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A New Method to Human Reliability Analysis for Seismic Events

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1. Introduction

There is increasing interest in advancing the state of art of conducting a probabilistic safety assessment (PSA) for seismic events especially in the wake of the Fukushima accident. One of the most dominant factors affecting the operational risk of nuclear power plants is human errors among other things. Traditionally a coarse conservative assumption used to be made in estimating the human error probabilities (HEPs) following a seismic event; e.g., the HEPs for post-earthquake human actions were assumed to be 10 times higher than the HEPs evaluated for internal events.

A new method to analyze human reliability in seismic events is presented herein along with a pilot application. It is based on the EPRI studies [1,2] that included trial evaluations of a preliminary approach on several U.S. nuclear power plants. Following the issue of a preliminary approach in 2012 [1], the approach was revised in the final report published in 2016 [2]. The new method discussed in this paper is concomitant with the EPRI's 2016 approach.

2. Damage States and Screening Tree

Traditional methods for seismic HRA used to rely on assumptions such that early actions are the most affected by the seismic event and the impact of human performance can simply be correlated to seismic ground motion by simple multipliers. The Insights from operational experience indicate that such traditional methods are inadequate to capture the performance drivers [1,2]. In order to evaluate the human reliability adequately by accounting for the different impacts of a wide range of seismic ground motion, damage state bins that group the hazard by expected human performance drivers should be defined up front.

Damage state bins can be defined by the break points at which the underlying context of the action changes substantially enough to impact the reliability of the action. These break points are based on an understanding of what are critical performance drivers or performance shaping factors (PSFs). In this way, the damage state bins define the context for the human actions within those bins including impact to local infrastructure and non-safety related systems, level of heightened stress, general increase in level of coordination and workload, and quality of working environment (e.g., high winds, water, aftershocks, etc.). Damage states are defined by grouping the structures, systems and components (SSCs) of the plant by their level of expected impact on human performance if they fail (e.g., increased general workload, more difficult cognition, more challenging working environment, etc.).

Table 1 shows example mapping of plant-specific ground motion bins to generic damage state definitions [2]. As shown in this table, the basic concept is to define the damage state bins in terms of the degree of the expected impact to safety and non-safety SSCs. Note in this specific example, among others, that the seismic ground motion corresponding to the 25th percentile probability of failure of turbine building, instrument air or offsite power is used as the upper limit of Bin 2, and the seismic ground motion corresponding to the 25th percentile probability of failure of the most fragile Seismic Category 1 structure as the upper limit of Bin 3.

In light of the significant complexity associated with prediction of post-earthquake human reliability, a screening tree (Fig. 1) was developed in the EPRI study [2] capturing the primary drivers of human performance. It is based on the assumptions that: 1) internal events HEPs were quantified in detail, and 2) seismic impacts on the PSFs of the human failure event (HFE) can be accounted for by use of the multipliers given in Fig. 1, and hence, no explicit changes to the PSFs are necessary (i.e. timing, stress, cue availability, etc.). If the definition of the HFE (e.g., timing) is substantially changed by the external event context, then using a multiplier is inappropriate and the HFE should be quantified using detailed analysis.

How to evaluate each node of the screening tree with respect to a target human failure event is discussed in detail in the EPRI report [2]. In particular, the node "Is Cue after Plant Damage Assessment?" identifies whether the cue for the operator action appears early (prior to or during the conduct of the plant damage assessment) or later (after the plant damage assessment is completed). Apparently the intent of this node is to identify whether the operator action will be performed with awareness of the post-earthquake plant situation.

In addition, note that the timeline of the internal events HFE needs to be confirmed as generally applicable to the external event, or adjusted to fit the change in definition. Actions can be delayed due to access issues, increased cognition time, delays due to inter-organization/multi-unit coordination and a host of other factors that are not explicitly accounted for in a timeline built in the internal events HRA. However, the "time margin" node of the screening quantification tree is based on the time margin evaluated in the internal events HRA, and such host of factors are implicitly taken into account in developing the screening tree. Therefore, the time margin evaluated in the internal events HRA can be used as it is in the screening tree.

Once the multipliers are determined from application of the screening tree to the target HFE, the seismic HEP for each bin can be evaluated by applying the multiplier to the HEP that was assessed in the internal event PSA. The seismic core damage frequency (CDF) can then be quantified (e.g., using SAREX code) for each bin by use of the newly evaluated HEPs for all target HFEs and the seismic-induced initiating-event frequencies for the bin.

3. Example Evaluation and Conclusion

The new method discussed above was applied to an operator action for early feed and bleed operation. The HEP evaluated in the internal events PSA for this operator action is 2.13E-2. This HEP was obtained by K-HRA [3] using the time margin of 46 min, which was calculated as follows: (a) system time window=50min; (b) time delay=1min; (c) cognition time=1min; (d) execution time=2min; and (e) time margin=50-1-1-2=46min. As mentioned earlier, this time margin evaluated in the internal events HRA is used in the seismic HRA screening tree.

