Transactions of the Korean Nuclear Society Autumn Meeting
Gyungju, Korea, October 29~30, 2015

Development of a PSA-based Loss of Large Area Analysis Method

Mee Jeong Hwang, Woosik Jung*, Myungsu Kim**

Korea Atomic Energy Research Institute, 989-111, Daedeok-daero, Youseong-Gu, Daejeon
*Sejong Univ., 209, Neungdong-ro, Gwangjin-gu, Seoul**
*Korea Hydro Nuclear Power, Central Research Institute, 1312-70, Youseong-daero, Youseong-Gu, Daejeon***

mjhwang@kaeri.re.kr

1. Introduction

After the September 11, 2001 terrorist attacks within the U.S., the U.S. Nuclear Regulatory Commission (NRC) in conjunction with U.S. Department of Energy (DOE) national laboratories (e.g., SNL) conducted a series of assessments of commercial aircraft impacts on NRC-licensed facilities using state-of-the-art structure and fire analyses. As a result of these initial post 9-11 assessments in 2002, the NRC issued an interim safeguards and security compensatory measures order. In "Interim Compensatory Measures for High Threat Environment," Section B.5.b (not publically available) of this order, current NPP licensees had to adopt mitigation strategies using readily available resources to maintain or restore reactor core cooling, containment, and spent fuel pool (SFP) cooling capabilities to cope with a LOLA due to large fires and explosions from any cause, including beyond-design basis threat (BDBT) aircraft impacts. In 2009, the NRC issued amendments to 10CFR Part 50, Part 52, and Part 73 for power reactor security requirements for operating and new reactors. New U.S. licensed commercial nuclear power plant operators are required to provide a LOLA (Loss of Large Area) analysis as per the U.S. Code of Federal Regulations, 10CFR50.54(hh)(2). Additionally 10CFR52.80(d) provides the required submittal information on how an applicant for a combined operating license (COL) for a nuclear power plant to meet these requirements. For the export of Korean nuclear power plant, it would be required to analyze LOLA. Therefore, it is necessary to prepare our own guidance for a development of LOLA strategies. Therefore, in this paper, we developed a PSA-based LOLA analysis method and applied it to APR1400.

2. LOLA Strategies for New Plants

In the U.S., current reactor licensees comply with the requirements of 10CFR50.54(hh)(2) through an operating license condition. The NRC has recognized that new plants may have special features in their designs that could preclude the need for some of the strategies developed for Phase 2 and Phase 3. NEI 06-12, guidance for new plants is presented to comply with all three phases of B.5.b requirements, which ultimately were codified into law for new plants through 10CFR50.54(hh)(2).

2.1 Phase 3 Guidance for New Plants

Guidance (NEI 06-12) [3] was developed by the Nuclear Energy Institute (NEI) and endorsed by the NRC for the development of LOLA strategies in compliance with U.S. Federal regulations. NEI has developed guidance for both existing plants and for new reactor designs. The fact that there is a distinction between strategies for existing plants and for new reactor designs is an acknowledgment by the NEI and the NRC that new plant designs could be inherently more robust against the circumstances associated with a LOLA event than existing plants. Therefore, it is possible that new plants may not need to address all the Phase 3 strategies for the current plants. This is because new plant design features could include such features as enhanced spatial separation between trains of safety systems, passive systems, and additional new safety systems or redundancies.

If an applicant for a new plant license chooses to factor the new plant design features into their Phase 3 strategies, then the applicant can follow the guidance in NEI 06-12 Section 4.2.3.2 through Section 4.2.3.6. This guidance allows an applicant to evaluate the equipment and features of the new plant design within the context of a set of deterministic rules that establish design specific LOLA damage footprints that test the spatial separation between redundant equipment or features that provide the necessary safety functions. The idea behind these deterministically defined damage footprints is that spatial separation and/or stout, robust barriers (e.g., thick, reinforced concrete walls) between redundant equipment or features is key to the survivability of a safety function.

