An Improved Modeling Method for ISLOCA for RI-ISI and Other Risk Informed Applications

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ABSTRACT

In this study, an improved modeling method for Interfacing Systems LOCA (ISLOCA) was developed in order to accurately and easily evaluate ISLOCA risk for risk informed applications. In the developed method, an event tree for identifying ISLOCA core damage sequences is constructed for each selected ISLOCA path. In developing an ISLOCA event tree, failure of multiple pressure barriers, failure of isolation, and failure of mitigation are considered. Then, for each identified ISLOCA core damage sequence, a fault tree is constructed. In an ISLOCA fault tree, not only the failure of components themselves but also failure of the support systems and operator errors are modeled. Once fault trees for all ISLOCA core damage sequences are developed, they are integrated into a linked core damage frequency (CDF) fault tree with fault trees of other initiating events' core damage sequences. Also, the ISLOCA fault trees are integrated into level 2 Probabilistic Risk Assessment (PRA) logic as a part of Large Early Release Frequency (LERF) fault tree. Then using the linked CDF (or LERF) fault tree, minimal cutsets for total CDF (or LERF) or for ISLOCA or other initiating events can be generated by evaluating associated gates in the linked fault tree. Either point estimate or probability distribution of CDF (or LERF) can be evaluated using the generated minimal cutsets and failure data. Furthermore, the impacts of failure of any components in ISLOCA paths on CDF (or LERF) can be easily evaluated just by setting the related components to fail and evaluate the linked fault tree. Also, since the each ISLOCA fault tree is logically combined with fault trees of other ISLOCA paths and those of other initiating events in the linked CDF and LERF fault trees, the impacts of a component which is shared by more than one ISLOCA paths or failure of support systems related with ISLOCA components can be directly evaluated from the linked CDF (LERF) fault tree model. Fault trees for ISLOCA through hot leg injection lines of the intermediate head safety injection system of a reference plant were developed as an example implementation of the developed method. Also, through two example applications, it was demonstrated that the linked CDF (LERF) fault tree model with the improved ISLOCA model could accurately evaluate the conditional CDF and LERF for a pipe segment break in an ISLOCA path for risk informed in-service inspection (RI-ISI) and the risk increase due to two leaking check valves in an ISLOCA path for risk informed decision making. The developed ISLOCA method was implemented in the PRA model for a reference plant and the PRA model was successfully used for the update of risk evaluations for RI-ISI. The developed ISLOCA modeling method will enable more accurate and easier evaluations of risks associated with ISLOCA in the future risk informed applications.

INTRODUCTION

Interfacing Systems LOCA (ISLOCA) has generally been modeled as one or several basic events which directly lead to core damage and their frequencies were pre-calculated [1, 2]. This simplified modeling of ISLOCA may cause problems when it is needed to evaluate the effects of failure at a specific location or component in an ISLOCA path on the plant risk for risk-informed in-service inspection (RI-ISI) and other risk informed applications. In this study, an improved modeling method for ISLOCA which utilizes event tree and fault tree linking methods was developed in order to accurately and easily evaluate ISLOCA risks for risk informed applications. The developed method was for modeling ISLOCA core damage sequences while a plant is at power. Since ISLOCA is one of the containment bypass scenarios, the ISLOCA core damage frequency (CDF) fault trees are also directly integrated into level 2 Probabilistic Risk Assessment (PRA) model as a part of Large Early Release Frequency (LERF) model. Even though the ISLOCA modeling method developed in this study was for Pressurized Water Reactor (PWR), the basic steps of the method can be used for modeling ISLOCA in any type of reactors.

AN IMPROVED ISLOCA MODELING METHOD

Steps of ISLOCA Modeling

First, candidates for potential ISLOCA paths are identified. Any system which interfaces with the Reactor Coolant System (RCS) and has a potential that, after pressure barrier(s) in its line fail, its low pressure piping or components outside containment can be exposed to the RCS pressure should be reviewed. Lines smaller than the lower end of small LOCA size spectrum (0.95 cm (3/8 inch) in diameter for example [3]) may be screened out because leakage through those lines is within the capacity of normal makeup system and the LOCA can be mitigated without emergency core cooling system (ECCS). For example, the following system lines were identified as potential ISLOCA paths for a reference plant [3]:

