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# COHRISK: A Multihazard Risk Quantification Software for Nuclear Power Plants

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## 1. Introduction

Due to inherent relationship or by coincidence, more than one hazard can effect nuclear power plant simultaneously. For example, in 2011 Japan, Tohoku earthquake-tsunami hazard occurred the core-damage accident Fukushima Daiichi NPP. Therefore, securing the safety of nuclear power plant (NPP) from multihazard is one of the priorities of NPP operation. Despite the its significance, however, multihazard risk quantification methods is relatively less investigated when compared to the those of single hazards [1]. In these circumstances, to resolve this problem, authors had been performing series of projects on multihazard risk quantification of NPP system and launch the software COHRISK. This paper present COHRIK, a tool to quantify the multihazard risk of NPPs.

## 2. Multihazard risk quantification methods of NPP

In this section, conceptual framework of COHRISK software and the simulation methods to deliver the corresponding concept are introduced.

### *2.1 Conceptual framework*

At the early stage of multihazard risk quantification project, Kim *et al*. (2017) performed a preliminary study of multihazard risk assessment, proposing the conceptual framework for the multi-hazard surface and multi-fragility surface [2]. The multihazard risk is obtained through the convolution of the multi-hazard surface with the multi-fragility surface. This idea becomes basic conceptual framework for the COHRISK. For example, multihazard risk of NPP can be expressed as follow:

$$Risk_{multi} = \int_0^\infty \cdots \int_0^\infty F(p, \cdots, q) \frac{dH(p, \cdots q)}{dp \cdots dq} dp \cdots dq \qquad (1)$$

where, $H$ and $F$ denotes yearly hazard occurrence rate and failure probability, and $p$ and $q$ denote different hazard parameters. The convolution equation can be extended to a multi-integration formula, when both the hazard surface and fragility surface consider more than one hazard intensity variables.

### *2.2 Multihazard risk quantification model*

After building conceptual framework, series of methods are developed to effectively quantify the multihazard risk of NPP systems [3-4]. Especially, to investigate multihazard with various relationship (e.g., independent, compound, triggering), series of direct quantification of fault tree using Monte Carlo simulation (DQFM) [5] based method had been developed. In the work of Kwag *et al.* (2019) original DQFM used to applied in single hazard risk quantification is extended in to two hazards, and method so-called extended DQFM (E-DQFM) is developed. The flowchart of extended DQFM is illustrated in Figure 1.

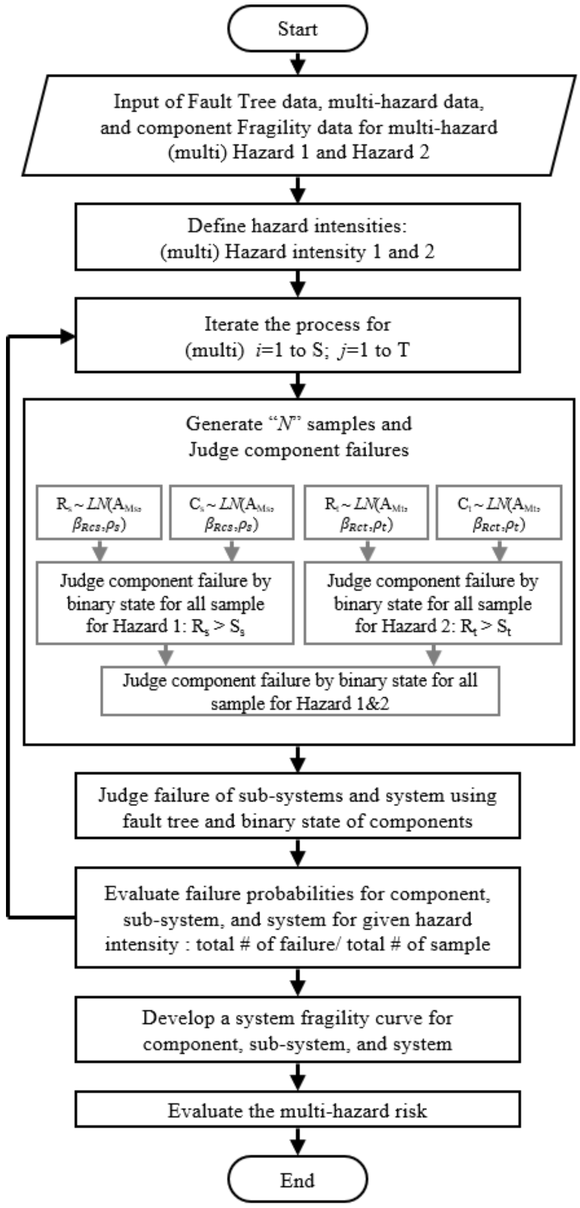



Fig. 1. Flowchart of extended DQFM (E-DQFM) for multihazard risk quantification of NPP

