Proc. of the European Safety and Reliability Conference (ESREL 2026)
Edited by José C. Matos, Paulo B. Lourenço, Michael Beer, Daniel Oliveira, Edoardo Patelli, Hélder S. Sousa, Rui A. Silva and Monica Santamaria

doi: 10.3850/ESREL2026061419_esrel26-p26327-cd

Seismic-HRA Methods Implementation in a Realistic-NPP Model: Comparative Analysis on a Plant-Level Risk Contribution

Dusko Kancev

Nuclear Safety Division, NPP Goesgen-Daeniken AG, Switzerland. E-mail: dkancev@kkg.ch

Gerben Dirksen

Process and Safety Engineering, Framatome GmbH, Erlangen, Germany.
E-mail: gerben.dirksen@framatome.com

Rainer Hausherr

Nuclear Safety Division, NPP Goesgen-Daeniken AG, Switzerland. E-mail: rhausherr@kkg.ch

Existing human reliability analysis (HRA) methods were developed mainly for internal events (IEs) probabilistic safety assessment (PSA). These methods often contain underlying assumptions, such as the availability of procedures and level of basic training, which may or may not be applicable to the challenging and new environment created by an external event.
For the evaluation of the operator actions (OAs) after an earthquake, the Swiss Regulator (ENSI) in its guideline ENSI-A05 proposes the refined basic model. The advantages of the method are its relative simplicity and its thoroughness. Naturally, this method has some disadvantages as well. Namely, for simple OAs with low values of the IEs human error probability - HEP_{int}, the increase factor is already very high for medium-strength earthquakes. Moreover, after a certain PGA-level, the human error probability as a response to an external hazard - HEP_{ext} becomes practically indifferent on its corresponding HEP_{int}.
On the other hand, in the U.S., HEP_{ext} are calculated using increase factors. One such approach is the EPRI approach to HRA for external events with a focus on seismic. The HEP_{int} are being multiplied by these increase factors, which in turn are a function of a range of parameters, e.g. action location, plant damage state, time margin, memorized OAs, etc. Although more time-consuming for implementation, the HEP_{ext} becomes not that steep and not indifferent on its HEP_{int}.
For the NPP Gösgen (KKG) PSA, a calculus of variations is carried out, using an approach that combines both the above methods. The so-called hybrid-method – the novelty of the work presented - makes distinction between four earthquake strengths and three time ranges. A distinction is also made between whether the action takes place in the command room or outside the command room. This method has the advantage over the refined basis model approach that the complexity of the human failure event (HFE) is directly incorporated into the HEP. Due to the large increase factors, especially for short-term HFE, sufficient conservatism is also guaranteed.
The objective of this manuscript is to obtain and present a quantitative assessment of the relative change in the computed plant risk if one swaps between the hybrid approach and the EPRI approach. A comparative analysis is conducted and the results are discussed.

Keywords: PSA, HRA, Seismic-HRA, Realistic-NPP PSA.

1. Introduction

In general, nuclear power plants (NPPs) have and are being planned and designed in a manner such that they can withstand certain and mainly conservatively selected ground motion accelerations, i.e. safe shutdown earthquake (SSE). The special characteristic of an earthquake is that it represents a challenge not just to all systems, structures and components (SSCs) but also to the personnel. Namely, after a certain peak ground acceleration (PGA) threshold, the human error probability (HEP) is expected to be affected as well.

Substantial research has been performed to-date to develop and improve methods to perform Human Reliability Analysis (HRA) in support of PSA. Existing HRA methods, however, were developed primarily for internal events PSA models and PSA applications. These methods often contain underlying assumptions, such as the availability of procedures and level of basic training, which may or may not be applicable to the challenging and new environment created by an external event. On the other hand, for existing external events analyses there is considerable variation in the methods used to perform HRA. Variation exists between methods used to evaluate different hazard types as well as plant-to-plant variation for evaluation of a given hazard type. The former variation makes it difficult to compile results in a meaningful manner to support a risk-informed application that includes multiple hazard types (Presley, 2016).