- Residual Heat Removal (RHR system): RCS cold leg injection lines, RCS hot leg injection lines, RHR suction lines from RCS hot leg
- Intermediate head Safety Injection System (SI system): RCS cold leg injection lines, RCS hot leg injection lines
- Chemical and Volume Control System (CVCS): BIT injection lines, normal charging lines, alternate charging lines, aux spray lines
- Auxiliary Component Cooling Water System (ACCW system): supply to and return lines from Reactor Coolant Pump (RCP) thermal barrier cooling heat exchanger
- RCP seal injection lines
- RCP seal leak off lines, RCS vent lines, and Excess let down lines (these lines merge to the RCP seal leak return line)

In the second step, an even tree is developed for each identified ISLOCA path. An even tree begins with the failure of the first barrier (usually the valve which directly interfaces with the full RCS pressure) and progresses to include other barriers. Core damage can be prevented if either by isolating ISLOCA path or by minimizing leakage through cool down and depressurization before the Refueling Water Storage tank (RWST) depletes. Such potential isolation (automatic or manual) or mitigation which can prevent core damage from ISLOCA should be included. The end state of each event tree sequence may be one of the followings:

no-LOCA: LOCA did not occur because at least one barrier did not fail,

LOCA-IN: LOCA inside containment occurred because a pipe rupture or opening of relief valves inside containment prevented the system out side the containment from being over-pressurized. LOCA-IN will not be analyzed further as an ISLOCA.

ISLOCA-I: ISLOCA occurred but was isolated before core uncovery /damage. After isolation, the event progresses like a transient. This sequence will not be further analyzed because the event progress would be similar to transients but its frequency is much lower than the frequency of transients.

ISLOCA-CD: LOCA outside containment occurred and isolation and mitigation of the ISLOCA also failed or was not possible. This sequence result in core damage.

ISLOCA-OK: LOCA outside containment occurred and also isolation of the ISLOCA path failed. But core damage was prevented by minimizing leakage before the ECCS injection is lost due to the depletion of the RWST. Operator action, ECCS injection, and Secondary heat removal are required for this recovery. This kind of recovery actions can be credited only for small size ISLOCAs because it takes time to cool down and depressurize the RCS to minimize the leakage. In the PRA model for a reference plant [3], this recovery action were credited only when ISLOCA equivalent break size is less than 2.54 cm (1 inch) in diameter (For a break with size of 2.03 cm (0.8 inch) in diameter, it takes about 17 hours to deplete the RWST for the reference plant[4]). For ISLOCA path with equivalent break size greater than 2.54 cm(1 inch) in diameter, the isolation of the ISLOCA path (by closing isolation valves) before the RWST depletes was considered as the only effective recovery to prevent core damage.

In the third step, all identified ISLOCA-CD sequences are converted into fault trees. For a barrier (normally closed valve), two failure modes, catastrophic rupture of the valve disk and failure to re-close after use, may be considered. The valves in low pressure systems are generally leak tested after its use or before bring a plant to at power. In such case, only catastrophic disc rupture may be considered. For catastrophic disk rupture, since an ISLOCA sequence begins with the failure of the first valve which directly interfaces with the RCS, the first valve should have 1 year exposure time (valve failure probability = failure rate x exposure time). The second valve will be exposed to the full RCS pressure only after the first barrier fail. Assuming the first valve fails at the middle point of its exposure time, the second valve will have 1/2 year exposure time. In the same way, the third valve will have 1/4 year exposure time and so on (In the PRA model for a reference plant, it was conservatively assumed that the exposure time for the third and beyond barrier is 1/4 year [3] for simplicity). For failure to re-close, failure to re-close on each demand should be counted. If isolation failure by closing a valve is modeled, valve failure, failures of valve support systems such as electrical power failure, and operator error should be modeled. If two or more similar redundant valves are credited for isolation, common cause failures among those redundant valves need to be modeled. Also, inventory makeup and decay heat removal before an ISLOCA path is isolated may need to be modeled. If an ISLOCA can be mitigated by operator actions to minimize the leakage before the RWST depletion, failures of the related mitigating systems as well as operator actions should be modeled.

Finally, all constructed ISLOCA fault trees are integrated into a linked CDF (and LERF) fault tree model with fault tress of other initiating events. An initiating event label (for example, a basic event, %ISLOCA with probability of 1 [3]) may be attached the ISLOCA fault trees before integration so that later ISLOCA minimal cutsets can be easily identified. In the following section, an example implementation of the improved ISLOCA modeling method was presented.

