Natural Hazard Screening Criteria in Probabilistic Safety Assessment for Nuclear Power Plants

Hyunsung Park*, Hyungkui Park, Youngsun Choun, Soohyuk Chang
CENITS Corporation Inc., 233, Gasan digital 1-ro, Geumcheon-gu, Seoul, South Korea
**Corresponding author: parkhs0328@gmail.com*

1. Introduction

Recently, record extreme rain caused lots of damage in a metropolitan area, and those hazards are increasing gradually in frequency and intensity of natural hazard due to climate change. Nuclear power plants (NPPs) are designed to minimize the impact of potential external hazards, however, climate change may affect the safety of NPPs by exceeding design standards or causing hazards that were not considered design. Although probabilistic safety assessment (PSA) should be performed to evaluate these potential natural hazards, but it is not reasonable to perform PSA for all external natural hazards. Therefore, given the multitude of natural hazards, efficient screening methods and criteria are extremely important. Methods for screening hazards use qualitative and quantitative screening criteria representatively. However, existing guidance documents or standards are not required qualitative screening criteria for potential natural hazards caused by climate change, in the case of quantitative screening criteria, core damage frequency (CDF) or conditional core damage probability (CCDP) is presented as quantitative screening criteria, but there is no way to calculate CDF or CCDP except for earthquakes.

This study proposes qualitative screening criteria with considered climate change and quantitative screening criteria with considered the frequency of the design basis hazards for NPP sites. additionally, potential natural hazards that may affect NPP sites were screened using the proposed screening criteria.

2. External hazard screening methods and criteria

The list of hazards was derived based on several standards, international studies, and guidance documents. The documents for the identification of potential natural hazards are shown in Table I.

Table I: Documents for identification of natural hazards

• IAEA TECDOC-1341	• SKI Report 02:27
• NUREG/CR-5042	• NUREG-1407
• NUREG-0800	• NUREG/CR-2300
• CNSC RD-346	• IAEA NS-G-3.4
• ENSI-A05/e	• IAEA NS-G-3.5
• NEA/CSNI/R (2009) 4	• WASH-1400
• IAEA 50-SG-9	• IAEA NS-G-1.5
• IAEA 50-P-7	• IAEA NS-G-3.1
• EPRI 1022997	

Screening criteria are required to consider efficiently external natural hazards. The screening methods and criteria currently used are as follows.

2.1. ASME/ANS screening method and criteria

Requirements for screening external hazards are provided in Section 6 of the ASME/ANS PRA Standard. Screening methods are presented as follows;

(1) All potential natural hazards that may affect the site shall be identified.
(2) Preliminary screening shall be performed by using defined qualitative screening criteria.
(3) A bounding or demonstrably conservative analysis shall be performed by using defined quantitative screening criteria.
(4) The basis for the screening out of a hazard shall be confirmed through a walkdown of the plant and its surroundings.
(5) Documentation of the screening out of a hazard shall be consistent with the applicable supporting requirements.

This method is divided into qualitative screening criteria and quantitative screening criteria. The criteria meet the criteria in the U.S. Nuclear Regulatory Commission Standard Review Plan or a later revision. Those screening criteria are represented in Table II and Table III.

Table II: ASME/ANS qualitative screening criteria [1]

No.	Description
1	The hazard is of equal or lesser damage potential than the hazards for which the plant has been designed. This screening out requires an evaluation of plant design bases in order to estimate the resistance of plant structures and systems to a particular hazard.
2	The hazard has a significantly lower mean frequency of occurrence than another hazard, taking into account the uncertainties in the estimates of both frequencies, and the hazard could not result in worse consequences than the consequences from the other hazard.
3	The hazard cannot occur close enough to the plant to affect it. This criterion must be applied taking into account the range of magnitudes of the event for the recurrence frequencies of interest.
4	The hazard is included in the definition of another hazard.
5	The hazard is slow in developing, and it can be demonstrated that there is sufficient time to eliminate the source of the threat or to provide an adequate response.