All in all, the so-called psycho-shock effect of an earthquake on the personnel performance, i.e. on the HEP, is quite an important aspect that needs to be considered and modelled as accurately as possible for one to obtain PSA results and insights as realistically as possible.

2. Methodology Overview

This section presents an overview of three different methods for assessing the seismically induced psycho-shock effect on the personnel HEP, i.e. the two approaches the Swiss national regulator suggests (ENSI, 2019) on one hand and the EPRI one (Presley, 2016) on the other, as well as a brief description of the approaches themselves.

2.1. *ENSI – Simplified Approach*

In case of earthquake, the HEPs can be adjusted as follows (ENSI, 2019):

1. Up to an earthquake intensity of 0.2 g (maximum horizontal ground acceleration at the foundation level of the reactor building), the failure probabilities for human actions can be taken over from the model for internal events (transients and LOCAs) without modification.

2. In the case of an earthquake with intensity from 0.2 g to 0.6 g, a linear interpolation between the values for 0.2 g and 0.6 g (guaranteed failure) shall be performed. Special case: for actions that must not be carried out within an hour after the earthquake, the failure probabilities up to an earthquake of magnitude 0.6 g can be taken over without modification from the model for internal events.

3. From 0.6 g, all personnel actions shall be considered as failed with probability one.

This simplified ENSI approach can be graphically described on the following Figure (Fig. 1).

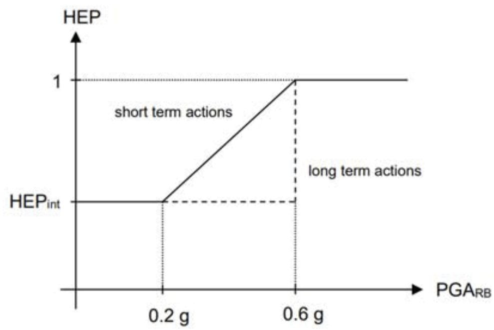

Fig. 1. Dependence of HEPs on the earthquake intensity – ENSI simplified model

2.2. *ENSI – Refined Approach*

Having the obvious advantage of being quite a straightforward approach, the ENSI simplified approach has some drawbacks as well, mainly related to its conservatism. Namely and as obvious from Fig. 1, after a certain PGA of 0.6g the HEP becomes 1.0, indifferent on the HEP_{int} and regardless of whether the OA is a short term or long term one. Hence, ENSI suggested a newer, refined approach. Namely (ENSI, 2019):

1. In the earthquake PSA, those human actions for which the:

a. instrumentation or

b. guidance within the emergency operating procedures needed for diagnosis, execution or monitoring is not available, shall be set as guaranteed failed.

2. If the instrumentation and operating procedures are available, the HEP is determined as follows:

a. Up to a PGA of 0.2 g (at the foundation level of the reactor building), the HEPs can be taken over from the model for internal events without modification.

b. To determine the HEP when the PGA is above the 0.2 g lower bound, the required actions are divided into short term (required < 1 h after earthquake), medium term (required 1-12 h after earthquake), and long term (required > 12 h after earthquake) actions. The limit (12 h) for beginning of the long-term range can be reduced to 8 hours, if precautions have been taken to ensure external support within 8 hours even if the earthquake accident occurs outside normal working hours and involves the destruction of normal access roads.

c. In case of a PGA above 0.2 g, the HEP increase from HEP_{int} is modelled as a function of PGA via a lognormal distribution, where $\Phi(\ldots)$ is the cumulative distribution function of the standard normal distribution:

$$HEP = \begin{cases} HEP_{int} + (1 - HEP_{int})\Phi\left[\dfrac{ln\left(\frac{PGA-0.2g}{0.273g}\right)}{0.566}\right], & \text{short term actions} \\ HEP_{int} + (1 - HEP_{int})\Phi\left[\dfrac{ln\left(\frac{PGA-0.2g}{0.4g}\right)}{0.566}\right], & \text{mid term actions} \\ HEP_{int} + (1 - HEP_{int})\Phi\left[\dfrac{ln\left(\frac{PGA-0.2g}{0.586g}\right)}{0.566}\right], & \text{long term actions} \end{cases}$$

