Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18 - 19, 2017

Comparison of Safety Improvement from New Containment Protection Systems in Operating Nuclear Power Plants

Eun-Chan Lee*, Kwangil Jung, Byung-Pil Choi

Korea Hydro & Nuclear Power Co., Ltd., 1312 Yuseongdaero, Yuseong-Gu, Daejeon, Korea
**Corresponding author: eclee5639@khnp.co.kr*

1. Introduction

The containment filtered venting system (CFVS) and the emergency containment spray backup system (ECSBS) have designs that can effectively reduce the probability of accident sequence progress that leads to containment failure even if core damage occurs during the accident. In this paper, the effects of safety improvements have been quantitatively evaluated by assessing the reduction of the containment failure frequency (CFF) with the CFVS or ECSBS installed by considering the characteristics of the representative nuclear power plants with different designs.

2. Methods

For representative units based on the reactor types, the effects of the new mitigation systems affecting the frequency of each damage mode of the containment, which is the result of the Level-2 PSA, were reviewed by simple sensitivity evaluation methods.

Fig. 1 represents a general containment event tree (CET) for PWR plants and includes headings classified into eight characteristics causing containment failures. [1] For example, 'CS-LATE' heading implies that CFVS or ECSBS can contribute to maintaining containment integrity when the operation on the spray recirculation mode fails in the late stage of an accident.

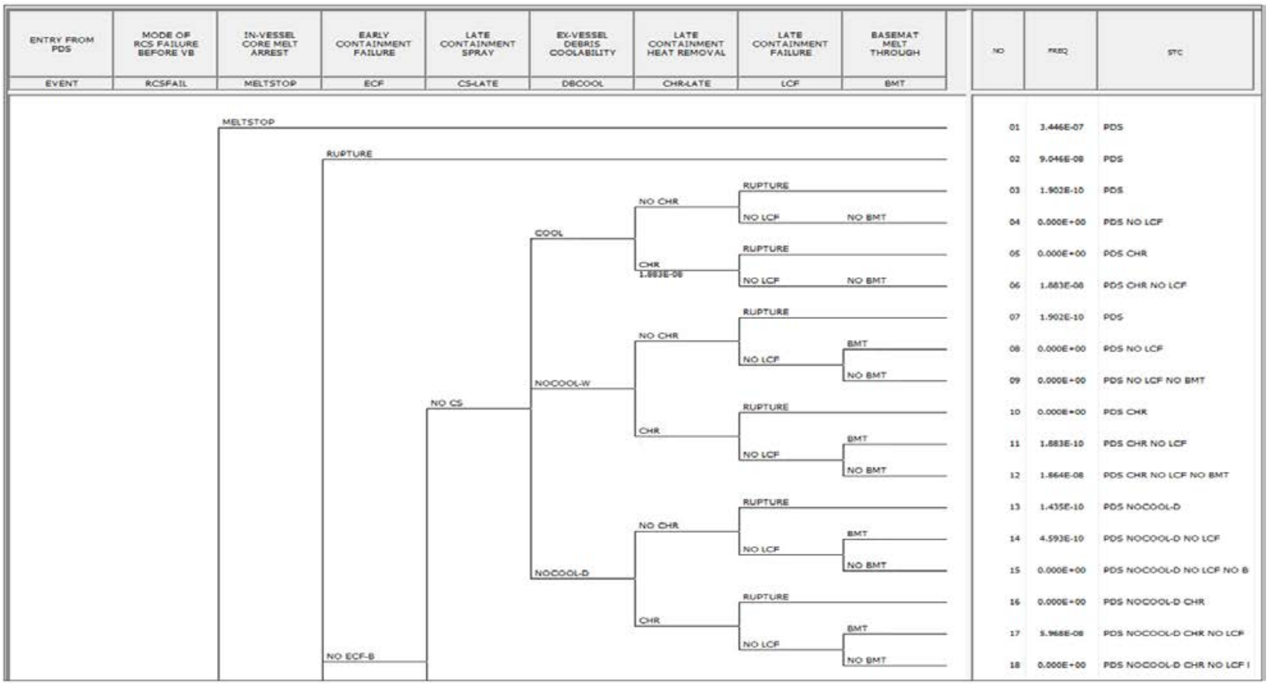

Figure 1. General containment event tree (CET)

The failure modes and their frequency to be prevented by CFVS can be calculated by considering the branches of the CET headings that are expected to be related to the effect of CFVS in order to determine how effective it will be to install CFVS for containment integrity.