As illustrated in the figure, DQFM based methods generates the sample set for each hazard points to evaluate components failure. Due to this procedure, it requires high computational cost to achieve accurate multihazard risk results. Therefore, in same period, to increase the computational efficiency of E-DQFM, improved DQFM method (I-DQFM) is also developed [3]. By re-using the sample set for each hazard grid points, simulation cost is reduced greatly. Later, Choi *et al*. (2021) further reduce the computational cost of multihazard risk quantification using two-stage DQFM method [4], which assign different the number of samples to each hazard points according to its contribution to final risk value. Currently, COHRISK provide three methods (i.e., Boolean, E-DQFM, and I-DQFM) as a computation module, and two-stage DQFM method will be implemented in next update.

## 3. Architecture of COHRISK

COHRISK provide the user friendly and flexible environment to quantify the multihazard risk of NPP system. This section introduces the architecture of COHRISK based on its input and output.

### *3.1 Input*

To perform the multihazard risk quantification, general simulation setting and various input data is required. in the general setting page, simulation method (e.g., Boolean, E-DQFM, and I-DQFM) and number of sample (e.g., $10^4$) used for each hazard points can be selected.

In addition, input data can be categorized in to three folds: 1) hazard, 2) component, and 3) system. First, for the hazard input, user can load the hazard matrix and set the upper bound, lower bound, and increment for each hazard intensity. For example, if setting the earthquake-tsunami hazard in the range of 0g to 2g and 0m to 20m with the increment of 0.1g and 0.5m, 21 by 41 hazard grid matrix is prepared. For each hazard points, yearly exceedance rate value is required. Figure 2 is the screenshot of COHRISK hazard input setting page.

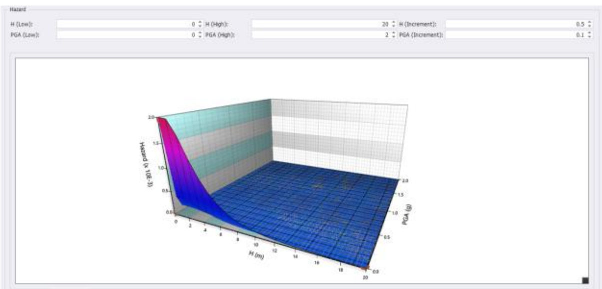


*Fig. 2. Hazard input setting page of COHRISK*

Second, component database is required. This component DB including component ID, name, description, hazard 1 and 2 fragility information (i.e., $A_m$, $\beta_r$, $\beta_u$), correlation matrix of component for hazard 1 and 2, and failure probability of random failure components (e.g., diesel generator common mode, containment heat removal, standby liquid control). With the correlation matrix, various relationship between the components (e.g., independent, correlated, fully independent) can be accounted. Figure 3 is the screenshot of COHRISK component input pages.

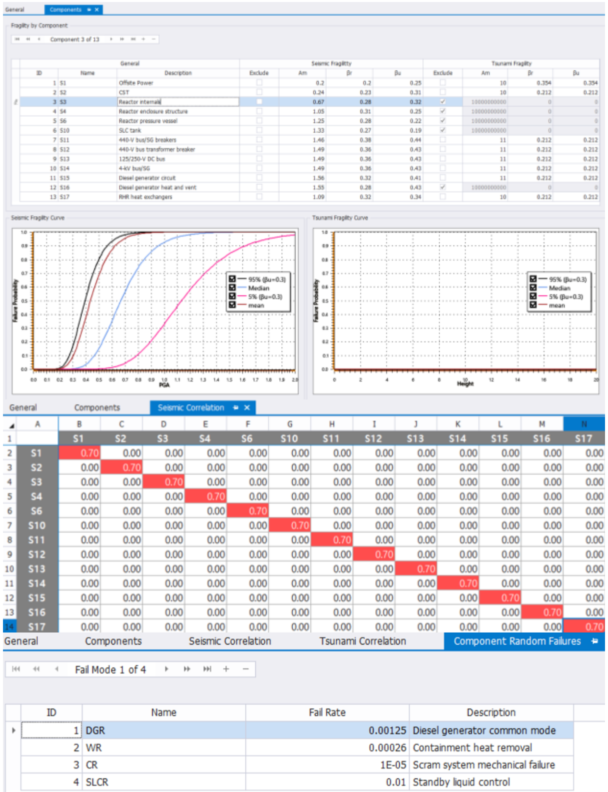



*Fig. 3. Component DB input pages of COHRISK (Hazard 1 and 2 fragility information of each component; correlation matrix of component for Hazard 1, random $P_f$)*

