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The Evaluation of CDF Considering with the External Cooling Water Injections

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1. Introduction

As a part of the action items after the Fukushima accident, KHNP has been undertaking the external emergency cooling water injection through EWS for both primary and secondary systems to mitigate the accident at the site. In addition to the existing ECCS and EWS, if the external cooling water injection by using the mobile diesel pumps is considered for the primary and secondary systems, it could result in a great improvement on the safety for the nuclear power plant.

The purpose of this paper is to evaluate the effects of the external cooling water injection during the SBLOCA for Wolsong NPP 1.

2. Methods and Results

Given the external cooling water injections for the primary and secondary systems during the special scenario specific SBLOCA of Wolsong NPP 1, for the external injection flow paths, both the fault tree(FT) and the event tree(ET) were created and then quantified in order to evaluate the effects on core damage frequency (CDF). Since the external injection is done manually, human reliability analysis (HRA) including human error dependency was also conducted and reflected to the quantitative results.

2.1 Event Selection

For this study, SBLOCA was selected among the 2015 Level 1 PSA models from the Wolsong NPP 1. It is the accident that considered having the highest CFD among LOCAs.

2.2 External Injection Methods

As illustrated in Figure 1, external cooling water injections for the primary and secondary systems of Wolsong NPP 1 are performed by using the mobile diesel driven pump. For the primary external injection, cooling water from the emergency water supply reservoir (EWSR) is injected into the primary system via flow paths of the EWS and ECCS. For the secondary external injection, cooling water from the EWSR is injected into the secondary system via flow paths of EWS.

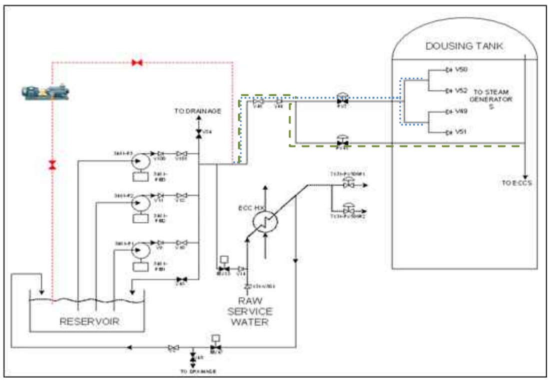

Figure 1. Simplified Diagram for External Injection

2.3 Assessment Methods and Assumptions

By using the mobile diesel driven pump to deliver the external injections to the primary and secondary systems, following assumptions are implicitly given.

- It is assumed that the external injections will be available promptly when needed and will provide enough flow from the reservoir.
- It is assumed that the mobile diesel driven pumps provide sufficient pressures for each case. However, the primary external injection is only possible if the primary system is sufficiently depressurized by the steam generator crash cool-down (SGCC).
  - ✓ Required pressure for primary external injection: 15 kg/cm^2
  - ✓ Required pressure for secondary external injection: 10 kg/cm^2
- NUREG/CR-6928 data is applied to the failure rate for the mobile diesel driven pump.
  - ✓ Fail to Start : 5.46E-3 /d
  - ✓ Fail to Run : 9.48E-5 /hr

2.4 Fault Tree Construction

According to the external injection flow paths shown in Figure 1, fault trees for both primary and secondary external injections were constructed (Fig. 2 and 3).