This analysis was conducted under the assumption that the integrity of the containment is generally maintained by CFVS in case of accident sequences that cause only late containment failure. [2]

ECSBS, which is installed in APR1400 design plants, is an alternative system that is used during the failure of the spray system. This ECSBS and operator actions can replace the function of the containment spray system when all spray pumps or the refueling water storage tank fail during extreme external events.

Fig. 2 is a fault tree for ECSBS; its safety effect was evaluated by applying the failure probability of ECSBS from the fault tree to the containment event tree (CET) and decomposition event tree (DET) of Level-2 PSA models for representative plants.

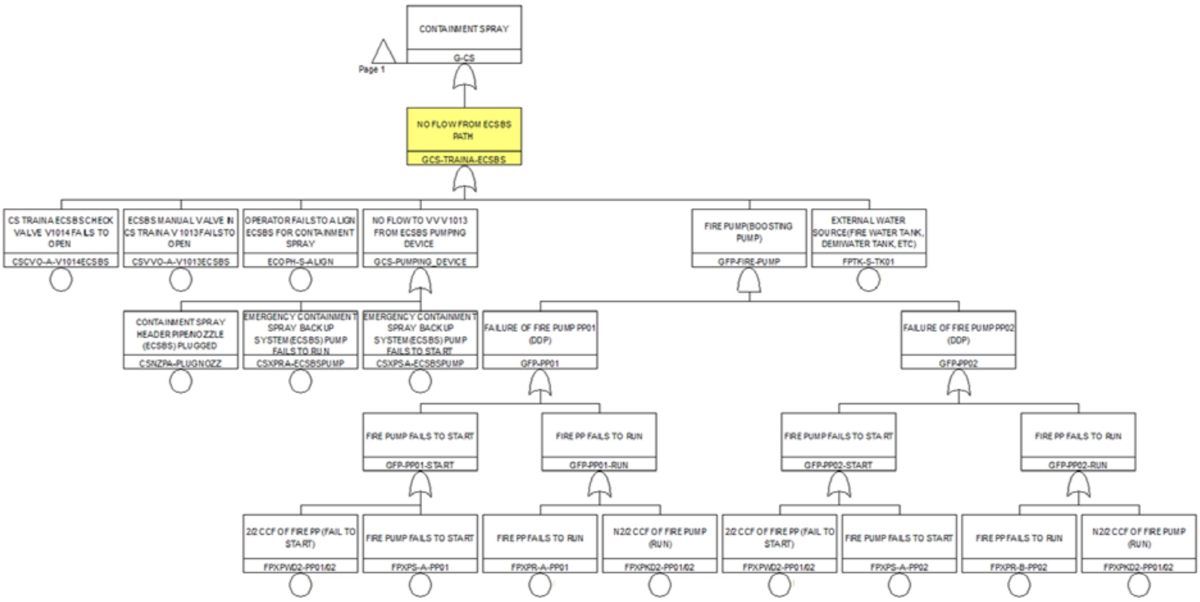

Figure 2. Fault tree for emergency containment spray backup system (ECSBS)

3. Evaluation

3.1. Safety improvement supposing CFVS installation

In 2011, the Korea Hydro and Nuclear Power Co. (KHNP) operated a special task force to review and confirm the enhancement effect on the containment integrity of the application of CFVS. [2] CFVS operates the venting system equipped with special filter, which captures radioactivity elements, to reduce containment pressure during severe accidents. Using insights and methods from the task force, this paper re-evaluated the PSA results by supposing that CFVS can reduce the containment failure by 90% of the performance.

In the case of the OPR1000 representative plants, CFF was reduced by 33 percent to 38 percent by supposing that CFVS had been installed. For one CANDU representative plant, CFF was reduced by 82 percent (refer to Table 2).

Westinghouse plants indicated that CFF was reduced by 3 to 20 percent considering CFVS. Westinghouse plants have a wide range of differences in terms of the benefits from CFVS because they have different system designs between two representative plants (refer to Table 2).

