Classification of Cold Leg LOCA by Thermal Hydraulic Analysis

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1. Introduction

In Level 1 PSA (Probabilistic Safety Assessment), a cold leg LOCA (Loss of Coolant Accident) scenario is significantly considered as an initiating event. The LOCA is formally divided into three groups according as different characteristics of transients which are coming from different break sizes. Because of different of transient trends of the three groups, heads and branches of an event tree analysis are also different [1, 2].

During an accident sequence and success criteria analysis of PSA model for the Hanul (originally the Uljin NPP) unit 3 and 4 NPP (Nuclear Power Plant), however, it came out into the open that the PSA model from traditional grouping of the cold leg LOCA cannot account for the results by the best-estimate TH (thermal-hydraulic) code. The one of main issues is that, in small break size LOCA (0.5in-2.0in), only one HPSI (High Pressure Safety Injection) pump satisfies the success criteria in some region of the break size, whereas, bleed operation by SDS (Safety Depressurized System) valve should be used to satisfy the success criteria in the other region of break size. Like this, there are discordances between the present PSA model and TH results for cold leg LOCA.

In this paper, TH analyses for the cold leg LOCA are described. Based on the TH results, damage map is illustrated for entire range of break size and characteristics of transient are identified. Using the damage map and characteristics of transient along the break size, recommendations on the re-classification for the PSA model is proposed.

2. Methods

TH calculation for the cold leg LOCA has been performed with the MARS (Multi-Dimensional Analysis of Reactor Safety) code. The MARS code has been developed for realistic analysis of two-phase thermal-hydraulic transients for pressurized water reactor (PWR) plants. Also, the MARS code is used in the PSA project for Hanul NPP unit 3 and 4, as a best-estimate TH analysis code.

The target reactor is the Hanul unit 3 and 4 NPP which is the OPR-1000 (Optimized Power Reactor) type. The OPR-1000 is a two-loop 1000MWe PWR generation-II nuclear reactor [3]. MARS model for the Hanul unit 3 and 4 NPP is illustrated in Fig. 1 [4]. It consists of two SGs (steam generators), pressurizer, four RCPs (Reactor Coolant Pump), HPSI pumps, LPSI (Low Pressure Safety Injection) pumps, AFW (Auxiliary Feed Water) pumps, four MSSV (Main Steam Safety Valve), four MSIV (Main Steam Isolation Valve), four ADV (Atmospheric Dump Valve), PSV (Pressurizer Safety Valve), and SDS (Safety Depressurized System) valve. With regards to the major contributor to reactor transients, the followings have been modeled.

- One HPSI pump (1 out of 2 trains) is available and SIAS (Safety Injection Actuation Signal) is generated at $124kg/cm^2$ of RCS pressure and delay time of injection is 30 seconds.
- One AFW pump (1 out of 4 pumps) is available and AFAS (Auxiliary Feed Actuation Signal) is generated at below 23.5% of SG wide-range level and delay time of injection is 45 seconds.
- Temperature of injection water by HPSI and AFW pumps is 30^oC.
- Four RCPs are automatically shut-downed in below 15^oC of sub-cooled margin.
- MSIV is closed in below $62kg/cm^2$ of SG pressure.
- PSV is gradually opened from $86.2e^5$Pa to $88.8e^5$ Pa of RCS pressure.
- While the increasing of RCS pressure, MSSV is suddenly opened at $1.75e^7$ Pa, and while the decreasing of RCS pressure, MSSV is gradually closed up to 80% from $1.75e^7$ Pa to $1.43e^7$ Pa and suddenly closed at $1.43e^7$ Pa.

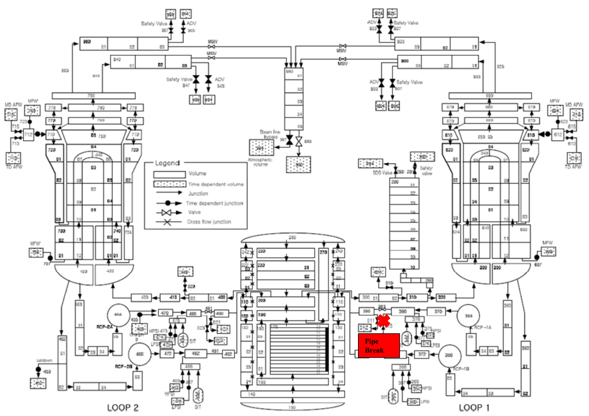

Fig. 1. Nodalization of the Hanul unit 3 and 4 MARS model

Damage condition is defined as PCT (Peak Cladding Temperature) of 2200^oF (1477K). In order to obtain the damage results for cold leg LOCA, several cases were calculated for entire range of break size. The followings have been considered.