An Example of ISLOCA Modeling

As an example, ISLOCA during power operation through RCS hot leg injection lines of intermediate head Safety Injection (SI) system of a reference plant [5, 6] was selected. Fig. 1 shows the flow paths, components, high pressure/low pressure boundaries, and inside/outside containment boundaries of the SI system. In a hot leg injection line, there are three barriers, two check valves (CVs) and a normally closed motor operated valve (MOV). The design pressure up to these three barriers is 18.5 MPa (2685 psig) which is greater than full RCS pressure of 15.5 MPa (2250 psig). If the first three barriers in any hot leg injection line fail, the discharge lines of both SI pumps (A and B) will be exposed to the RCS pressure. The design pressure of the pump discharge lines (including pump) is 12.4 MPa (1800 psig). Even though the design pressure is about 30 percent lower than the full RCS pressure, it was assumed that the pump discharge line would withstand failure during over-pressurization and the pump discharge check valves can be considered as the fourth barrier. This assumption was based on a study [7] which concluded that a system piping was capable of withstand failure during an ISLOCA even through it was exposed to pressure 275 percent higher than system design pressure. If operators close any of the two MOVs (HV8821A and HV8821B in Fig. 1), one of the pump trains can be isolated from ISLOCA (pump B train is isolated from ISLOCA through hot leg 1 or 4, pump A train from ISLOCA through hot leg 2 or 3). The design pressure at the suction of the SI pump is 1.0 MPa (150 psig). Thus, if exposed to the full RCS pressure, SI pump suction side will not survive. The relief valve in each pump train may not be large enough to prevent over-pressurization of the lines. Note that, since the first check valves in hot leg 1 and 4 (CV 126, 125) are shared with RHR hot leg injection, they should be modeled also in ISLOCA through RHR hot leg injection lines as well as SI system hot leg injection lines. Since the smallest piping size of a SI hot leg injection line is 5.08 cm (2 inch) in diameter (between the second check valve and the merging point with RHR hot leg injection), an ISLOCA with equivalent size of 5.08 cm (2 inch) in diameter will occur through a SI hot leg injection line, if all barriers fail.

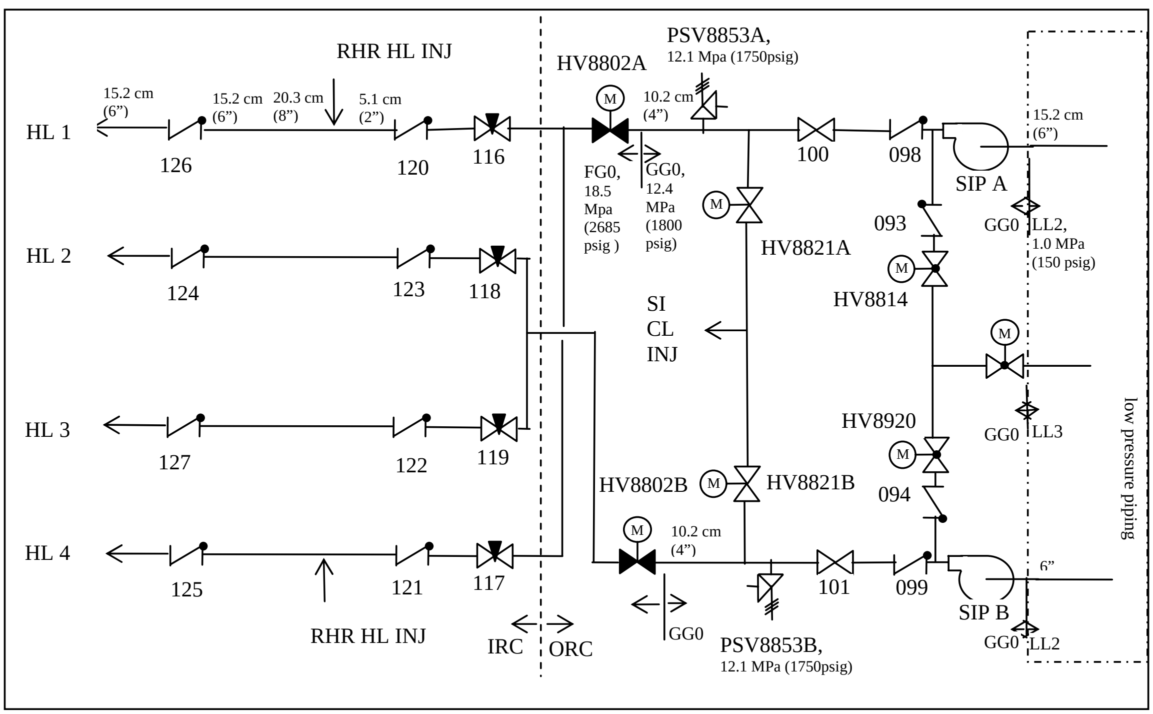

Fig 1. Potential ISLOCA Paths through Hot Leg Injection Lines of Safety Injection System

Fig.2 shows the event tree for ISLOCA through SI system hot leg 1 injection line. Similarly, event trees for ISLOCA paths through other hot leg injection lines in the SI system can be constructed.