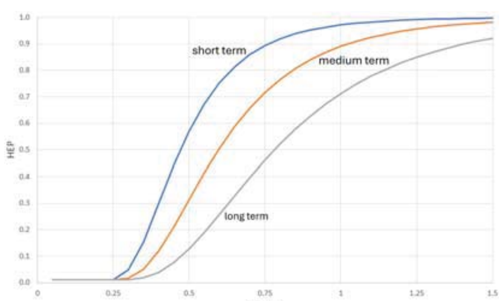

Fig. 2. Dependence of HEPs on the earthquake intensity – ENSI refined model

This method has the following disadvantages:

- For simple measures with a small HEP_{int}, the amplification factor is already very high for moderate earthquakes (the multiplication factor can easily exceed 100).
- The final, seismic HEP is only slightly dependent on HEP_{int} or not at all, so the method does not adequately distinguish between simple measures that the personnel themselves can reliably implement even under difficult conditions and measures with a high HEP_{int}. Measures with a high HEP_{int} are often complex, implemented at different locations, or involve numerous steps.

2.3. *EPRI - Approach*

According to EPRI (Presley, 2016), the seismic hazard can have a wide range of impact on both the environmental conditions and the plant SSCs. In the PRA, external hazards are typically split into bins so SSC failure probabilities can be calculated across the spectrum of the hazard ("external hazard bins" on Figure 3).

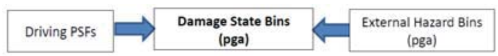

Fig. 3. Damage state bins according to EPRI (Presley, 2016)

Both the screening HRA method and the detailed HRA method start defining the damage states of the plant following the earthquake.

EPRI Bin #	Damage State Description	Plant Hazard Bins		Plant Specific Criteria Used
		Bin	PGA Range (g)	
1	No expected damage to safety and non-safety related SSCs	1	0.09-0.18	Plant SSE = 0.18 g
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.	2	0.18-0.3	0.5 g is the lowest HCLPF of any safety-related SSC on the SEL.
		3	0.3-0.5	
3	Widespread damage expected to non-safety related SSCs and/or some damage expected to safety related SSCs. Lots of alarms and vibration trips.	4	0.5-0.8	2.0 g is the threshold at which instrumentation is no longer credible. For hazard bin 6, instrumentation failure probability was 0.42, for bin 7 it was 0.9. For this model, instrumentation was modeled explicitly in the PRA, so a higher threshold could be justified without feasibility concerns.
		5	0.8-1.2	
		6	1.2-2.0	
4	Substantial damage to safety related and non-safety related SSCs.	7	2.0-3.0	Defined as guaranteed failure for all HFEs.
		8	>3.0	

Fig. 4. Example mapping of plant-specific ground motion bins to generic damage state definitions according to EPRI (Presley, 2016)

The damage state bins defined for HRA must be eventually mapped to the hazard bins, e.g. the seismic bins in this case, as defined by the PSA. The idea is to interface the HRA analysis with both the internal events PSA as well as the fragility analysis in order for the damage states to be correlated, i.e. mapped against the hazard bins (e.g., PGA intervals) as well as component fragilities used in the PSA. This correlation will consider the critical break points in terms of probability, number and types of SSC failures that can produce a context that matches the qualitative definitions, one example of which is presented on Fig. 4. (Presley, 2016).

In the case of OAs which were adopted from the internal events PSA into the external events PSA, the internal events qualitative and quantitative analysis can be used as the starting point for the external events PSA quantification. In this direction, EPRI suggest a multiplier matrix (Fig. 5), i.e. a decision event tree for determining which multiplier should be applied to the internal events HEPs given different PGA-levels (Presley, 2016).