- Case I: No safety functions
- Case II: One HPSIP available
- Case III: One AFWP available
- Case IV: SDS valve open with case II
- Case V: ASC (Aggressive Secondary Cooldown) operation by ADV with case III

3. Results

The Fig. 2 shows the reaching time to PCT for the TH case that one HPSI available case for entire range of break size. For the range of 0.5 inch to 0.7 inch of break size, PCT reaches the limit at about 150 - 220 minutes because the RCS pressure is not depressurized enough to inject the HPSI. For the range of 9.4 inch to 30.0 inch of break size, PCT also reaches the limit because released reactor coolant quite larger than supplemented injection coolant.

For 0.5 inch to 0.7 inch of break size, HPSI is not available due to high pressure of RCS. RCS pressure is increased to PSV open pressure, after that, SDS valve is manually opened by operator (case IV). In this case, all transients meet the success criteria. Based on the TH results, safe operator's action time for SDS valve is within 35 minutes.

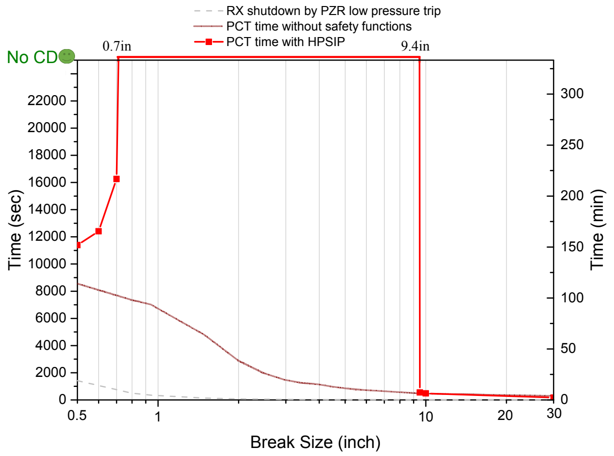

Fig. 2. Reaching time to PCT limit for one HPSI pump available (Case I, Case II)

The Fig. 3 shows the reaching time to PCT for the TH case that one AFWP available with ASC by ADV for entire range of break size. For the range of 1.4 inch to 30.0 inch of break size, PCT reaches the limit because the RCS pressure is not depressurized enough to inject the HPSI. For the range of 9.4 inch to 30.0 inch of break size, PCT also reaches the limit because accumulated loss of coolant is so large that secondary cooling is meaningless.

For the case of one AFW pump available (case III), entire range of break size exceed PCT limit. AFW is automatically injected along the SG level, so the cooling capacity is not matched with core residual heat.

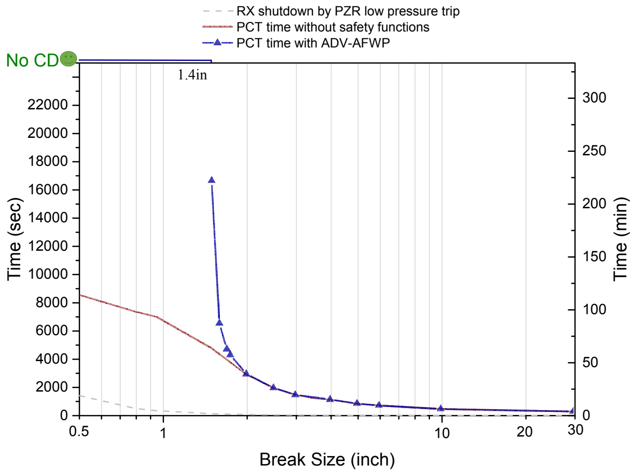

Fig. 3. Reaching time to PCT limit for ASC by ADV with one AFW pump available (Case I, Case V)

4. Discussion

Based on the TH analysis for cold leg LOCA for entire range of break size, damage map is illustrated as shown in Fig 4. When the LOCA occurs, if we know specific break size, specific time, and recovery type, then, the damage map can explain the plant has damaged or not. The red dot background means damage state in spite of one HPSIP recovery. The blue check background means damage state in spite of one AFWP recovery and ASC operation. The orange comb-pattern background means not only damage state in spite of one HPSIP recovery, but also damage state in spite of one AFWP recovery and ASC operation.

The followings are characteristics for each region of Fig. 5. Based on the characteristics of transient trends, simplified event tree for cold leg LOCA is constructed as shown in Fig. 6.

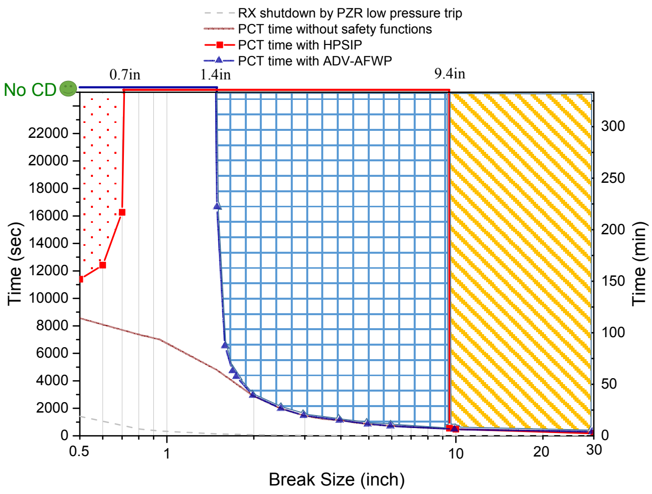

Fig. 4. Damage map for cold-leg LOCA

For the smallest break size region (Group I), from 0.5 inch to 0.7 inch, reactor coolant system inventory is maintained above the critical point of threshold damage level, and reactor coolant system pressure cannot be depressurized by leakage. In this respect, success criteria is 1) one HPSIP and SDS valve open, or 2) one AFWP and ADV cool-down operation.

