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Implementation of the EPRI Approach to Seismic Human Reliability Analysis on the OPR1000 NPP

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1. Introduction

Assessing risk for seismic events has been highlighted in the field of probabilistic safety assessment (PSA). In the past few years, Kashiwazaki-kariwa and Fukushima nuclear power plants (NPP) were affected by seismic events. For the Kashiwazaki-kariwa NPP event, it resulted in a leakage of radioactive material to outside, besides the Fukushima NPP event led to a severe accident. These cases have raised issues on how to evaluate the risks and prevent catastrophic results from seismic events.

As the interest in seismic PSA increases, how to give credit to human failure events (HFEs) in the seismic PSA model and estimate human error probabilities (HEPs) for them are emphasized in the field of human reliability analysis (HRA). In the seismic events, there are critical operator actions that should be manually treated by local operators, and these are highly influential on the mitigation of the accident. Accordingly, several institutions have tried to suggest how to identify, qualify, and quantify seismic operator actions. Most of the approaches developed so far depend on integrated performance shaping factors (IPSFs), which combines effects of PSFs (i.e., any factor that influences operator performances such as experience and workload) that are influential and specific to seismic events.

This paper describes how to select and implement an approach for seismic event HRA. First, we select the approach through comparison, and briefly describe the selected approach. Next, the electric power research institute (EPRI) seismic event HRA approach is detailed, and the example of analysis is introduced.

2. Selection of a Seismic HRA approach

The purpose of this section is to describe the selection of a seismic HRA approach for performing OPR1000 seismic HRA. Seismic HRA approaches are mostly based on IPSFs that has been applied to several NPP seismic HRA. The approach is applied in either of two ways. One way is to use the internal HEP and interpolate other HEPs values over a specific range of peak ground accelerations (PGAs). The other way is to use internal HEP while providing specific multipliers to be applied. Each approach was compared to decide the approach to be implemented on the OPR1000.

2.1 Interpolating for HEPs values

The Swiss Federal Nuclear Safety Inspectorate provides a PSA guideline to Swiss utilities through the ENSI-A05/e [1] report. This guideline provides the Seismic HRA IPSF as; action start time and earthquake intensity (PGA). Two values for applying this guidance must be defined as below;

- Horizontal peak ground acceleration of the Reactor building (0.2g)
- Guaranteed failure acceleration (0.6g)

2.2 Using Specific Seismic HEP Multipliers

Several US NPPs provide multipliers for conducting seismic HRAs. Also, based on technical investigations and operator experience, the approach developed by EPRI provides specific multiplier values through decision trees. It is the general approach at the san onofre NPP.

2.3 Comparison of seismic HRA approaches

The PSFs considered in each seismic HRA approach were compared, as summarized in Table I. The EPRI seismic HRA approach is considered the most holistic approach as it considers the most PSFs. Therefore, it is more flexible for implementation of various NPPs.

Table I: Summary of IPSFs in seismic HRA approaches

IPSFs application Approach	Institutions	PSFs Considered
Interpolating for HEP values	Swiss Federal Nuclear Safety Inspectorate	Action start time, Earthquake intensity (PGA)
Using Specific Seismic HEP Multipliers	San Onofre	Earthquake intensity (PGA), Time available to start action, Location of action
	Columbia	Earthquake intensity (PGA), Location of the operator action, Fragility analysis of Non-safety building, Action time frame
	Surry	Location of the operator action, Time After Seismic Event, Earthquake intensity (PGA)
	EPRI	Immediate Memorized Action, Action Location, Damage state, Time Margin, Plant Damage Assessment

3. Implementation of Seismic HRA for OPR1000

This section describes the implementation of a seismic HRA based on the EPRI seismic HRA process [2], and an example for OPR1000 to explain in detail. The process in Fig.1 can summarize the EPRI seismic HRA approach.