Lastly, system model is required to run the simulation. More than one system failure model can be evaluated. Figure 4 is the screenshot of COHRISK system input setting page.

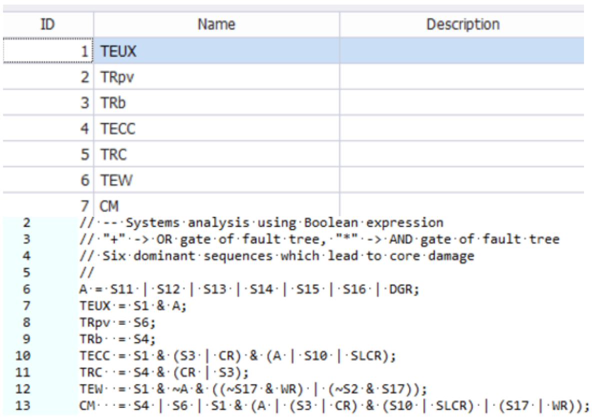
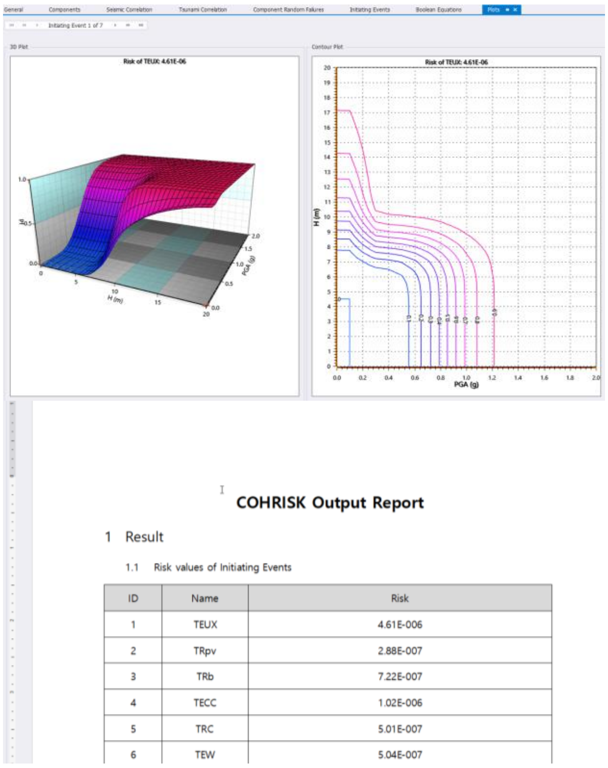



*Fig. 4. NPP system input pages of COHRISK*

*3.2 Output*

After run the COHRISK with the input data and setting, results are displayed in both plot and report format. In the 'plot' tab, user can see the multi fragility surface of NPP system in both 2D and 3D. Additionally, the final multihazard risk result is summarized in report. Figure 5 is the screenshot of COHRISK output page.




| ID | Name | Risk |
|---|---|---|
| 1 | TEUX | 4.61E-006 |
| 2 | TRpv | 2.88E-007 |
| 3 | TRb | 7.22E-007 |
| 4 | TECC | 1.02E-006 |
| 5 | TRC | 5.01E-007 |
| 6 | TEW | 5.04E-007 |

*Fig. 5. Output pages of COHRISK*

## 4. Conclusion

This paper introduces COHRISK, a multihazard risk quantification software for NPP system. COHRISK effectively evaluate multihazard risk by convoluting multihazard surface and system fragility surface. Especially, using correlation matrix of each hazard, components with not only independent and fully dependent but also partially correlated relationships can be accounted.

To date, COHRISK is yet applied to the earthquake and tsunami cases. However, COHRISK is design to applicable to other independent, compound, and sequential multihazard as well. Currently, various multihazard use case for COHRISK is under development.

## Acknowledgment

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