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A Literature Review on Element Technology in the Multi-Unit Probabilistic Risk Assessment

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1. Introduction

Since the Fukushima accident occurred by the external source (earthquake and tsunami) in March 2011, interests in multi-unit probabilistic risk assessment (MUPRA) and Seismic event have been increased.

In addition, there is a great need for MUPRA in South Korea because there are at least 6 units located on each site. Therefore, in this study, we surveyed the element of MUPRA such as initiating event and inter-unit dependency by reviewing the previous studies.

2. Literature Review

2.1 Summary of MUPRA process

In the IAEA report [1], major issues and the overall process of a MUPRA were described through the review of recent studies and operating experiences in multi-unit sites.

Table I: MUPRA Process [1]

Step	Description
1	Select MUPRA scope and risk metric
2	Review or complete PRA for each reactor unit
3	Analyze initiating events (IEs) for MUPRA
4	a. Level 1, 2 event sequence model for single reactor events
	b. Level 1, 2 event sequence model for multiple reactor events
5	Mechanistic Source Terms (MSTs) for all events
6	Radiological consequences for all events
7	Risk Integration and interpretation of results

Table I shows an overview of the process, which begins with selecting a scope and a risk metric for the analysis. In this step, the scope of the MUPRA is determined.

The purpose of step 2 is to review or complete a single unit probabilistic risk assessment (SUPRA) in order to accomplish the scope selected in step 1. If necessary, SUPRA model can be modified to consider the technical issues of MUPRA.

Analyzing initiating events for MUPRA is performed to resolve which apply to individual reactor units and which impact two or more reactor units at the site simultaneously and to resolve the initiating event causes including internal events, internal hazards, and external hazards. Re-screening the initial list of events considered in the SUPRA can be required and sub-dividing some events can be needed to resolve the multi-unit common cause initiating events.

Initiating events for MUPRA can be classified into following two groups [2]:

- Common Cause Initiators (CCIs) – initiating events simultaneously challenge all units at the site
- Single-Unit Initiators (SUIs) – events that occur at one unit

SUIs will result in one of the following three types of sequences:

- Restricted sequence – a single unit (reactor) event sequence caused by an SUI that causes core damage and release only from the unit where the initiator occurred
- Cascading sequence – a multi-source event sequence caused by an SUI that causes core damage and release from the reactor where the SUI occurred and in one or more additional reactors
- Propagating sequence – a multi-source event sequence caused by an SUI that does not cause core damage in the reactor where the SUI occurred, but causes core damage and release in one or more additional reactors.

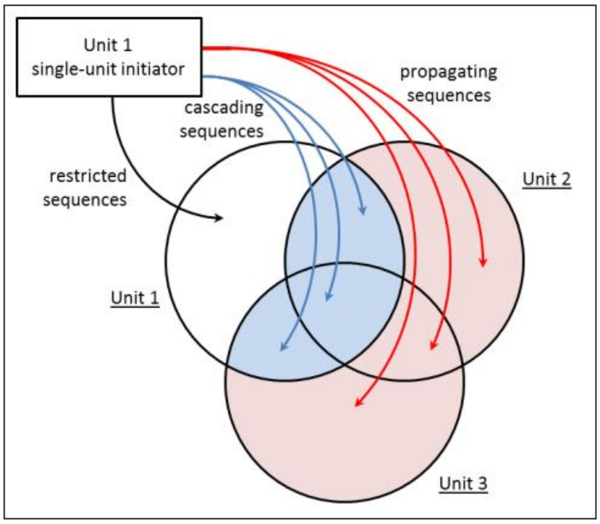

Fig. 1. Restricted, Cascading, and Propagating Sequences Caused by a Single-Unit Initiator [2]

Figure 1 shows the possible restricted (black arrow), cascading (blue arrows), and propagating sequences (red arrows) that causes core damage and release that are generated by the incidence of an SUI at Unit 1, SUI 1, which is placed at a site including three units.

The restricted sequences from SUIs have been evaluated in the SUPRA. The cascading and propagating sequences are subject of this figure. To capture these sequences initiated by SUIs, consequential failures are modeled in the MUPRA, which will result in a new set of multi-unit initiators (MUIs). The modeling of consequential faults considers cross-unit dependencies, spatial interactions, common cause failures (CCFs) or operator actions.

Consequently, MUIs are caused by one of two kinds of event scenarios: CCIs and consequential failures after SUIs. Table II describes MUI types and examples of each type.

Table II: Types of multi-unit IEs [3]

Multi-unit IE type	Example
Proximity event sequence	– Drop of 529 tons stator onto turbine deck floor caused loss of offsite power (LOOP) at Unit 1, transient at Unit 2
Cascading event sequence	– Loss of unit auxiliary transformer (UAT) at Unit 1 results in loss of component cooling water (CCW), which was crosstied to Unit 2; caused transients at both units – Incorrect operator response (manual scram) based on transient at the other unit and what the operator heard
Propagating event sequence	– Electrical fault at Unit 1 caused a grid disturbance, which in-turn caused a trip of Unit 2 – Generator trip at Unit 2 caused voltage transients on emergency buses at Unit 1
External event sequence	– Grid disturbances (e.g., voltage, current) where offsite power remained available and caused transients at both units – Undervoltage generated in switchyard, not offsite transmission system, caused transients at both units.
Restricted event sequence	– IE does not propagate or cascade to the other unit

The next step is to develop a sequence model of events. an event sequence model needs to be developed for both the single-unit events (Step 4a) and the multi-unit events (Step 4b). In Step 4b, a new model needs to be developed to identify event sequences involving damage and release on two or more reactors.