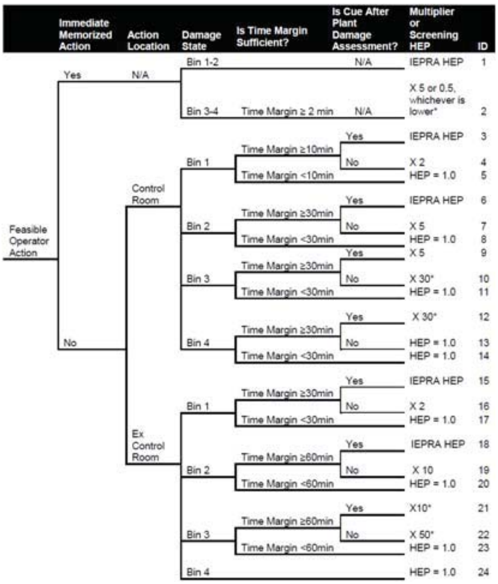

Fig. 5. Multiplier Decision Tree for existing operator actions from internal events PSA according to EPRI (Presley, 2016)

For high damage states (e.g., Bin 4), the uncertainties dominate, so for screening the HEP should be capped at 0.01, even if application of the multiplier provides a lower value. The time margin is quite an important aspect in the above decision matrix. Namely, the timeline of the internal events OAs can be either accepted as-is from the internal events PSA or can be adjusted in case the external hazards imply an altered timeline of certain accident sequence(s). This initial timeline, however, is not expected to account for, in detail, every potential delay caused by the impact of the external event. 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 for a screening-level analysis. Hence, the main question at this node ("Is Time Margin Sufficient") is: is the action still feasible from a timing perspective after accounting for the impact of some of these uncertainties. In this direction, EPRI suggests the following delineation (Fig. 6).

HFE Type	Damage State Bin 1	Damage State Bins 2-4
Immediate Operator Actions	0 min	2 min
In-CR	10 min	30 min
Ex-CR	30 min	60 min

Fig. 6. Time margin requirements according to EPRI (Presley, 2016)

The mapping between the PGA-intervals, considered within the KKGPSA on one side, and the bins suggested from EPRI, on the other, is as follows:

- Below Bin 1: SEIS1 (< 0.071 g): Earthquake goes undetected, reactor will be scrammed;
- Bin 1: SEIS2 to SEIS3 (0.071 g - 0.25 g): Earthquake well below SSE
- Bin 2: SEIS4 to SEIS5 (0.25 g - 0.60 g): Many weaker components damaged, almost certain LOOP
- Bin 3: SEIS6 to SEIS7 (0.60 g - 1.10 g): Significant damage
- Bin 4: SEIS8 (1.10 g - 1.70 g): Major damage to the SSCs, potentially uncontrollable.

2.3. *Discussion EPRI vs ENSI Approaches*

The EPRI approach differs from the ENSI approach in several respects. As can be seen from the decision tree (Fig. 5), the critical times after the earthquake are in the range of 10 to 60 minutes. This contrasts with the refined approach described above according to the guideline ENSI-A05 (Section 2.2).

Another difference from the ENSI approach is the increased probability of failure even in the case of very weak earthquakes. The most critical point, however, is the question "*Is Cue After Plant Damage Assessment?*", i.e., whether the signal that triggers the action is only available after a damage assessment has been carried out. Such an assessment is not generally possible because the shift and the emergency response team are primarily occupied with the safe shutdown of the plant, and a comprehensive damage assessment can only be performed after the plant's condition has been stabilized.

3. New Method for Seismic HEP Modelling

The results of an EPRI pilot study (Presley, 2016) have demonstrated that the generic damage state bins can be aligned well with the plant-specific hazard bins for some plants. Some plants have unique issues such that the hazard bins do not align well with the generic damage states, or the defined damage states are too coarse for screening and/or detailed analysis. In those cases, EPRI suggests that the plant may choose to develop their own plant-specific damage state bins and correlate the contexts for each bin to conservative modeling rules using the detailed analysis method in Section 6 of EPRI (Presley, 2016). Also, some plants may find some other penalization factors more suitable than the ones suggested in the EPRI approach as well as they might find some of the decision questions within the EPRI decision tree (Fig. 5) not suitable (e.g. cue after assessment) (Pellissetti et al., 2021). This approach – sometimes referred to as a “hybrid approach” – is actually what KKG opted for, as part of the development of their new PSA. This approach distinguishes between four earthquake magnitudes and three time ranges, i.e. it is in accordance with the three time ranges (short-term, medium-term, long-term) as suggested by the refined approach from ENSI. It also differentiates between whether the action takes place within or outside the main control room (MCR). Both the multiplication factors and the time ranges are chosen to cover the EPRI approach (Section 2.3). As with the EPRI approach, the following distinctions are made:

- **Bin 1**: Earthquake < 0.25 g (corresponds to SEIS1 – SEIS3): Nominal HEP according to ENSI-A05;
- **Bin 2**: 0.25 g - 0.6 g (corresponds to SEIS4 – SEIS5): Multiplication factors for the HEP are modified as follows depending on the implementation location and time after the earthquake:

Table 1. Multiplication factors for Bin 2.