Table 1. Effects of CFVS for containment building of W design plant

Containment Failure Modes		Current design (%)	Supposing CFVS (%)
No Containment Failure		72.9	73.7
Containment Failure (CF)		27.1	26.3
Failure Modes	Early CF	1.3	1.3
	Late CF	0.8	0.1
	Bottom Melt Through	9.1	9.1
	Not Isolation	7.6	7.6
	Bypass	8.2	8.2
Summation		100.0	100.0

Table 2. Safety improvement effects through CFVS

Plant Design	No CFVS (% of CF)	Supposing CFVS (% of CF)	Change (%)
CANDU Unit	36.1	6.6	-82
OPR1000 Unit 1	27.6	17.0	-38
OPR1000 Unit 2	33.7	22.5	-33
W Unit 1	81.7	65.2	-20
W Unit 2	27.1	26.3	-3

3.2. Different effects of CFVS installation

Table 2 shows that the effects of CFVS are different according to the plant design. One major reason is that the Level-1 PSA result for each plant is different because of design differences. In addition, the branch probability of DET for accident sequences propagated to containment failure after core damage is differently evaluated for application to the Level-2 PSA for each plant. That is, differences from CFVS effect analyses are created by differences of the plant damage state (PDS) frequency, according to the containment failure modes from the system design characteristics, and by the branch probability difference for the accident sequence.

3.3. Safety improvement supposing ECSBS installation

Table 3 includes a CFF value change based on the failure modes of the containment building in the OPR1000 representative plant, supposing new design with ECSBS installed. For this, the ECSBS heading is added to the general CET and to DETs, expecting good effects if ECSBS is installed. The fault tree analysis result of ECSBS is applied to the heading.

Table 3. Containment integrity of the OPR1000 plant considering application of ECSBS

Containment Failure Modes		Current design (% of CF)	Supposing ECSBS (% of CF)
No Containment Failure		72.4	87.6
Containment Failure (CF)		27.6	12.4
Failure Modes	Early CF	0.7	0.7
	Late CF	11.7	1.5
	Bottom Melt Through	2.6	3.1
	Not Isolation	6.2	0.7
	Bypass	6.5	6.5
Summation		100.0	100.0

The safety improvement evaluation supposing ECSBS effectiveness during a severe accident shows that OPR1000 plants have a CFF value reduced by a range of 44 percent to 55 percent; Westinghouse plants have CFF values that decreased by 7 to 25 percent.

Table 4. Safety improvement through ECSBS

Plant Design	No ECSBS (% of CF)	Supposing ECSBS (% of CF)	Change (%)
OPR1000 Unit 1	27.6	12.4	-55
OPR1000 Unit 2	33.7	18.9	-44
W Unit 1	81.7	75.8	-7
W Unit 2	27.1	20.4	-25

3.4 Review of differences in ECSBS effects

Evaluation of the expected safety improvement through ECSBS for operating plants demonstrated that OPR1000 design plants have relatively larger advantages than Westinghouse design plants. The addition of ECSBS to the containment spray system is more effective for the OPR1000 design because the function of the reactor containment fan cooler (RCFC), which is a non-safety related system, cannot be credited during a severe accident. In the case of the Westinghouse design plants, the containment cooling fan can perform cooling and decompression of the containment building.

4. Conclusions

As a result of reviewing the containment damage in the late stage, in which the effect of CFVS is significant, safety enhancement in terms of containment failure frequency (CFF) is differently evaluated considering the system design differences.

In the case of CFVS, it is determined that the effect is relatively larger for CANDU and OPR1000 design plants as well as for old Westinghouse design plants, which have accident sequences in which the leakage rate of high temperature and high pressure primary material to the containment building during core damage is relatively fast.

For ECSBS, it is evaluated that application of this system to OPR1000 plants may be one effective alternative during loss of containment spray.

As this review is a sensitivity study using the PSA model, a final judgment on the benefits of additional mitigation systems such as CFVS and ECSBS should be comprehensively reviewed while considering other mitigation systems and equipment for the integrity of containment buildings.

References

[1] Probabilistic safety assessment, K2, KHNP, 2007.
[2] Task force review on CFVS, KHNP, 2011.