

- Highlighted the importance of Multi-Unit PRA
 - Over 80% of operating nuclear power plant(NPP) sites worldwide have more than one reactor units. [S. Samaddar et al; 2014]
 - Fukushima-Daiichi accident occurred in 2011
 - the first severe accident affecting multiple units due to single initiating event
 - particularly underlined possibility of unit-to-unit dependencies (e.g. common cause failure across reactor units)
- How to consider unit-to-unit dependencies ?
 - Extending the parametric method(e.g. alpha factor method) to the multi-unit context has been recognized as a promising solution.

- The parametric method proposed by Modarres et al
 - The parametric estimation is
 - based on the analysis of the U.S. Licensee Event Reports(LERs) (i.e. U.S. NPP incident occurrences reported by law to the U.S. NRC)
 - limited to the NPPs with two or three units at a site.
- There are many multi-unit sites in the rest of the world with more than three units.
 - In Japan, 7 of 18 NPP sites (including decommissioning plants) have more than three reactor units.



↓

The framework of the proposed parametric method would need to be extended to address the cases beyond three reactor unit sites in Japan.

Purpose

an extension of the application of the proposed parametric method by using Japanese NPP incident reports in Nuclear Information Archives(NUCIA).

Contents

- 1) The extension of parametric estimation based on NUCIA
- 2) The parametric estimation based on NUCIA

- In NUCIA, there are 3 kinds of reports;

Trouble Information	Incidents which legally obligate the plant owners to submit a report
Maintenance Quality Information	Incidents which are advised to be shared with plant owners to improve maintenance activities
Others Information	Events which are not classified into Trouble and Maintenance Quality Information

Methodology of The Proposed Parametric Estimation 5

- The conditional probability of multiple failure events or human errors involving multiple units are estimated.
- The proposed parametric estimation consists of 4 steps[※];
 1. Identification of Relevant Multi-Unit LERs
 2. Application of Exclusion Criteria
 3. Differentiating Common Cause and Causal Events
 4. Parametric Estimation of the Multi-Unit Dependencies

Reviewing NUCIA reports,

Step3 and Step4 are extended to address cases beyond three reactor unit sites.

※) M. Modarres et al "Advances in multi-unit nuclear power plant probabilistic risk assessment"

- One way of the extension
 - Simply add the categories of multi-unit effects
(i.e. when considering 5-unit sites, the effect in four and five units are added respectively into the original categories.)



The drawback of this extension

The number of events in four or five units would not be sufficient to calculate the probability

(i.e. the interval of the probability would be too high.)

- The effect of more than three units are put together and multi-unit events in case of more than three units are added into the categories.

- The extended categories of Multi-Unit events;
 1. Identical human error events in two units
 2. Identical human error events in three units
 3. Identical human error events in more than three units
 4. Human error event in one unit caused different human error(s) in another unit(s)
 5. Identical component failure/degradation in two units
 6. Identical component failure/degradation in three units
 7. Identical component failure/degradation in more than three units.
 8. Identical initiating events in two units
 9. Identical initiating events in three units
 10. Identical initiating events in more than three units.
 11. Initiating events in one unit caused a different initiating event(s) in another unit(s)
 12. Component failure/degradation in one unit caused initiating event(s) in another unit(s)
 13. Component failure/degradation in one unit caused different component failure/degradation event(s) in another unit(s)
 14. Initiating event in one unit caused component failure/degradation event(s) in other units

Extension of Criteria for identifying Total number of events(Step4)

8

- In the parametric estimation
 - Necessary to identify the total number of events (the denominator N in equation)
- Reviewing Trouble Information and Maintenance Quality information in NUCIA, it was found that some reports show
 - Events which occurred in other facilities (e.g. a facility for waste disposal)
 - Events of worker's injury without any effect on plant operations

$$\hat{p}_{i,j} = \frac{n_{i,j}}{N}$$

The parametric method currently focuses on risks originated from the multiple units, not the entire site.