Location	Short term (< 1h)	Medium term (1-8h)	Long term (>8h)
MCR	x 5	x 2	x 1
Outside MCR	x 10	x 3	x 2

- **Bin 3**: 0.6 g – 1.1 g (corresponds to SEIS6 – SEIS7): Multiplication factors for the HEP are modified as follows depending on the implementation location and time after the earthquake:

Table 2. Multiplication factors for Bin 3.

Location	Short term (< 1h)	Medium term (1-8h)	Long term (>8h)
MCR	x 30	x 5	x 2
Outside MCR	x 50	x 10	x 5

- **Bin 4**: 1.1 g – 1.7 g (corresponds to SEIS8): Multiplication factors for the HEP are modified as follows depending on the implementation location and time after the earthquake:

Table 3. Multiplication factors for Bin 4.

Location	Short term (< 1h)	Medium term (1-8h)	Long term (>8h)
MCR	Fail.	x 30	x 10
Outside MCR	Fail.	x 100	x 30

4. Analysis

For the purpose of the analysis within this paper, performed on a realistic PSA-model, a set of 37 different OAs was selected. These OAs (Table 2) cover practically all the personnel responses, both preventive as well as mitigative, modelled and challenged throughout all the accident sequences in cases where an earthquake is the IE.

Due to the partial or fully proprietary/confidential nature the exact qualitative descriptions of the analyzed OAs have or might have, these OAs are referred not according to their exact names/description herein, but simply as dummies, with forth numbered IDs, i.e. "OA_1", "OA_2" and so on.

The following tables (Table 4, Table 5) summarize these OAs together with their corresponding HEPs (point estimates only for the purpose of this paper), both regarding implementing the EPRI approach (Table 4 and as described in Section 2.3) as well as the Hybrid approach (Table 5 and as described in Section 3).