Table III: ASME/ANS quantitative screening criteria

No.	Description
1	The current design-basis hazard event has a mean frequency $<10^{-5}$ /yr, and the mean value of the CCDP is assessed to be $<10^{-1}$.
2	The CDF, calculated using a bounding or demonstrably conservative analysis, has a mean frequency $<10^{-6}$ /yr.

2.2. SKI Report 02:27 screening method and criteria

SKI 02:27 is a research report developed under a contract with the Nordic PSA Group. The following four methods are considered for screening external hazards. The screening criteria is represented in Table IV.

- Relevancy Screening (ReSc) is to screen out those potential external events, which are not relevant to the site, which means that they cannot occur at the site or in its relevant surroundings or that their strength is evidently too low.
- Impact Screening (ImSc) is to screen out those potential external events, which are not relevant to the plant.
- Deterministic Screening (DeSc) is to screen out those potential external events, which do not cause any initiating event of PSA and losses of safety systems thus needed.
- Probabilistic Screening (PrSc) is to calculate the contribution to the frequency of core damage for each external event.

Table IV: SKI 02:27 Screening criteria [2]

No.	Description	App.
1	The event cannot occur close enough to the site and its relevant surroundings during future decades.	ReSc
2	The event shall be included into the definition of another event.	ReSc
3	The event is not applicable to the site.	ReSc
4	The event is already or is planned to be included into some other study. (e.g., PSA).	ReSc
5	The event has a damage potential that is less or equal to another event that the plant is already designed for.	ImSc DeSc
6	The anticipation time of the event is less than the time specified, or the increase rate of the strength of the event is low enough for carrying out the precautions preplanned.	ImSc DeSc
7	The severity of the event is known at the plant but the analyzing work shall be postponed because the plant shall be modified having remarkable effects on the endurance of the plant.	ImSc
8	The effects of the estimated maximum strength of the event does not exceed the design basis documented or the endurance based expert estimate. This means that the event does not cause: - during power operation at least a need for controlled shut down or scram and additionally some losses of safety system functions required for the need. - during shutdown losses of safety systems required during shut down.	DeSc
9	The risk contribution of the event is minor and acceptable.	PrSc

2.3. EPRI screening method and criteria

The recommended qualitative screening criteria were presented with reference to IAEA 50-P-7 [3], ASME/ANS standard, and SKI Report 02:27. And the recommended quantitative criteria were established using typical current U.S. The screening criteria are represented in Table V and Table VI.

Table V: EPRI recommended qualitative screening criteria [4]

No.	Description
1	The hazard is of lesser damage potential than other similar hazards for which the plant has been designed.
2	The hazard has a significantly lower mean frequency of occurrence than another hazard that has screened, and the hazard could not result in worse consequences than the other screened hazard.
3	The hazard cannot occur at the site or close enough to the site to affect the plant.
4	The hazard is included in the definition of another hazard.
5	The hazard is slow in developing such that it can be demonstrated that there is sufficient time to eliminate the source of the threat or provide an adequate response.
6	The hazard does not cause an initiating event (including the need for a controlled shutdown) as well as safety system function loss(es) needed for the event.
7	The consequences to the plant do not result in a reactor trip or shutdown, and do not require the actuation of front-line systems.

Table VI: EPRI recommended quantitative screening criteria

No.	Description	Direct containment bypass or failure
1	CDF < 10^{-6} /yr	No
2	Design Basis Hazard Frequency < 10^{-5} /yr and CCDP < 0.1	No
3	CDF < 10^{-7} /yr	Yes
4	Design Basis Hazard Frequency < 10^{-6} /yr and CCDP < 0.1	Yes

3. Proposed screening method and criteria

3.1. Screening method

In order to efficiently select all natural hazards that can occur at NPP sites, a screening method is proposed based on reviewed documents. The process of hazards identification and screening is that first, all potential natural hazards that may affect the NPP sites shall be identified. And then identified natural hazards are screened using the proposed screening criteria. Finally, PSA is performed for hazards. Screening methods are presented in Fig. 1.