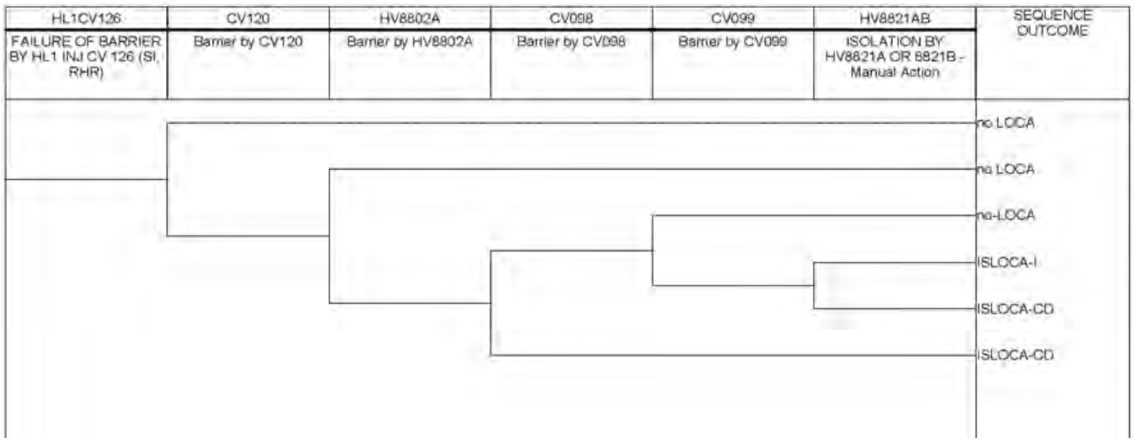

Fig 2. Event Tree for ISLOCA through SI System Hot Leg 1 Injection Line

The followings describe the headings of the event tree in Fig 2 (ISLOCA through SI System Hot Leg 1 injection line):

HL1CV126: Barrier by Hot Leg 1 injection line CV 126 fails

ISLOCA through SI system hot leg 1 injection line begins with the failure of CV126. Note that ISLOCA through RHR system hot leg 1 injection line begins in the same way. CV126 is leak tested per procedure before returning to the power operation and after use, thus only “disk rupture” was considered as the valve failure mode.

CV120: Barrier by CV120

If barrier by CV120 remains intact, ISLOCA through this path will not occur. CV 120 is leak test per procedure before returning to power operation and after use, thus only “disk rupture” was considered as the valve failure mode. CV120 will not be exposed to RCS pressure until the first CV (CV126) fails.

HV8802A: Barrier by HV8802A

If barrier by HV8802A remains intact, ISLOCA through this path will not occur. Note that HV8802A is a barrier also for ISLOCA through SI system hot leg 4 injection line.HV8802A is a normally closed MOV. MOV HV8802A’s status (closed, power removed) is checked during operations shift and daily surveillance log. Thus, only “disk rupture” was considered. HV8802A will not be exposed to the RCS pressure until the first two barriers fail.

CV098: Barrier by CV098

If barrier by CV098 remains intact, ISLOCA paths from any of SI system hot leg injection lines to SI pump A suction will not occur. CV098 is SI pump A discharge check valve and it is not-leak tested. Thus two possible failure mode, disk rupture and failure to re-close after previous open demands were considered. CV098 is partially stroked during SI Pump A in-service and response time test (every 3 months per procedure). Common cause failure to close after previous tests between CV098 and CV099 are not considered because only one CV is allowed to stroke test at a time and, furthermore, they are not redundant valves in preventing ISLOCA. CV098 will not be exposed the RCS pressure until the first three barriers fail.

CV099: Barrier by CV099

If barrier by CV099 remains intact, ISLOCA paths from any of SI system hot leg injection lines to SI pump B suction will not occur. CV099 is SI pump B discharge check valve and it is not-leak tested. Thus two possible failure mode, disk rupture and failure to re-close after previous open demands were considered. CV099 is partially stroked during SI Pump B In-service and response time test (every 3 months per procedure).Common cause failure to close after previous tests between CV098 and CV099 were not considered because only one CV is allowed to stroke test at a time and, furthermore, they are not redundant valves in preventing ISLOCA. CV098 will not be exposed the RCS pressure until the first three barriers fail.

