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About the Use of Scoping Estimation for Conservative Multi-Unit Risk Quantification – Problems and Restrictions

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1. Introduction

For a simple estimation of a multi-unit risk, scoping estimate [1] was frequently referred in many papers and used to estimate a bounding risk of a nuclear plant site. However, it was not recognized that this method can has very large conservativeness.

In this paper, we discuss the problem and restriction of the method.

2. Structure of the Scoping Estimation

The formula of the scoping estimate for multi-unit accident risk is investigated by inspecting the derivation method and the assumptions used. We discuss the overall structure of the formula in Section 2.1. In section 2.2, the derivation method of the formula is investigated to understand the rationale for the conservativeness of the result.

2.1 Structure of the Formula

The proposed formula for the scoping estimation of multi-unit risk is as follows:

$$R_S^{(n)} < n \cdot R_{one-unit,CCI} + n^2 \cdot R_{one-unit,SUI} \quad (1)$$

Where,

$R_S^{(n)}$: Total risk of a site with “n” numbers of nuclear power plant (NPP) units

$R_{one-unit,CCI}$: A unit NPP risk due to a common cause initiator

$R_{one-unit,SUI}$: A unit NPP risk due to a single unit initiator

Three main assumptions were used for the derivation of the formula. First one is that all NPP units in the site are identical. The second one is that the consequence of a multi-unit accident is proportional to the numbers of units which experience severe (radioactive nuclide release) accident. In the formula, it is expressed as follows:

$$C_k^{(n)} = kC_1^{(n)}$$

The final assumption is that an initiating event in a NPP unit can be propagated to neighboring NPP unit. However, additional chain of propagation was not considered in the formula. As the cause of the initiating event propagation, the author mentioned spatial interferences, common cause failure, and operator actions. As the representative spatial interference, the author considered fire and flooding event.

However, in case of Korean NPP sites, there is little possibility of initiating event (IE) propagation due to spatial interference and operator action because most of the Korean NPPs in a site do not allows the dependency among NPPs in terms of spatial interference and operator action. There may be a possibility of IE propagation due to common cause failure. However, most of IEs due to common cause may be categorized in the common cause initiators.

In the formula of Eq. (1), first term in the right-hand side means a site risk from common cause initiators and the second term means a site risk from individual initiators. When a common initial event such as an earthquake occurs, all the NPPs of the site experience the same initiating event of an earthquake, and the average expectation is same with the first term. The same result is also obtained when “n” independent runs (binomial distribution).

The second term multiplies the individual risk by the square of the number of NPPs, which leads to an excessive value of the multi-unit risk. This problem is caused by deleting the terms that cannot be ignored in the process of the simplification of the formula, and consequently the individual initiating events have the same effect as 100% probability of propagation to all other units in the site (see below for details)

2.2 The formula Derivation

(1) Site risk by common cause initiator

By the common initiator, all the NPPs in the site experience same event at the same time, and if the accident progression of each NPP on the Venn diagram in Fig (1) does not affect the other units, the accident of each unit can be divided into the number of Venn diagrams as follows.

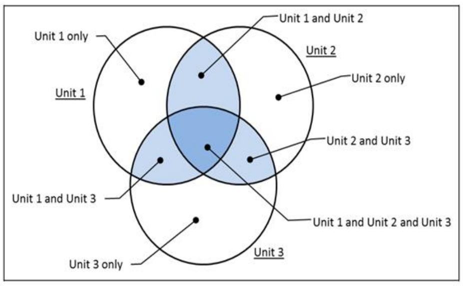

Fig. 1. Accident categorization for three NPP units by common cause initiator

The following terms are defined and used for the development of the formula.

n : The number of NPPs of the site (assuming the same design)

f_{CCI} : Frequency of common initiating events

$p_{k,CCI}$: Probability of occurrence of severe accidents only in k NPPs when a common initiating event occurs