For small break size region (Group II), from 0.7 inch to 1.4 inch, reactor coolant system inventory is maintained above the critical point of threshold damage level, and reactor coolant system pressure can be depressurized to safety injection available pressure level. In this respect, a success criterion is 1) one HPSIP, or 2) one AFWP and ADV cool-down operation.

For the medium break size region (Group III), from 1.4 inch to 9.4 inch, reactor coolant system inventory is decreased below the critical point of threshold damage level, and reactor coolant system pressure can be depressurized to safety injection available pressure level. In this respect, a success criterion is one HPSIP.

For the large break size region (Group IV), from 1.4 inch to 9.4 inch, reactor coolant system inventory is decreased below the critical point of threshold damage level, and reactor coolant system pressure can be depressurized to safety injection available pressure level. However, due to the large amount of leakage, one HPSIP is not sufficient. Based on analysis result, success criteria is one HPSIP, one LPSIP, and two SIT.

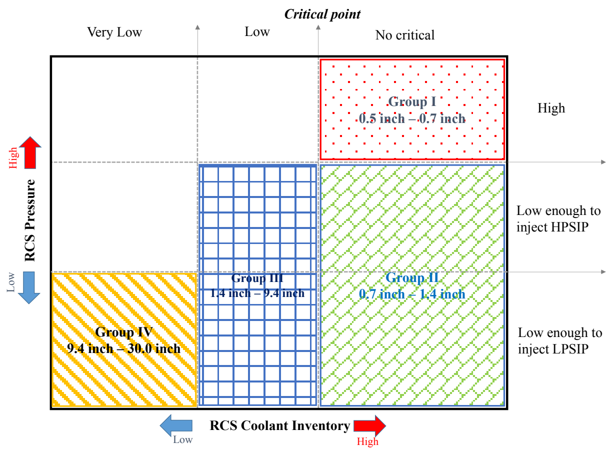

Fig. 5. Characteristics of cold-leg LOCA

5. Conclusion

In this paper, based on best-estimate TH results for entire range of break size of the cold leg LOCA, specific transient characteristics were identified and four groups re-classification for the cold leg LOCA was suggested.

It is not recommended that this work directly apply the present PSA model because of several remain issues such as initiating event frequency, uncertainty analysis, and its impact on the core damage frequency. Major contribution of this work is to identify the main factors which have a decisive effect on the transient of cold leg LOCA.

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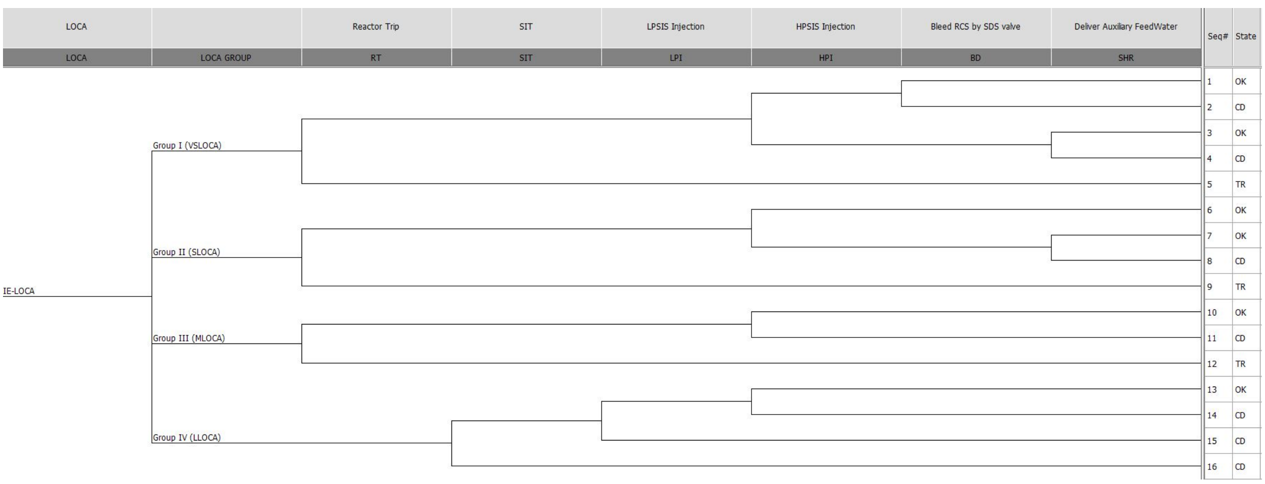

Fig. 6. Event tree for re-classification of cold-leg LOCA