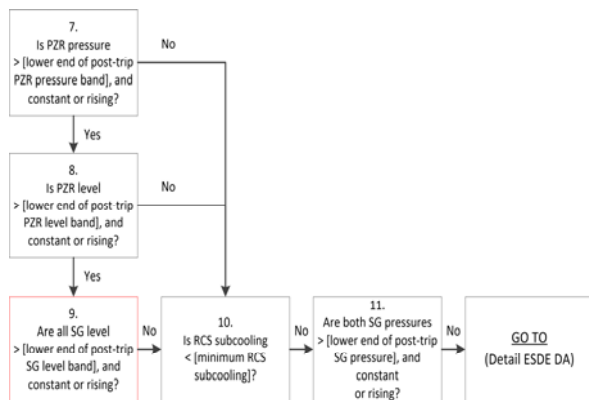


Fig. 8. Proposed Diagnostic Actions Process

4. Conclusions

In this study, based on the BE analysis results of the FLB, a limitation in the current DA process was identified, which could lead to an unnecessary transition into the FRG depending on the break size. To improve this, a revised process was derived by adding a new step to verify the SG level conditions within DA. Accordingly, this revision guarantees an accurate transition to the ESDE guideline during an FLB regardless of the break size. Furthermore, it is expected to contribute to enhancing the consistency and safety of future accident management.

REFERENCES

- [1] KEPCO E&C, APR1400 Emergency Operating Guidelines and Technical Background Documents.
- [2] Korea Hydro & Nuclear Power (KHNP), SAEUL Units 1 and 2 Accident Management Plan.
- [3] KEPCO E&C, SAEUL Units 1 and 2 Setpoint Bases Document.
- [4] Information Systems Laboratories (ISL), RELAP5/MOD3.3 Code Manual, December 2001.