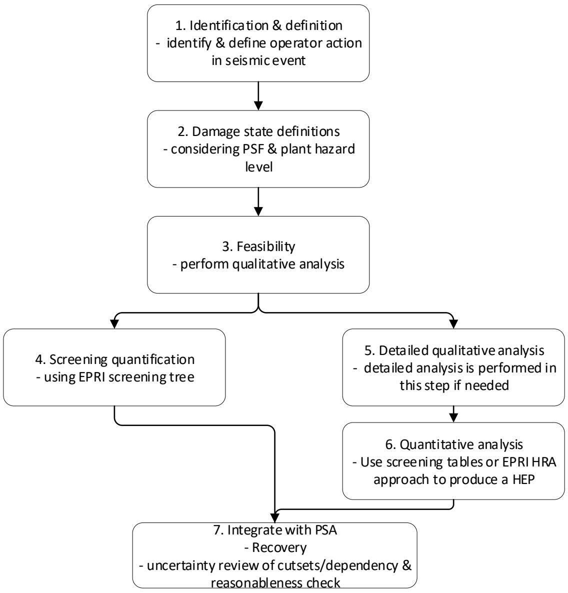

Fig. 1. A summarized flowchart of the EPRI seismic HRA process

3.1Identification & definition

Pre-initiator actions are not affected by seismic events, so the same HEP as those in the internal event HRAs would apply to such actions. EPRI suggests two ways to identify and define operator action in a seismic event: 1) HFEs carried over from the internal PSA, and 2) new operator actions from procedures such as the response procedure for a seismic event. Therefore, the HFEs in the OPR1000 internal PSA model can be modeled in seismic OPR1000 PSA model, or a new operator action can be identified by referring to the response procedure for a seismic event. For example, the operator manual reset of relays was identified because the relay alarm occurs due to a seismic event and after that, needs to be reset.

3.2 Damage state definition

Three values of plant information are required for damage state definition.

- Plant safe shutdown earthquake (SSE)
- Lowest HCLPF of any safety-related SSC
- Instrumentation threshold (HCLPF)

Plant SSE of OPR1000 is 0.2g. According to the korea atomic energy research institute (KAERI) report [3], the lowest high confidence low probability of failure (HCLPF) of any safety-related SSC was chosen as 0.41g of emergency diesel generator (EDG). EDG was evaluated as a much more critical system than component cooling water (CCW) or essential chilled water (ESW), which has the lowest seismic acceleration of 0.35g. The instrumentation HCLPF value of 0.74g is selected based on the EPRI generic data for instrumentation HCLPF [4]. As a result, the damage states of OPR1000 are determined, as shown in Table II.

Table II: Damage states of OPR1000

EPRI Bin #	Damage state of OPR 1000
1	Hazard<0.2g
2	0.2g≤Hazard<0.41g
3	0.41g≤Hazard<0.74g
4	Hazard≥0.74g

3.3 Feasibility analysis

The EPRI approach provides a seven-item assessment of feasibility. Six factors were reviewed to determine whether the HFE is feasible or not.

Cue available: the operator cue was evaluated by developing a tree for the analysis, as shown in Fig.2.

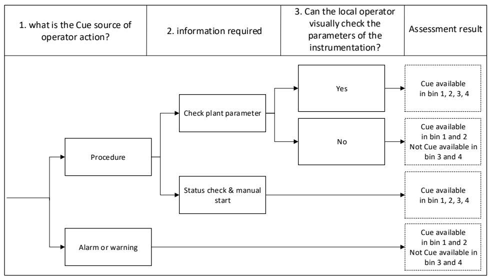

Fig. 2. Assessment tree for cue available

1. What is the cue source of operator action? : The operator may have two types of cues that indicate the demand for action. One is a procedure step, and the other is the alarm. If the cues are alarms, the system for alarms can be damaged by a seismic event. Therefore, it is assumed that alarms in bins 3 and 4 are not available.

2. Information required:

If the operator cue is a procedure step, the next investigates whether the information required is checking state or reading parameter values. If the information just requires to check the state, the action can be performed without the information, i.e., anyway, operators perform the action. However, if the information requires to read parameter values, e.g., pressurizer pressure, the action may not be credited without the information.

It is also assumed that plant parameters are not available at the main control room (MCR) in damage bins 3 and 4. According to [3], HCLPFs of components in the path of information from the sensors to the MCR are given in Table III. Relays, and some cabinets can be damaged in Bins 3 and 4.