HV8821AB: Isolation by HV8821A or B

Emergency Operating Procedures direct operator to detect ISLOCA and to close HV8821A and HV8821B to identify and isolate ISLOCA through SI cold leg injection line. Closure of HV8821A or HV8821B will also isolate ISLOCA path from hot leg 1 to the SI pump B suction. However, ISLOCA path from hot leg 1 or hot leg 4 to SI pump A suction can not be isolated by these valves. Common cause failures (to close) between HV8821A and HV8821B should be modeled. Operator must close either HV8821A or HV8821B before the RSWT depletes in order to prevent core damage due to ISLOCA through SI system hot leg 1 injection-SI pump B suction path. Also 1 of 2 Centrifugal Charging pumps (CCPs) (SI pumps will not be available in these ISLOCAs) is required for inventory make up before the isolation of ISLOCA path (break size will be ~5.08 cm (2 inch) in diameter, the size of a SI hot leg injection line). According to an analysis for a reference plant [4], for a break with size of 4.06 cm (1.6) inch diameter, the RWST will deplete in 8.4 hours if all ECCS pumps are running and switching to the recirculation can not be performed. Thus, operators would have at least several hours to close HV8821A or B.

From the event tree in Fig. 2 the following two ISLOCA core damage (ISLCOA-CD) sequences were identified:

(1) (HL1 CV126 ruptured) AND (CV120 ruptured) AND (MOV HV8802A ruptured) AND (CV098 ruptured)

(2) (HL1 CV126 ruptured) AND (CV120 ruptured) AND (MOV HV8802A ruptured) AND (CV099 ruptured) AND (Isolation by HV8821A or HV8821B failed)

Then, fault tree for each identified ISLOCA-CD scenario was constructed. Fig. 3 and Fig 4. show the high level fault tree logic for core damage sequences of ISLOCA through SI system hot leg 1 (gate ISL-SIS-HL1INJ in Fig. 3) and hot leg 4 injection (gate ISL-SIS-HL4INJ in Fig 3) lines. Since, after the first three valves, SI system hot leg 1 and hot leg 4 injection share the same piping and trains, the same fault tree (gate ISL-SIS-HL14-FI in Fig 3 and Fig 4) was used for both paths. Note that in Fig. 4, the fault tree for isolation failure (gate HV8821AB) included not only the failure of the valve itself but also an operator error, and the failure of inventory makeup until the ISLOCA path is isolated. Also, failure of MOV HV8821A or B (gate HV8821AFTC& or gate HV8821BFTC&) included the valve random failure, the valve common cause failure, and the failure of AC motive power (fault tree logic was not shown). Similarly, fault trees for ISLOCA paths through SI system hot leg 2 and 3 can be constructed.

The constructed ISLOCA fault trees can be integrated into the link CDF (LERF) fault tree model with fault trees for other ISLOCA paths and other initiating events. With the ISLOCA fault trees integrated into the linked CDF (LERF) fault tree, the effects of break of a piping segment or failure of some barriers in an ISLOCA path can now be accurately and easily evaluated. Two examples of the application of the improved ISLOCA model to risk informed applications were presented in the next section.

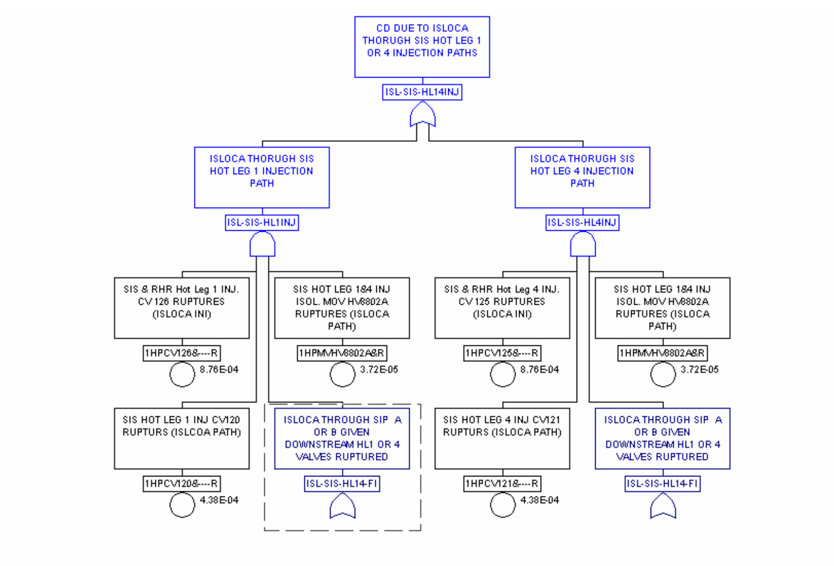

Fig 3. Fault Tree for ISLOCA Path through SI System Hot Leg Injection Lines 1 and 4 (part)