Table 4. Applied seismic HEPs for the EPRI Method

ID	Basis HEP	Bin 1 HEP	Bin 2 HEP	Bin 3 HEP	Bin 4 HEP
OA_1	1.02E-2	2.04E-2	1.00E+0	1.00E+0	1.00E+0
OA_2	1.39E-3	2.78E-3	6.95E-3	4.17E-2	1.00E+0
OA_3	1.11E-3	1.11E-3	1.11E-3	5.55E-3	3.33E-2
OA_4	1.01E-3	2.02E-3	5.05E-3	1.00E+0	1.00E+0
OA_5	1.08E-3	1.08E-3	1.08E-3	5.40E-3	1.00E+0
OA_6	3.40E-3	3.40E-3	3.40E-3	1.70E-2	1.02E-1
OA_7	3.37E-2	6.74E-2	3.37E-1	1.00E+0	1.00E+0
OA_8	2.98E-2	1.01E-1	1.49E-1	8.94E-1	1.00E+0
OA_9	7.50E-2	1.50E-1	1.00E+0	1.00E+00	1.00E+0
OA_10	5.07E-2	1.01E-1	1.00E+0	1.00E+00	1.00E+0
OA_11	3.41E-2	6.82E-2	3.41E-2	3.41E-01	1.00E+0
OA_12	1.88E-2	1.88E-2	1.88E-2	1.88E-01	1.00E+0
OA_13	2.74E-2	5.48E-2	2.74E-1	2.74E-01	1.00E+0
OA_14	1.62E-2	1.62E-2	1.00E+0	1.00E+00	1.00E+0
OA_15	1.13E-2	2.27E-2	1.13E-1	5.67E-01	1.00E+0
OA_16	1.35E-2	2.70E-2	1.35E-1	6.75E-01	1.00E+0
OA_17	1.00E-1	1.00E-1	1.00E-1	5.00E-01	5.00E-1
OA_18	1.00E-1	1.00E-1	1.00E-1	1.00E+00	1.00E+0
OA_19	5.34E-3	1.07E-2	5.34E-2	2.67E-01	1.00E+0
OA_20	1.00E-1	1.00E-1	1.00E-1	1.00E+00	1.00E+0
OA_21	6.47E-2	1.29E-1	1.00E+0	1.00E+00	1.00E+0
OA_22	6.82E-3	1.36E-2	6.82E-2	1.00E+00	1.00E+0
OA_23	2.83E-2	5.66E-2	1.00E+0	1.00E+00	1.00E+0
OA_24	4.32E-3	8.64E-3	2.16E-2	1.00E+00	1.00E+0
OA_25	3.98E-4	7.96E-4	1.99E-3	1.19E-02	1.00E+0
OA_26	2.32E-3	4.63E-3	1.16E-2	1.00E+00	1.00E+0
OA_27	4.00E-2	8.00E-2	1.00E+0	1.00E+00	1.00E+0
OA_28	4.68E-4	9.36E-4	2.34E-3	1.40E-02	1.00E+0
OA_29	1.86E-2	1.86E-2	1.86E-2	5.58E-1	5.58E-1
OA_30	3.13E-4	6.26E-4	1.57E-3	9.39E-03	1.00E+0
OA_31	1.00E-2	2.00E-2	1.00E-1	1.00E+00	1.00E+0
OA_32	1.50E-1	3.00E-1	1.00E+0	1.00E+00	1.00E+0
OA_33	5.29E-2	1.06E-1	5.29E-1	5.29E-01	1.00E+0
OA_34	3.12E-2	6.24E-2	3.12E-1	3.12E-01	1.00E+0
OA_35	1.00E-1	2.00E-1	1.00E+0	1.00E+00	1.00E+0
OA_36	5.72E-2	1.14E-1	5.72E-1	5.72E-01	1.00E+0
OA_37	3.54E-3	7.08E-3	3.54E-2	1.00E+00	1.00E+0

Hence, the goal of the analysis herein is to deliver a comparative assessment on the quantitative and qualitative effects on the Level 1 risk measure (CDF) of the KKGPSA model, when swapping from between these two approaches for modelling the seismic HEPs.