Table III: The HCLPF of information transfer components [3]

Component	HCLPF
Transmitter	1.24g-2.79g
Relay	0.38g
Process cabinet	0.36g-1.82g
MCR control board	0.94g

3. Can the local operator visually check the parameters?: If the instrument is not available in the main control room due to a seismic event, the local operator can visually check the parameter on the site. For example, the OPR1000 refueling water storage tank (RWST) is located outside the reactor building; as such, the operators may move to the RWST to check the level.

Procedures available and training conducted: The internal PSA for OPR1000 has already analyzed the procedures and training levels required for operator actions. Therefore, the actions credited in the internal PSA analysis are assumed to have a certain level of procedure and training.

Sufficient manpower: A single shift in Korea has a total of ten (10) operators, including five (5) MCR operators and five (5) local operators. Current PSA typically excludes the operator actions for equipment such as mobile power generators. Therefore, it is assumed that sufficient manpower is present.

Equipment Operable: If an earthquake damages the equipment, the operator action is not feasible. However, regardless of equipment operability, the operator actions are still modeled in PSA, and so HRA gives credit to such actions.

Sufficient time: The KAERI report [3] assumed that as the seismic event acceleration increased, the operator execution time and operator delay time for the task becomes longer. Therefore, T_{exe} is more than three times the internal operator action time in damage state 3 and 4. T_{delay} is more than three times the internal operator action time in damage state 2, 3, and 4.

Accessible location and environmental factor, equipment/tools accessibility, and availability: Evaluate whether the route (travel path) of the local operator to the action location is feasible. This factor was evaluated based on the HCLPF of the building, where the action needs to be taken through an interview with operators.

3.4 Screening quantification

The EPRI seismic HRA approach provides quantification using a decision tree as in Fig.3, where multiplier or screening HEPs are also indicated. Six factors need to be considered such as immediate memorized action, action location, damage state, time margin sufficiency, and whether cue is after plant damage assessment or not.

- Immediate memorized action: Only the action, 'operator manually inserts the control rod' if the automatic control rod input fails, is regarded as an immediate memorized action.

- The action location is concerned with where the operator executes the action

- The damage state is already defined in section 3.2.

- The time margin is the spare time that is available for operator's action. This can be evaluated using the equation provided by the EPRI process i.e., $T_{margin}=T_{sw}-T_{delay}-T_{cog}-T_{exe}$.

- Is Cue after plant damage assessment?: NPPs in Korea should carry out "Plant walkdown examination & inspection" within 8 hours after the seismic event occurs. When this is finished, the operator would have an overview of the plant damage. This can be assessed whether T_{delay} exceeds 8 hours.

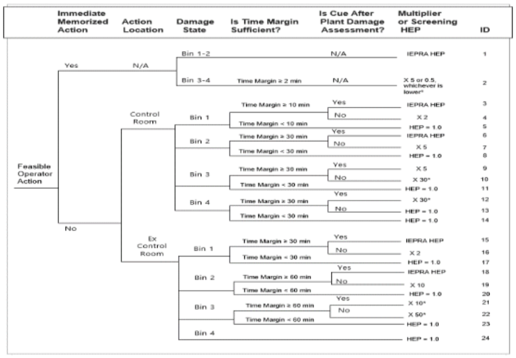

Fig. 3. EPRI screening tree

3.5 Detailed qualitative analysis

Qualitative analysis is a vital part of HRA. The results of qualitative analysis are used for two of the key HRA process steps: the identification and definition of HFEs and the development of HEPs.

3.6 Quantitative analysis

Detailed quantification of HEPs for the seismic PRA can be done for HFEs that are shown to be risk significant to the model after initial quantification with the screening method discussed in section 3.4.

3.7 Integrate with PSA Model

Model integration has an iterative nature, but it requisitely consists of four components which are: 1) Cutset Review and HEP Reasonableness Check, 2) Recovery Evaluation, 3) Dependency Evaluation, and 4) Uncertainty evaluation.

4. Example application of the EPRI seismic HRA approach

Table IV shows the results of the analysis of the HFE in changing auxiliary water sources. The following is a description of the execution process.