The five step process to evaluate the survivability of a new plant's safety functions is summarized below:

1) Identify Functional Attributes: For each key safety function, identify the minimal set of equipment for both the primary and alternate means of satisfying the safety function. Include necessary support equipment.

2) Identify Equipment Locations: For each safety function, identify the physical locations of the equipment

and support equipment needed for the success of that safety function.

3) <u>Credit Existing Design Features:</u> Redundant or alternate features for a specific safety function can be credited for LOLA strategies if there is adequate separation and/or barriers between the primary and alternate means, including necessary support equipment. Adequate separation or protection is defined if one of the following four deterministic criteria is satisfied:

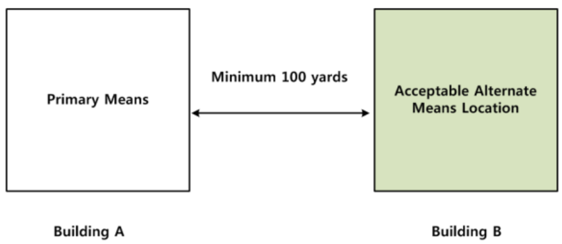

Fig.1 Separate Building Criteria

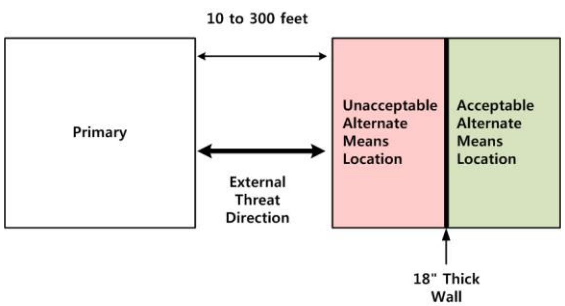

Fig.2 Nearby Building Criteria

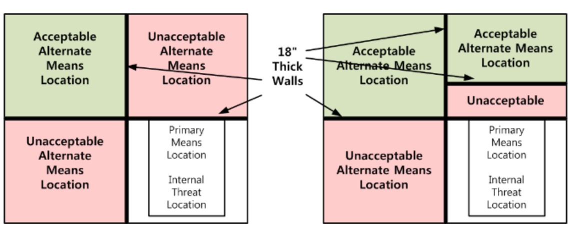

Fig.3 Same Face Criteria

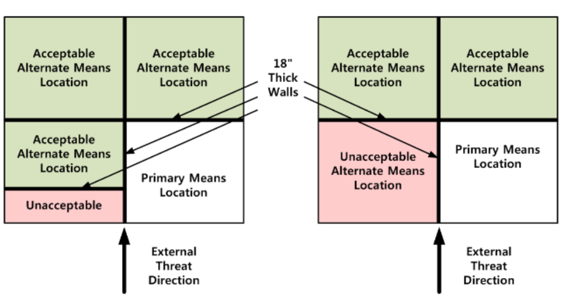

Fig.4 Internal Threat Separation Criteria

4) <u>Assessment of Key Safety Functions:</u> For each safety function for which at least one criteria from Step 3 is satisfied for at least one alternate means to provide that safety function, a check should be made on the system and/or features that would provide the alternate means. It should be verified that the success criteria for meeting the key safety function can be satisfied by the existing redundant spatially separated equipment or features. If for any safety function, the success criteria cannot be guaranteed despite the spatial separation and/or protection; then strategies for mitigation reactor and containment challenges (Section 3 of NEI06-12) should be developed as appropriate for the safety functions of the new reactor design.

5) <u>Mitigation Strategies:</u> This step is merely a reiteration for any key safety function that cannot be satisfied through the previous four steps; strategies for mitigation reactor and containment challenges (Section 3 of NEI06-12) should be developed as appropriate for the safety functions of the new reactor design.