Extension of Criteria for identifying Total number of events(Step4)

9



$$\hat{p}_{i,j} = \frac{n_{i,j}}{N}$$

- The extended criteria for identifying N;
 1. Only events that occurred in sites involving more than a single unit were considered.
 2. The events involving organizational, technical specifications violations were eliminated.
 3. The events were put into one of the categories: initiating event, component failure/degradation and human error.
 4. The events that occurred in other facilities in sites without involving any reactor units were eliminated.
 5. The events that didn't effect any components in the site units were eliminated.

Parametric Estimation Based on NUCIA

1
0

- The reports submitted from 2000 to 2011 were analyzed.

Event Description	Number of events for 2- or more unit sites	Number of events for 3- or more unit sites	Number of events for 4- or more unit sites
Initiating Events	138	111	79
Component Failure/ Degradation	1041	874	610
Human Error	129	110	85
Total	1308	1095	774

- Over half of total events in Japan occurred in 4- or more unit sites.

Parametric Estimation Based on NUCIA

1
1

- Examining 1308 events, it is identified that 91 of these events are events affected more than one unit.
- 26 events of the identified 91 events were eliminated based on the proposed exclusion criteria※ for identifying events with important impact on the multi-unit dependent parametric estimation.

1. Organizational LER events were not considered due to lack of a universally accepted procedure to explicitly model them in the single-unit PRAs.
2. Other events that are not normally considered in the single unit PRAs were eliminated.
3. LERs involving violation of the technical specifications involving multi-units (missed, falsification or incorrect actions) were also eliminated for consideration, if they involved no component degradation or failure events.
4. Design errors with no impact on safety function of equipment or operator actions were eliminated.
5. Events involving software logic faults that did not affect emergency operation of equipment were also excluded.

※) M. Modarres et al "Advances in multi-unit nuclear power plant probabilistic risk assessment"

Parametric Estimation Based on NUCIA

1
2

- The remained 65 events were divided into the 14 categories of multi-unit effects.

$$\hat{p}_{i,j} = \frac{n_{i,j}}{N}$$

Parametric estimation in case of “Identical Component failure/degradation”

Event Categorization	Number of occurrences $n_{i,j}$	Number of events occurred in multi-unit sites N	Point estimate of the probability
Identical Component failure/degradation events in two units	37	1041	0.036
Identical Component failure/degradation events in three units	6	874	0.007
Identical Component failure/degradation events in more than three units	9	610	0.015

Discussion

1
3

Identical component failure/degradation	2 unit	3 unit	More than 3unit
Point Estimate of Probability	0.036	0.007	0.015

- The probabilities of multi-unit events don't become less with the increase of the number of units.
 - The number of 3-unit sites is only 2 of 18 Japanese NPP sites.
 - The ratio of external events(especially earthquake) in reported Japanese incident reports is higher than that in U.S.
 - 12 reports of the 65 multi-unit reports in Japan involved an earthquake.
 - The Niigata-Ken Chuetsu-Oki earthquake(16 July 2007) affected the Kashiwazaki-Kariwa nuclear power plants.
 - In LER's research, only one of the reports of years 2000-2011(4207 events) involved an earthquake.

- In this study, organizational events were not considered.
 - In LER's research※, about half of the relevant multi-unit events are organizational events.
 - In NUCIA research, 19 of 91 relevant multi-unit events are organizational events.



Organizational event is significant in multi-unit PRA.

- The extension of the parametric estimation proposed by Modarres et al was discussed based on the reported Japanese NPP incidents using NUCIA.
- The extension allows applications of the results to multi-unit PRA for sites having more than three units.
- The reported Japanese NPP incident reports were analyzed and the extended parameters for unit-to-unit dependencies in multi-unit PRA were estimated.

Future Work

- Further comparison of the result in LER and NUCIA will be discussed.
- An application of the estimated parameters in NUCIA will be discussed.