4.1 Identification & definition

Table IV: Example of analysis HFE

HFE description	Damage state		Feasibility analysis							Screening quantitative						
Operator fails to arrange alternate water source	Bin #	Hazard level	PT	SM	AL & EF	CA	ST	E/T A&A	EO	IMA	AL	DS	TM	PDA	Multipliers	ID
	1	Hazard<0.2g	Yes	Yes	Yes	Yes	Yes	Yes	In PSA model	No	EX-CR	1	808 min	No	2	16
	2	0.2g≤Hazard<0.41g	Yes	Yes	Yes	Yes	Yes	Yes	In PSA model	No	EX-CR	2	784 min	No	10	19
	3	0.41g≤Hazard<0.74g	Yes	Yes	Yes	Yes	Yes	Yes	In PSA model	No	EX-CR	3	724 min	No	50	22
	4	Hazard≥0.74g	Yes	Yes	Yes	Yes	Yes	Yes	In PSA model	No	EX-CR	4	724 min	No	HEP=1	24

* PT: Procedure/training SM: Sufficient manpower AL & EF: Accessible location & Environmental factor CA: Cue available ST: Sufficient time E/T A&A: Equipment/Tools Accessibility and Availability EO: Equipment Operable IMA: Immediate memorized action AL: Action Location DS: Damage state TM: Time Margin PDA: Plant Damage Assessment

The first step identified the HFE in a PSA model. This action is that the operator fails to arrange alternate water source.

4.2 Damage state definition

- The damage states for the OPR1000 NPP have been defined in table II. The HFE is evaluated for all of the four (4) damage states.

4.3 Feasibility analysis

- Procedures available and training conducted: the HFE selected is already considered in the internal event PSA based on EOP. The procedure and training for this HFE were evaluated as positive PSFs in the internal event HRA.
- Sufficient manpower: this HFE does not use mobile equipment such as a mobile generator. Therefore available manpower is assumed to be sufficient.
- Accessible location and environmental factor, equipment/tools accessibility, and availability: this HFE is only evaluated if the execution is local. According to an MCR operator interview, this HFE was executed in the yard of the NPP. The HFE is not affected by the fragility of the building. Hence, the location is accessible for all plant damage states.
- Cue available: Assessment tree in Fig.2 is used. The Cue source for this HFE is in the EOP. The information required by the procedure should identify the plant parameters about the auxiliary feed water tank (AFWT) level. However, the control room instrument fails at 0.36g-0.38g. MCR operators can request the local operator to check AFWT level. The cue was assessed to be available to all damage state because the local operator can get the required information.
- Sufficient time: Time is evaluated as sufficient for cognitive and execution actions because $T_{margin} \geq 0$.
- Equipment Operable: Since the PSA model evaluates the equipment operability following an earthquake, HRA does not evaluate it further.

4.4 Screening quantification

- Immediate memorized action: No, i.e., the HFE is performed before the auxiliary water tank dried up, so it is not critical in time and not immediately after reactor shutdown.
- Action location: Ex-control room (CR), i.e., operator is required to connect containment storage tanks (CSTs) from the NPP yard, which is outside the control room.
- Damage state: bin 1, 2, 3, 4, i.e., all bins are evaluated.
- Is time margin sufficient?: The calculated time margin for each damage state is shown in Table IV. T_{margin}>30min in damage bin 1 while T_{margin}>60min in damage bins 2 and 3. However, according to the EPRI screening tree, Ex-control room actions in damage bin 4 are not evaluated for time margin.
- Is Cue after plant damage assessment?: No, the cue is before plant damage assessment in all the plant damage state bins 1, 2, 3, and 4. This is because, the T_{delay} of the HFE is 12min, which is less than 8 hours required for plant damage assessment in the OPR1000 NPP.

Finally, for damage bins 1, 2, and 3 the HEP multipliers for the HFE are 2, 10, and 50 respectively. However, for damage bin 4, the HEP for the HFE is 1.0.

5. Conclusions

This work has examined some of the seismic HRA approaches, and the EPRI methodology was adopted. The process of performing the EPRI seismic HRA was explained, and its implementation to the OPR1000 NPP was described in detail using an example. Finally, the seismic HEP multipliers were derived for integration to seismic PSA model.

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