3. Development of a PSA-based LOLA Analysis Method

The U.S. nuclear industry felt it was not feasible to define a 'bounding' scenario for a LOLA event. The NRC ultimately agreed with the industry's position and even adopted their guidelines for LOLA analyses. Never the less, a VAI-type of analysis can produce useful insights that could be used to influence LOLA strategies, but are not required by the NRC to meet regulatory requirements.

The method by which new plant designs may be evaluated for LOLA involves the evaluation of alternate means to provide a plant's safety functions against deterministically defined spatial separation and protection criteria. If a safety function at a new reactor can be provided through at least one alternate means for which at least one of the four spatial separation and/or protection criteria can be satisfied, than that alternate means can be credited as an acceptable LOLA strategy for that safety function.

Therefore, we performed a LOLA proof-of-concept analysis for the APR1400 reactor design. The purpose of this study is not to literally design LOLA strategies to explicitly avoid all rooms in the target sets that were evaluated, but to look for interesting combinations of rooms in certain target sets, and produce useful insights that can be used to influence LOLA strategies.

3.1 Analysis Concept

3.1.1 Vital Area Identification

In the LOLA strategies, a role of the VAI model information is to provide target set and prevention set evaluation results. This results is used as an information to identify the spatial separation condition. Also, the VAI model can be used as a mean to identify adequacy for the LOLA strategies. If the rooms in target sets are located on which at least one of the four spatial separation criteria (Fig.1~4) can be satisfied, than that alternate means can be credited as an acceptable LOLA strategy for that safety function.

We don't consider the destruction of an adjacent room sharing the wall when a room is exploded during the vital area identification. However, it is necessary to consider the destruction of adjacent rooms in case of the LOLA due to large fires and explosions and for main components and alternate components to design not to be located on the adjacent room.

(Sabotage model evaluation): When the components, {A, B, C} are located in the rooms, {R1, R2, R3} as shown in Fig. 5 and the minimal cut sets inducing core damage are as follows;

MCS inducing core damage = {A*B, A*C}

The target sets and the prevention sets are evaluated as follows;

Target sets = {R1*R2, R1*R3}
Prevention sets = {/R1, /R2*/R3}

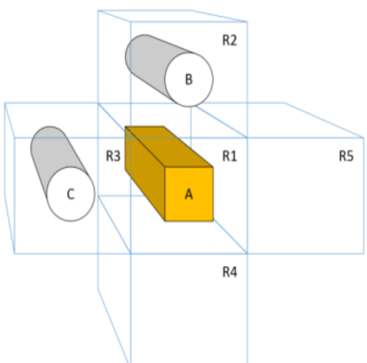

Fig.5 Location of components and rooms

(Vital area identification) Here, a member of prevention set {/R1}, room {R1} is a vital area or a member of prevention set {/R2*/R3}, rooms {R2, R3} are selected as vital area. However, we can find a vulnerability through the following LOLA analysis.

(LOLA analysis 1) If the LOLA occurs, core would be damaged since the rooms {R1, R2} which is a member of the first target set {R1*R2}, are located on the adjacent area. Therefore, it is necessary to relocate the component {A, B} the adjacent rooms should not to be included in the same target set.

(LOLA analysis 2) Also, core damage occurs directly because the room {R1, R3} which is a member of the target set {R1*R3} are adjacent. Therefore, it is necessary to design the component {A, C} the adjacent rooms should not to be included in the same target set.

