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A Comparison Study of Dependency Assessments: EMBRACE Method and EPRI Calculator

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Recently, nuclear power plants have seen a shift from analog-based main control rooms to digital-based main control rooms, incorporating large display panels (LDP) along with individual operator displays, computerized procedures, and software-based controllers. These digital-based main control rooms provide a completely different operational environment compared to the previous analog types, emphasizing the importance of human reliability analysis (HRA). Human reliability analysis has been implemented to quantify human error probabilities (HEPs) for given human failure events (HFEs) via work domain analysis, task analysis, human error identification, situational factor assessment, and likelihood quantification.

Dependency in HRA is quantified as the conditional probability of the successor HFE, which modifies its individual HEP. Dependency analysis within human reliability analysis is conducted when two or more events coexist in an accident scenario. Given that the actions of one operator often influence the actions of another, and this interdependence can lead to further accidents, dependency analysis becomes crucial. In this paper, EMBRACE method is described to address the dependency analysis of human error probability in a Loss of Feed Water accident sequence. It applies a newly developed dependency method to analyze specific scenarios leading to core damage and quantifies the frequency of accidents.

The proposed method (EMBRACE dependency method) developed by KAERI (Kim Y. et al., 2023) is based on the techniques utilized in the EMBRACE method developed for the Advanced Pressurized Reactor-1400(APR-1400) that has a fully computerized control room. It incorporates the EMBRACE definitions of time required and time available, as well as rules for selecting crucial procedural steps, into the current dependency assessment approaches. The EMBRACE dependency method calculates the conditional failure probability of a successor HFE based on quantitative evidence of the dependency between two events. Considering the factors influencing dependency, the proposed method can be expressed by (1):

$$HEP(B|A) = [TRI + \{PTS + CRD\} * RF] * CS + HEP_B * ACE_B \quad (1)$$

A and B are sequentially occurring human failure events, and HEP_B is the human error probability of HFE B.

For the following factors of Eq. (1) are defined:

- TRI (Temporal Resource Insufficiency) is the probability of insufficient temporal resources when performing both HFEs;
- PTS (Procedure Transition Similarity) is the similarity of procedures between the two events;
- CRD (Cue Recognition Dependency) is the dependency of recognizing the same device signal within the two events;
- RF (Recovery Factor) is an additional recovery factor for HFE B;
- CS (Cue Sameness) indicates whether there is consistency in operator group between the two HFEs;
- ACE (Additional Contextual Effect) represents additional influences affecting HFE B.

General Transient-18 (GTRN-18) in APR-1400 is a scenario where, following the initial event, appropriate measures are not taken at each stage, resulting in core damage. Immediately after the initial event occurs, the reactor successfully shuts down, and pilot operated safety relief valve (POSRV) operates successfully. However, the attempt to remove heat through main steam atmosphere dump valve (MSADV) and main steam safety valve (MSSV) fails, leading to entry into the safety depressurization stage. Operator checks opening of safety valve of pressurizer and directly conducts feed and bleed through open safety valve of safety depressurization systems. Table 1 shows estimated factors of (1) in GTRN-18 by EMBRACE method (Kim et al., 2018).

Table 1. Quantified factors with GTRN-18 scenario conditions.

TRI	PTS	CRD	RF	CS	ACE
3.52E-03	0.4	0.5	1	1	5

Let the first HEP, following HEP without consideration of dependency, and following HEP with consideration of dependency denote HEP(A), HEP(B), and CHEP(B), respectively. When these values are substituted into the proposed dependency calculation formula (1), the probability of occurrence of the subsequent event, i.e., CHEP(B), is estimated as 9.28E-01. This probability is 187 times higher than the original one where the dependency is not considered. The probability of consecutive failures is 8.903E-03 by multiplying HEP(A) and CHEP(B). In the EPRI method, since there is a high dependency relationship between the two events, the final composite probability derived by multiplying the probability of previous event and high dependency value of 0.5 is 4.79E-03.

Table 2. Comparison dependency assessment methods.

Case	HEP(A)	CHEP(B) by (1)	HEP(A)*CHEP(B)
Dependencies not considered		0.00494	4.74E-05
EPRI dependency method	0.00959	0.50000	4.79E-03
EMBRACE dependency method		0.92822	8.90E-03

Utilizing the EMBRACE dependency method, a quantitative evaluation of dependency was performed for GTRN-18 scenario involving HFEs. In contrast to the widely adopted EPRI methodology, which utilizes fixed probability values and lacks integration of human error data, the proposed approach accounts for human errors in computerized main control rooms. The probability value derived from the proposed method is 8.90E-03, approximately 1.8 times greater than that of the EPRI method. This outcome highlights a notable impact on core damage frequency, underscoring the necessity to scrutinize the underlying mechanisms causing disparities between the two methodologies for a more precise assessment of nuclear safety. Additionally, further investigations, such as uncertainty analysis and exploration of other factors influenced by operators' available time, should be undertaken.

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