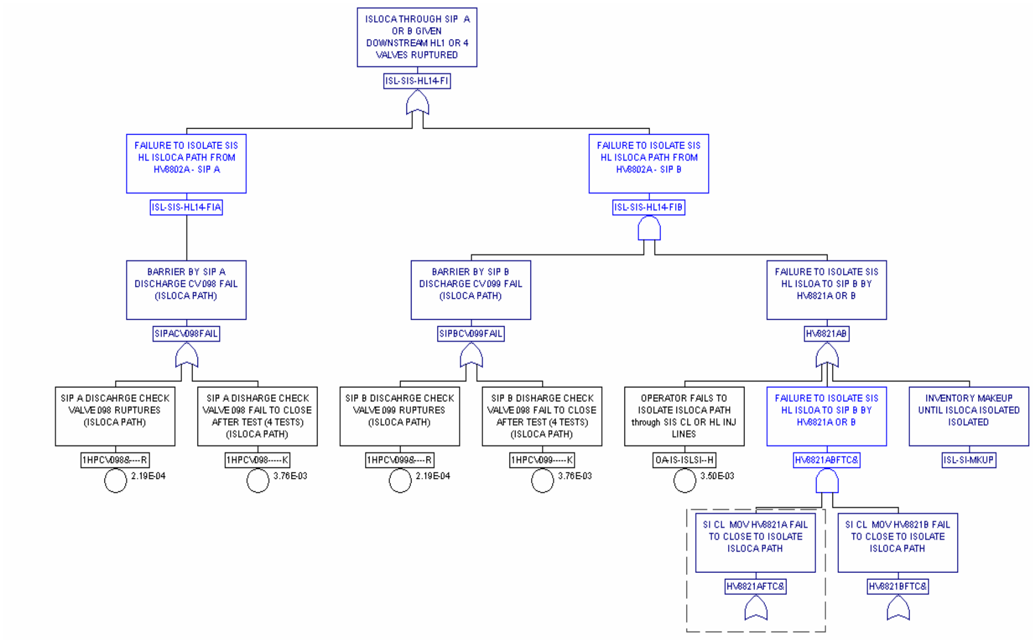

Fig 4. Gate ISL-SIS-HL14-FI (a part of fault Tree for ISLOCA through SI system Hot Leg 1 and 4 Injection Lines

APPLICATION OF THE IMPROVED ISLOCA MODEL TO RISK INFORMED DECISION MAKING

Once the linked CDF (or LERF) fault tree model is constructed, minimal cutsets for total CDF (or LERF) or those of ISLOCA or other initiating events can be generated by evaluating associated gates in the linked fault tree. Either point estimate or probability distribution of CDF (or LERF) can be evaluated using the generated minimal cutsets and failure data. Also, if a pipe segment ruptures, some barriers fail, or a support system fails within an ISLOCA path, their impact on ISLOCA and total plant risk can now be easily evaluated by setting the basic events (or gates) for the affected components to "fail" in the fault tree and reevaluate the linked fault tree. Even the impact of a component in support systems can be evaluated in the same way. If a 480 V AC power, which supplies power to one of the MOVs used for isolation of ISLOCA as well as many other MOVs in mitigating systems, is lost, setting the 480 V AC to "fail" in the linked fault tree will automatically propagates its impact on ISLOCA and other initiating events. Two exampled of such risk informed applications were presented below. In the following examples, the latest PRA model for a reference plant [8], in which all ISLOCA fault tree models were integrated into the linked CDF and LERF fault trees was used.

Application Example 1: Evaluation of Conditional CDF and LERF for RI-ISI

The first application example of the improved ISLOCA model was for the evaluation of the conditional core damage frequency given a break in a pipe segment between CV120 and MOV HV8802A outside containment in Fig.1. This segment is common to SI system hot leg 1 and hot leg 4. This kind of risk evaluation is typical calculation for RI-ISI [9]. Given the pipe segment break at this location, barriers HV8802A, CV098, CV099, and isolation by HV8821A or B would be lost.
To reflect the loss of these barriers and isolation, the following basic event and gate in ISLOCA fault tree (Fig.3 and Fig. 4) were set to "fail" (or logically set to "TRUE"): basic event 1HPMVHV8802A&R (for MOV HV8802A) and gate ISL-SIS-HL14-FI (for CV098, CV099, HV8821A,HV8821B). Note that the pipe segment break also affect SI system hot leg injection through hot leg 1 and hot leg 4. However, it was not reflected because the PRA model for the reference plant did not have SI system hot leg injection modeled. Table 1 shows the comparison of CDF and LERF for base case and case with the pipe segment break.