Table 5. Applied seismic HEPs for the Hybrid Method

ID	Basis HEP	Bin 1 HEP	Bin 2 HEP	Bin 3 HEP	Bin 4 HEP
OA_1	1.02E-2	1.02E-2	5.10E-2	3.06E-1	1.00E+0
OA_2	1.39E-3	1.39E-3	6.95E-3	4.17E-2	1.00E+0
OA_3	1.11E-3	1.11E-3	1.11E-3	5.55E-3	1.11E-2
OA_4	1.01E-3	1.01E-3	2.02E-3	1.01E-2	3.03E-2
OA_5	1.08E-3	1.08E-3	2.16E-3	1.08E-2	3.24E-2
OA_6	3.40E-3	3.40E-3	3.40E-3	1.70E-2	3.40E-2
OA_7	3.37E-2	3.37E-2	1.01E-1	6.74E-1	1.00E+0
OA_8	2.98E-2	2.98E-2	1.49E-1	8.94E-1	1.00E+0
OA_9	7.50E-2	7.50E-2	2.25E-1	1.00E+0	1.00E+0
OA_10	5.07E-2	5.07E-2	1.52E-1	1.00E+0	1.00E+0
OA_11	3.41E-2	3.41E-2	6.82E-2	3.41E-1	1.00E+0
OA_12	1.88E-2	1.88E-2	3.76E-2	1.88E-1	5.64E-1
OA_13	2.74E-2	2.74E-2	2.74E-2	1.37E-1	2.74E-1
OA_14	1.62E-2	1.62E-2	3.24E-2	1.62E-1	4.86E-1
OA_15	1.13E-2	1.13E-2	3.39E-2	2.26E-1	1.00E+0
OA_16	1.35E-2	1.35E-2	4.05E-2	2.70E-1	1.00E+0
OA_17	1.00E-1	1.00E-1	5.00E-1	1.00E+0	1.00E+0
OA_18	1.00E-1	1.00E-1	1.00E+0	1.00E+0	1.00E+0
OA_19	5.34E-3	5.34E-3	1.60E-2	1.07E-1	5.34E-1
OA_20	1.00E-1	1.00E-1	2.00E-1	1.00E+0	1.00E+0
OA_21	6.47E-2	6.47E-2	6.47E-1	1.00E+0	1.00E+0
OA_22	6.82E-3	6.82E-3	2.05E-2	1.36E-1	6.82E-1
OA_23	2.83E-2	2.83E-2	1.42E-1	8.49E-1	1.00E+0
OA_24	4.32E-3	4.32E-3	2.16E-2	1.30E-1	1.00E+0
OA_25	3.98E-4	3.98E-4	7.96E-4	3.98E-3	1.19E-2
OA_26	2.32E-3	2.32E-3	1.16E-2	6.95E-2	1.00E+0
OA_27	4.00E-2	4.00E-2	2.00E-1	1.00E+0	1.00E+0
OA_28	4.68E-4	4.68E-4	9.36E-4	4.68E-3	1.40E-2
OA_29	1.86E-2	1.86E-2	1.86E-2	9.30E-2	1.86E-1
OA_30	3.13E-4	3.13E-4	6.26E-4	3.13E-3	9.39E-3
OA_31	1.00E-2	1.00E-2	7.66E-3	3.83E-2	1.15E-1
OA_32	1.50E-1	1.50E-1	1.87E-1	9.35E-1	1.00E+0
OA_33	5.29E-2	5.29E-2	1.09E-1	5.44E-1	1.00E+0
OA_34	3.12E-2	3.12E-2	6.24E-2	3.12E-1	9.36E-1
OA_35	1.00E-1	1.00E-1	1.00E+0	1.00E+0	1.00E+0
OA_36	5.72E-2	5.72E-2	5.72E-2	2.86E-1	5.72E-1
OA_37	3.54E-3	3.54E-3	1.06E-2	7.08E-2	3.54E-1

4. Results and Discussion

Two variation Level 1 quantifications run were performed, such that in the first one, the seismic HEPs according to the EPRI approach were assigned to the selected 37 OAs, whereas in the second run – the seismic HEPS as derived according to the Hybrid approach.

The obtained results imply an increase of the seismic hazard contribution to CDF of ca. 19% when the EPRI approach is applied instead of the Hybrid approach.

The Hybrid method has the advantage over the refined ENSI approach such that the complexity of the OAs is directly incorporated into the seismic HEP value. Furthermore, due to the large increase factors, especially for short-term measures, sufficient conservativeness is ensured. In comparison to the EPRI approach as well, the advantage herein lies with the better distribution of the time intervals, i.e. incorporation of the ENSI definition of short-, medium- and long-term OAs.

Acknowledgement

The authors are grateful to their colleagues from NPP Goesgen-Däniken AG as well as from Framatome GmbH, who provided insights and expertise that greatly assisted the project development. The authors also thank the management of NPP Goesgen-Däniken AG for supporting the *PSASPECTRUM* Project.

Disclaimer

The views, assumptions, opinions and analysis expressed in this article are those of the authors and do not necessarily reflect the official policy or position of their employer (NPP Goesgen-Däniken AG).

References

Sursock, J. (2013). *Seismic Probabilistic Risk Assessment Implementation Guide*. EPRI, Report No. 3002000709. December 2013.

Presley, M. (2016). *An Approach to Human Reliability Analysis for External Events with a Focus on Seismic*. EPRI, Report No. 3002008093. December 2013.

ENSI-A05/e. (2019). *Probabilistic Safety Analysis (PSA): Quality and Scope*. March 2019.

Pellissetti M. et al. (2021). *PSA-based Seismic Margin Assessment for a New Reactor Design*. International Topical Meeting on Probabilistic Safety Assessment and Analysis. November 2021.