In the figure above, the overlapping part may have different endings, so the decomposition can be done by dividing the risk as follows.

$$R_{S,CCI}^{(n)} = f_{CCI} \sum_{k=1}^{n} k \binom{n}{k} p_{k,CCI} C_{1,CCI}^{(n)} \quad (2)$$

The number of combinations can be transformed as follows:

$$k \binom{n}{k} = n \binom{n-1}{k-1} \quad (3)$$

Using Eq. (3), Eq. (2) can be expressed as follows:

$$R_{S,CCI}^{(n)} = n f_{CCI} \sum_{k=1}^{n} k \binom{n-1}{k-1} p_{k,CCI} C_{1,CCI}^{(n)} \quad (4)$$

The combination, $\binom{n-1}{k-1}$ is the number of all possible events including specific one unit. So,

$$R_{S,CCI}^{(n)} = n R_{one-unit,CCI} \quad (5)$$

Eq. (5) is established under the assumption of the identical NPPs of the site regardless of the probability distribution of each event.

(2) Site risk by single unit initiator

To investigate the conservativeness of the formula, we try to derive the site risk under the condition that all individual initiating event are propagated to other plant with the probability of 1.0

Let an individual initiating event frequency be f_{SUI} and n is the numbers of NPPs in a site. Then, the total sum of frequency occurring in a site is nf_{SUI}. Since all individual initiating event are propagated to all other plant, one can use Eq. (2). Inserting the total initiating frequency, site risk by one-unit initiator can be expressed as follows:

$$R_{S,SUI}^{(n)} = n f_{SUI} \sum_{k=1}^{n} k \binom{n}{k} p_{k,SUI} C_{1,SUI}^{(n)} \quad (6)$$

Using the same process used in the derivation of site risk by common cause initiator, one can obtain the following

$$R_{S,SUI}^{(n)} = n^2 f_{SUI} \sum_{k=1}^{n} \binom{n-1}{k-1} p_{k,SUI} C_{1,SUI}^{(n)} = n^2 R_{one-unit,SUI} \quad (7)$$

Eq. (7) says that the formula by Eq. (1) can be identically obtained if one uses the assumption that individual initiating event are propagated to other NPPs with the propagation probability of 1.0

The cause of such conservativeness is due to the operation in the derivation of formula. Eq. (8) is the intermediate result of the formula as follows

$$R_{k,SUI}^{(n)} = n R_{one-unit,SUI}^{(n)} + n(n-1) f_{SUI} C_{1,SUI}^{(n)} \sum_{k=2}^{n} \binom{n-2}{k-2} \left(p_{k,SUI}^{(n)} + q_{k,SUI}^{(n)} \right) \quad (8)$$

To make Eq. (8) be simple, the author make series of operations. Eq. (9) is the final expression of Eq. (8)

$$R_{k,SUI}^{(n)} = n R_{one-unit,SUI}^{(n)} + n(n-1) R_{one-unit,SUI}^{(n)} - n(n-1) f_{SUI} C_{1,SUI}^{(n)} \sum_{k=2}^{n} \binom{n-2}{k-2} \left(p_{k-1,SUI}^{(n)} + q_{k-1,SUI}^{(n)} \right) \quad (9)$$

By ignoring final term in Eq. (9), the scoping estimating formula is obtained for one-unit initiator. The main cause of the conservativeness is that the final term is not a trivial value. As a result, the scoping estimate is identical with Eq. (7) which used the assumption of perfect propagation of all individual initiating event into all other NPPs in a site.

3. Conclusions

Scoping estimate of site risk including multi-unit accident is conservative approach since this method is identical with the one which uses the assumption that all individual initiating event may be perfectly propagated to all other NPPs in a site. One should be careful in using the formula since the final result may be misleading by exaggerating the site risk due to the single unit initiator.

REFERENCES

[1] Martin A. Stutzke, Scoping Estimate of Multiunit Accident Risk, PSAM12, Honolulu, 2014