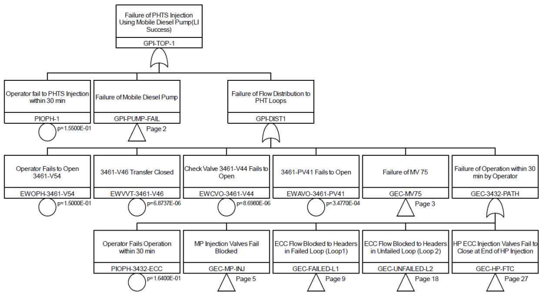

Figure 2. Fault Tree for Primary External Injection

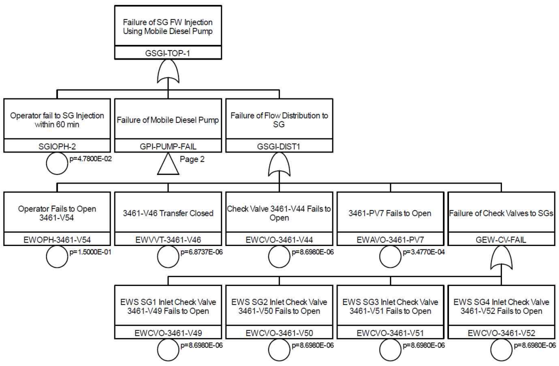

Figure 3. Fault Tree For Secondary External Injection

2.5 Event Tree Construction

Figure 4 shows the ET with the external emergency water injection for SBLOCA. When SBLOCA occurs, ECC is injected into the primary system if the primary system is depressurized by rapid SGCC. When ECC injection into the primary system fails, the external injection into the primary system will then be available by using the mobile diesel driven pump. Accordingly, PHTS-INJ for the primary external injection was added to the event tree header. Also, when the EWS system fails, the external injection into the secondary system will be available via mobile diesel driven pump. Accordingly SG-INJ for the secondary external injection was added to the event tree header.

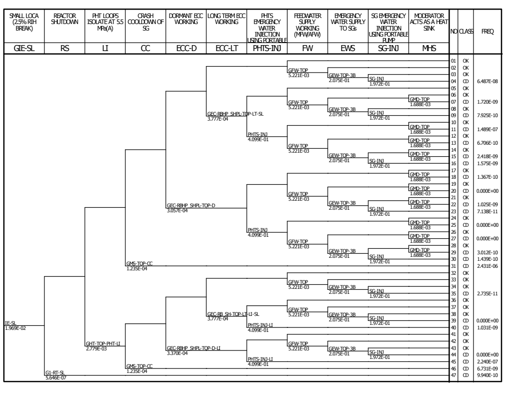

Figure 4. SBLOCA Event Tree Considered With External Injection

2.6 Human Reliability Analysis

2.6.1 Human Error Probabilities

Operator's actions are required to move and arrange the mobile diesel driven pump, and then to connect it to the piping for activation. For primary external injection, it is required to open the manual valve (3461-V54) which are located on the EWS flow paths and the motor driven valves (3432-MV31, -MV50, 3432-MV39 ~ -MV46, 3432-MV59 ~ MV66) which are located on the ECC flow paths. Accordingly, calculations based on the K-HRA[2] approach were made for the human error probabilities for the operator's actions.

Table 1. Human Error Probability Analysis Result

External Injections	Event	Description	Human Error Probability
Primary External Injection	PIOPH-1	Mobile diesel driven pump fails to move and start	1.55E-01
	EWSOPH-3461-V54	3461-V54 fails to open	1.50E-01
	PIOPH-3432-ECC	Fails to open ECC injection flow path	1.64E-01
Secondary External Injection	SGIOPH-2	Mobile diesel driven pump fails to move and start	4.78E-02

2.6.2 Dependency Analysis

When it comes to any possible human error related to starting the mobile diesel driven pump, there exists a dependency between human errors and operations for the EWS system or the emergency diesel generator for this case. The dependency for the operator's action was calculated based on K-HRA[2] methodology.

Different operators run the mobile diesel driven pumps, the EWS system, and the emergency diesel generator. Since the external injection is the last measure to mitigate the consequences after an accident; these operators are involved in considerable stress, and the dependency between them is evaluated as Low Dependency (LD).

2.7 Quantification Results

	Before External Injection	After External Injection	Effect of External Injection
SBLOCA CDF	3.11E-06 /yr	2.87E-06 /yr	CDF was reduced by 7.5%

3. Conclusions

For Wolsong NPP 1, the external emergency cooling water injection into the primary and secondary systems by using mobile diesel driven pump has been incorporated as an additional measure to mitigate the consequences when an accident occurs. Since SBLOCA is considered to have the highest frequency of core damage among LOCAs, it was evaluated based on PSA methodology to analyze the effects on the safety of NPP resulting from the external injections. As a result, the frequency of core damage was reduced by 7.5% when the external injections were considered in this study. Although it is highly unlikely for the existing ECCS and EWS system to fail to function, if they do fail to function; the external injection could improve the safety of NPP since it is considered as an additional mitigative measure.

REFERENCES

[1] KHNP, Probabilistic Safety Assessment Report of Wolsong Unit 1, 2011.
[2] KAERI, Development of A Standard Method for Human Reliability Analysis (HRA) of Nuclear Power Plants, 2013. 8.