Table 1. Comparison of CDF and LERF for base case and case with the pipe segment break

Risk (/yr)[1]	base case	case with the pipe segment break
total CDF	1.52E-5[2]	1.59E-5
ISLOCA CDF	3.02E-8	7.98E-7
total LERF	1.82E-7	9.49E-7
ISLOCA LERF	3.02E-8	7.98E-7

[1] 5E-12 was used as a truncation value
[2] E-5 = x 10^{-5}

In Table, it can be seen that total CDF would not increase that much but total LERF would increase by about 5.2 times if the pipe segment breaks (if the plant operates with the break not fixed for a year.). In RI-ISI, the conditional CDF and LERF values like those in Table 1 are used to calculate the pressure boundary CDF and LERF and risk importance measures. Then this risk information is presented to the Expert Panel along with other deterministic information. The Expert Panel then makes the final high safety significant (HSS) and low safety significant (LSS) determination for each segment.

Application Example 2: Risk Evaluations for Leaking Check Valves

The second example was for the evaluation of risk associated with leaking CV126 and CV120 in Fig.1. At a reference plant, CV126 and CV120 showed leakage during leak tests performed during restart after refueling outage. As a part of risk informed decision making process, it was asked to evaluate risk increase if the plant operates at power with these two CVs leaking [10]. For the analysis, it was assumed that the leakage rate through these two check valve was so large that these CVs could not be credited as pressure barriers for preventing ISLOCA. The evaluation of risks were more complex than the first example above because in the second example leakage of CV126 affect not only SI system but also RHR system hot leg injection ISLOCA paths. In addition, assuming the first two barriers fail, the exposure times for the rest of barriers should be changed because the third barrier (HV8802A in Fig. 1) will be exposed to a full year if plant operates with the first two barriers gone. And the exposure time for the fourth barrier will now be 1/2 year on so on. For the analysis, it was assumed that the leakage of these CVs would not affect SI system and RHR system hot leg injection function because the SI system and the RHR system would still be able to inject water through these CVs when the RCS pressure is below the pump head. To reflect the all these impacts into the model, the following modification to the PRA model were made (Table 2). The risk evaluation results were presented in Table 3.

Table 2. Modifications to the PRA model for reflecting the impacts of leaking CV126 and CV120

basic event [8]	modification	remark
1HPCV126&----R	set to “fail”	CV126 (SI hot leg 1 inj, RHR hot leg 1 inj)
1HPCV120&----R	set to “fail”	CV120 (SI hot leg 1 inj.)
1HPMVHV8802A&R	exposure time 1/2yr -> 1 yr	HV8802A (SI hot leg inj, 1&4 common)
1HPCV098&----R	exposure time 1/4 yr -> 1/2 yr	CV098 (SI pump A discharge)
1HPCV099&----R	exposure time 1/4 yr -> 1/2 yr	CV099 (SI pump B discharge)
1LPCV128&----R	exposure time 1/2yr -> 1 yr	CV128 (RHR hot leg 1 inj.)
1LPMVHV8840&-R	exposure time 1/4 yr -> 1/2 yr	MOV HV8840 (RHR hot leg 1 inj.)

Table 3. Comparison of CDF and LERF for base case and case with leaking CV126 and CV120

Risk (/yr)[1]	base case	case with leaking CV126 and CV120	delta CDF (LERF) (/yr)[3]
total CDF	1.52E-5[2]	1.58E-5	6.00E-7
ISLOCA CDF	3.02E-8	7.23E-7	6.93E-7
total LERF	1.82E-7	8.75E-7	6.93E-7
ISLOCA LERF	3.02E-8	7.23E-7	6.93E-7

[1] 5E-12 was used as a truncation value
[2] E-5 = x 10^{-5}
[3] Delta CDF, as defined in US NRC risk significance determination process [11] is an annualized increase in CDF which is calculated as (CDF assuming the conditions exist for a year - base line annual CDF)x(actual duration of the condition existence). Since the actual duration of the condition existence is 1 year in example 2, delta CDF = (CDF assuming the condition exist for a year - base line annual CDF). Delta LERF is calculated in a similar way.