3.1.2 Loss of Large Area Analysis

(Sabotage model evaluation) One of the options reflecting LOLA analysis result is to move component A to room R4 or R5. When we move component A to room R5 as shown in Fig. 6, target sets and prevention sets are as follows since the minimal cut sets are {A*B, A*C} inducing core damage:

Target sets: {R5*R2, R5*R3}
Prevention sets: {/R5, /R2*/R3}

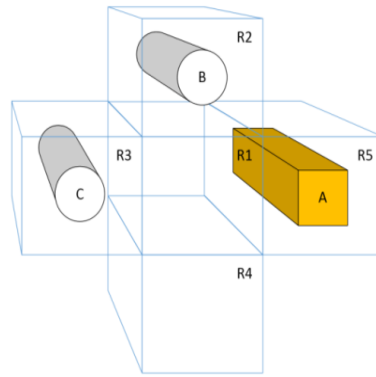

Fig.6 Component's relocation example

(Vital area identification) Here, a member of prevention set {/R15, room {R5} is a vital area or a member of prevention set {/R2*/R3}, rooms {R2, R3} are selected as vital area. However, we cannot find a vulnerability through the following LOLA analysis.

(LOLA analysis 1) If the LOLA occurs, core would not be damaged since the rooms {R5, R2} which is a member of the first target set {R5*R2}, are not located on the adjacent area.

(LOLA analysis 2) Also, core damage would not occur because the room {R5, R3} which is a member of the target set {R5*R3} are not adjacent. Therefore, it is necessary to design the component {A, C} the adjacent rooms should not to be included in the same target set.

3.2 A PSA-based LOLA Analysis Process

The process of a developed PSA-based LOLA analysis is described in Table 1.

Table 1. A VAI and LOLA analysis process

Stage	Description	S/W
1	Collection of Fire/Flood PSA model	N/A
2	Integration of Fire/Flood PSA model	VIPEX
3	Conversion to Sabotage FT	VIPEX
4	Evaluation pf target sets and prevention sets	VIPEX
5	(LOLA analysis) Adjacent room in the target sets	VIPEX
6	(LOLA analysis) Relocation of components I	N/A

	adjacent rooms	
7	Selection of vital area	N/A

4. Application

We applied a PSA-based LOLA analysis method to APR1400, and found that 2 target sets of 112,466 target sets are located on adjacent area. However, we don't describe the application results in this paper since the LOLA analysis results are not in public.

5. Conclusions

For the export of Korean nuclear power plant, it would be required to analyze LOLA. Therefore, it is necessary to prepare our own guidance for a development of LOLA strategies. In this paper, we proposed a method to look for interesting combinations of rooms in certain targets getting through VAI model, and produced insights that could be used to influence LOLA strategies. Also, we found that the vital area cam be changed reflecting LOLA analysis results.

REFERENCES

1. USNRC, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Editions," NUREG-0800, U.S. Nuclear Regulatory Commission, Washington D.C., USA, 2013.
2. USNRC, "Issuance of Order for Interim Safeguards and Security Compensatory Measure for Nuclear Power Plants," EA-02-026, U.S. Nuclear Regulatory Commission, Washington D.C., USA, 2002.
3. Erin Engineering, "B.5.b Phase 2 & 3 Submittal Guideline – Revision 3," NEI 06-12, Nuclear Energy Institute, Washington, D.C., USA, 2009.
4. NEI, "Diverse and Flexible Coping Strategies (FLEX) Implementation Guide – Revision 0," NEI 12-06, Nuclear Energy Institute, Washington D.C., USA, 2012.
5. IAEA, "Severe Accident Management Programmes for Nuclear Power Plants – Safety Guide," Safety Guide No., NS-G-2.15, International Atomic Energy Agency, Vienna, Austria, 2009.
6. USNRC, "Compliance with 10CFR50.54(hh)(2) and 10CFR52.80(d) Loss of Large Areas of the Plant due to Explosions or Fires from a Beyond-Design Basis Event," DC/COL-ISG-016, U.S. Nuclear Regulatory Commission, Washington D.C., USA, 2009.
7. KAERI, "Guidelines on APR1400 Loss of Large Area Analysis (Rev. 0)," KAERI/TR-5983/2015, 2015.
8. KEPCO E&C, "APR1400 물리적 방호 설계체계 구축 과제, APR1400 핵심구역파악 보고서," KEPCO E&C/14-TRG05-01, 2014.