The operator action for early feed and bleed is applied to general transients (GTRN) initiating event in the internal events PSA, and so, will be applied to seismic induced GTRN initiating event. The GTRN initiating event frequency assessed in the internal event PSA is 4.30E-4/yr. The GTRN initiating event frequency for each bin was evaluated in this study using PRASSE code as follows: (1) 2.88E-4/yr for Bin 1; (2) 1.34E-4/yr for Bin 2; (3) 6.88E-6/yr for Bin 3; and (4) 7.74E-9/yr for Bin 4.

Table 2 shows the example quantification results of the seismic HEPs and the bin CDFs for the feed and bleed operator operation. The original CDF for the GTRN initiating event with the HEP of 2.13E-2 and the GTRN frequency of 4.30E-4/yr was 5.31E-9/yr. However, the new CDF for the GTRN initiating event with the four HEPs shown in Table 2 is assessed to be 1.07E-9/yr.

Application of the new seismic HRA method shows about a factor of 5 reduction in the GTRN core damage frequency in this specific case. More importantly, the new method advances the state of the art of evaluating human reliability in the context of a seismic event by accounting for the different impact of seismic ground motions on human performance.

REFERENCES

[1] Electric Power Research Institute, A Preliminary Approach to HRA for External Events with a Focus on Seismic, EPRI 1025294, December 2012.

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[3] Korea Atomic Energy Research Institute, Development of A Standard Method for Human Reliability Analysis (HRA) of Nuclear Power Plants, KAERI/TR-2961/2005, December 2005.

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Table 1. Ground Motion Bins for Seismic HRA [2]

EPRI BIN #	Damage Sate Description	Plant Hazard Level	Plant Specific Criteria Used
1	No expected damage to safety and non-safety related SSCs	Up to Plant SSE	Plant SSE
2	No expected damage to safety-related SSCs or to rugged industrial type non-safety SSCs. Damage may be expected to unimportant non-safety SSCs and to switchyard.	SSE - 0.25	0.25 g is 25th percentile probability of failure of the turbine building. Loss of instrument air and LOOP likely, but otherwise few failures expected.
3	Widespread damage expected to non-safety related to non-safety related SSCs and/or some damage expected to safety related SSCs. Lots of alarms and vibration trips.	0.25 - 0.5	Start to experience significant damage to Seismic Cat Ⅱ structures and failures of water, liquid N2 and fuel storage tanks(median PGA values range from 0.4-0.6). 0.5g is the 25th percentile probability of the most fragile Seismic Cat Ⅰ structure.
4	Substantial damage to safety related and non-safety related SSCs.	> 0.5	

Table 2. Seismic Bin HEPs and CDFs

Bin	Immediate Memorized Action	Action Location	Damage State	Time Margin	Cue after Plant Damage Assessment	Multi-plier	Seismic HEP	Bin CDF (/yr)
Bin 1	No	CR	1	>10min (46min)	YES	1	2.13E-02	7.78E-10
Bin 2	No	CR	2	>30min (46min)	YES	1	2.13E-02	2.85E-10
Bin 3	No	CR	3	>30min (46min)	YES	5	1.07E-01	1.12E-11
Bin 4	No	CR	4	>30min (46min)	YES	30	6.39E-01	3.86E-14

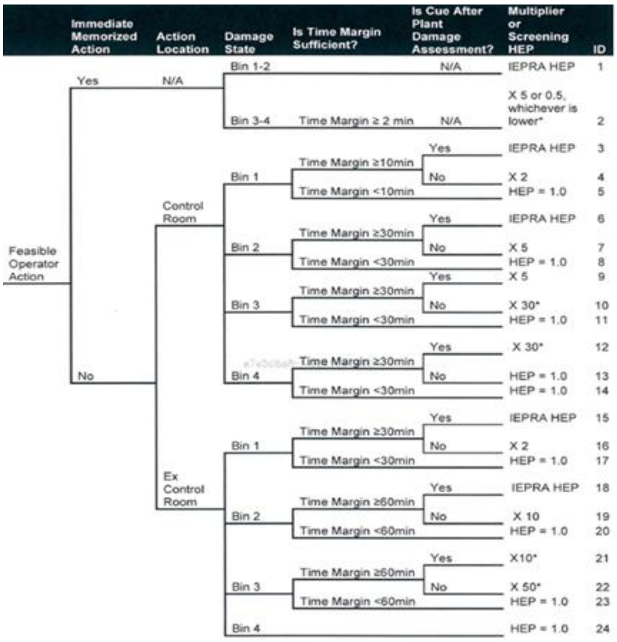

Fig. 1 Screening Tree for Seismic HEP Evaluation [2]