The delta CDF and the delta LERF values in Table 3 can be used to determine if the risk associated with leaking CV126 and CV120 is significant. According to the criteria for NRC signification determination process [11], risk is considered insignificant if delta CDF < 1E-6/yr and delta LERF < 1E-7/yr. For example 2, delta CDF is 6.00E-7/yr and delta LERF is 6.93E-7/yr. So CDF increase is insignificant. However, delta LERF is greater than 1E-7/yr and thus the risk associated with operating plant at power with leaking CV126 and CV120 for a year would not be insignificant. As a result, operation of the plant at- power for a year with leaking CV126 and CV120 may not be allowed.

SUMMARY AND CONCLUSIONS

In this study, an improved modeling method for ISLOCA was developed in order to accurately and easily evaluate ISLOCA risk for risk informed applications. The improved ISLOCA modeling method utilizes event tree method to identify ISLOCA core damage sequences and fault tree linking methods to develop fault trees of ISLOCA core damage sequences and to integrate them into a linked core damage frequency (CDF) fault tree with fault trees of other initiating events' core damage sequences. Also, the ISLOCA fault trees are integrated into level 2 Probabilistic Risk Assessment (PRA) logic as a part of Large Early Release Frequency (LERF) fault tree. Then using the linked CDF (or LERF) fault tree, minimal cutsets for total CDF (or LERF) or for ISLOCA or other initiating events can be generated by evaluating associated gates in the linked fault tree. Either point estimate or probability distribution of CDF (or LERF) can be evaluated using the generated minimal cutsets and failure data. Furthermore, the impacts of failure of any components in ISLOCA paths on CDF (or LERF) can be easily evaluated just by setting the related components to fail and evaluate the linked fault tree. Also, since the each ISLOCA fault tree is logically combined with fault trees of other ISLOCA paths and those of other initiating events in the linked CDF and LERF fault trees, the impacts of a component which is shared by more than one ISLOCA paths or failure of support systems related with ISLOCA components can be directly evaluated from the linked CDF (LERF) fault tree model. Fault trees for ISLOCA through hot leg injection lines of the SI system of a reference plant were developed as an example implementation of the developed method. Also, through two example applications, it was demonstrated that the linked CDF (LERF) fault tree model with the improved ISLOCA model could accurately evaluate the conditional CDF and LERF for a pipe segment break in an ISLOCA path a RI-ISI and the risk increase due to two leaking check valves in an ISLOCA path for a risk informed decision making. The developed ISLOCA method was implemented in the PRA model for a reference plant [3, 8] and the PRA model was successfully used for a update of risk evaluations for RI-ISI [12]. The developed ISLOCA modeling method will enable more accurate and easier evaluations of risks associated with ISLOCA in the future risk informed applications.

REFERENCES

1. Jo, Y.G., Park, C. K., Kang, D. I., Chang, S. J., and Sung T.Y., "Final Level 1 PRA Update of Yonggwang Nuclear Units 3&4," Korea Atomic Energy Research Institute, 1994.
2. Scott, O.M., Jo, Y. G., and Hance, D. G., "Vogtle PRA Model - Revision 2c," calculation PSA-V-0-030, Southern Nuclear Operating Company, 2000.
3. Jo, Y. G., "VEGP LEVEL 1 PRA model Rev 3," PRA-BC-V-06-001, Southern Nuclear Operating Company, 2006.
4. Jo, Y.G, "MAAP Analyses for VEGP PRA model revision 3 - Small LOCA scenarios," calculation PRA-BC-V-06-005, Southern Nuclear Operating Company, 2006.
5. "VEGP P&ID Reactor Coolant System," 1X4DB111 rev. 27, Southern Nuclear Operating company, 2002.
6. "VEGP P&ID Safety Injection System," 1X4DB121 rev. 35, Southern Nuclear Operating Company, 2003.
7. "Technical Report 23.5: Evaluation of Containment Bypass and Failure to Isolate Sequences for the IDCOR Reference Plants", Fauske and Associates, Inc.. 1986.
8. Jo, Y.G. "VEGP Level 1 and Level 2 PRA Model Revision 4 - at power, internal events", calculation PRA-BC-V-07-003, Southern Nuclear Operating Company, 2007.
9. Scott, O.M., "RI-ISI Documentation of PRA Run Surrogate Assignments and CD/LER Analyses Results," calculation REES-V-01-005, Southern Nuclear Operating Company, 2001.
10. Scott, O.M., "Risk impact of HL injection check valve leakage while at power," calculation RBA-07-002-V, Southern Nuclear Operating Company, 2007.
11. "Reactor Oversight Process", NUREG-1649 Rev 3, NRC, 2000.
12. Powers, K. H, "Update of RI-ISI PRA Run Surrogate Assignments and CDF/LERF Results," calculation PRA-BC-V-06-012, Southern Nuclear Operating Company, 2007.