The fifth step is to develop the radioactive release source terms for all the event sequences and release categories obtained from Step 4. To support the MUPRA, it is necessary to address the unique accident sequences associated with multiple reactor source terms.

In the following step, developing the radiological consequences for all events is needed for all the release categories and source terms obtained from Steps 4 and 5. And then, the results for the event sequence frequencies and consequences will be integrated into the Level 3 risk metrics such as quantitative health objectives (QHOs) and the plant Complementary Cumulative Distribution Function (CCDF) curves for public health and safety impact, property damage, and economic impact.

In the last step, risk integration and interpretation of results such as individual risk and economic risk will be carried. The integrated risk results are compared with the chosen risk significance criteria and safety goals.

2.2 Survey of inter-unit dependency

In the paper written by S. Schroer [4], Six main commonality classes that could cause multi-units to be dependent were presented: initiating events, shared connections, identical components, proximity dependencies, human dependencies, and organizational dependencies. The report by M. Modarres [5] considered these dependencies and presented the conceptual two-unit logic examples using the postulated units as shown in Figure 2.

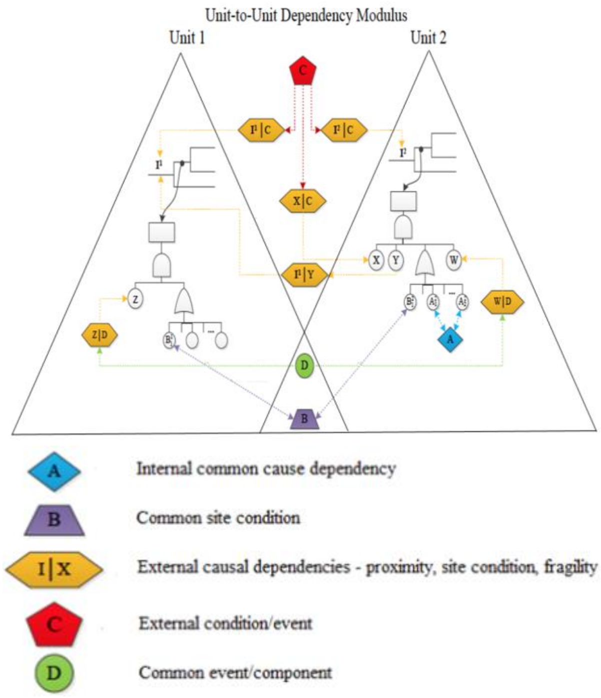

Fig. 2. Conceptual Examples of Unit-to-Unit Dependencies [5]

Figure 2 shows examples of the dependencies originated from events within one unit or from external causes. In this diagram, the external event “C” could lead to initiating events in the multi-units. The conditional probability of the external event “$I^i|C$” means the chance that the root external event will cause the initiating events in unit i. Likewise, other common conditions which is not clearly defined such as the organizational, design, environmental and operational events may also be the source of causal failures. These events are described as “B” which lead to similar events in the two units. In addition, the event “D” shows shared events. Similarly, failures originated in one unit could cause to another event in the other unit. This case is illustrated by event Y in unit 2 and initiated event in unit 1 described by the conditional probability "I^1|Y".

3. Conclusions

Because all nuclear power plant sites of the South Korea include multi-units originated from geological reason, MUPRA is required. This report reviewed the state of the art studies which described a general process of MUPRA and element technologies for MUPRA. The first piece of element technologies for MUPRA was initiating event in which MUIs were the combination of CCIs and SUIs that caused consequential failures on two or more units. The second piece of that for MUPRA was inter-unit dependencies which was illustrated by example figure and which conditionally come from events within one unit or from external causes.

Although MUPRA is internationally hot issue, but competent outcomes have not emerged. More research of MUPRA would be necessary and should be applied on the basis of regulation guide and social state of the countries.

Acknowledgements

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REFERENCES

[1] International Atomic Energy Agency, Technical Approach to Multi-Unit Site Probabilistic Safety Assessment, Safety Report Series No. XX (Draft), 2014.
[2] L. Burgazzi, Application of Risk-informed Probabilistic and Deterministic Safety Approach to Estimate the Risk of External Events, ENEA, 2015.
[3] M. D. Muhlheim, G. F. Flanagan and W. P. Poore III, Initiating Events for Multi-Reactor Plant Sites (No. ORNL/TM--2014/533), Oak Ridge National Laboratory (ORNL), Oak Ridge, TN (United States), 2014.
[4] S. Schroer and M. Modarres, An Event Classification Schema for Evaluating Site Risk in a Multi-Unit Nuclear Power Plant Probabilistic Risk Assessment, Reliability Engineering and System Safety, Vol. 117, pp.40-51, 2013.
[5] M. Modarres, T. Zhou and M. Massoud, Advances in Multi-unit Nuclear Power Plant Probabilistic Risk Assessment, Reliability Engineering and System Safety, Vol. 157, pp.87-100, 2017.