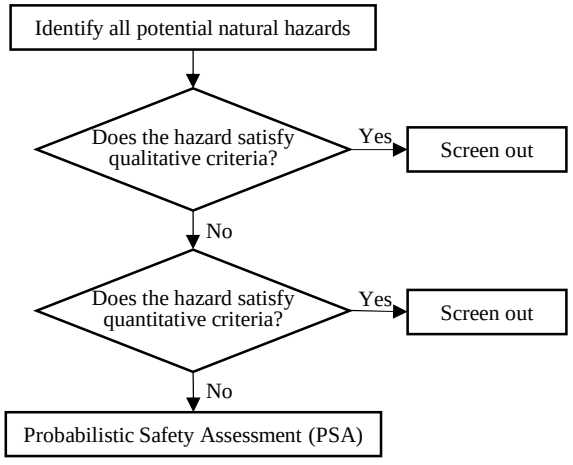

Fig. 1. Screening method

3.2 Screening criteria

3.2.1. Qualitative screening criteria

The qualitative criteria use criterion 1 to 7 of the EPRI qualitative criteria. The criteria from 1 to 7 are described briefly as follows. And the proposed criterion of climate change can be considered as follow criterion 8.

- Criterion 1: includes design aspects of the plant and is intended to eliminate hazards that could not initiate an event sequence that could lead to core damage.
- Criterion 2: is to compare against another hazard that was screened.
- Criterion 3 and 4: are understood easily and can be applied objectively with little judgment required.
- Criterion 5: requires a warning system or process that is very reliable, procedural guidance that is clear and unambiguous, and adequate time available to allow for plant action.
- Criterion 6: is described in criterion 8 of SKI 02:27.
- Criterion 7: is described in ENSI-A05/e [5].
- Criterion 8: The hazard is expected to increase the frequency or intensity due to climate change, but the hazard could not result in worse consequences during operating NPPs.

3.2.2. Quantitative screening criteria

Quantitative screening criteria for reviewed documents are based on CDF or CCDP, but if CDF is not calculated for potential natural hazards, other criteria are required to replace the CDF.

Therefore, this study proposes to screen with a frequency of design-basis natural hazard. Although the frequency of design-basis hazard in NPP is generally 10,000-year frequency (10^{-4}/yr), the criterion set less than 100,000-year frequency ($<10^{-5}$/yr), considering the "cliff edge" effect additionally. When the PSA method for potential natural hazards will be developed in the future, it is necessary to screen the hazard based on CDF.

4. Screening hazards using proposed screening criteria

In the list of hazards referenced in Chapter 2.1, potential natural hazards without human-made hazards were screened using proposed qualitative screening criteria. Table VII shows screening potential hazard for individual hazards. This table is the preliminary result of reviewing the screening results for all sites in domestic NPPs.

The screening was classified by considering the design criteria capabilities, site characteristics, etc. of each NPP, this screening was conducted by marking* for hazards that require confirmation of design characteristics or site characteristics as preliminary screening results before screening for each plant site.

Table VII: Screening potential hazard for individual hazards

No	Natural hazard	Qualitative criteria							
		1	2	3	4	5	6	7	8
1	Extreme winds	X	○	○	○	○	○	○	X
2	Extreme rain	X	○	○	○	○	○	○	X
3	Landslide	○	○	△	○	○	○	○	○
4	High tide	○	○	○	○	○	○	○	X
5	Organic material in water	○	○	○	○	X	○	○	○
6	External fire	○	○	△	○	X	○	○	○
7	Hail	○	○	○	○	○	○	○	X
8	Air temperature	○	○	○	○	○	○	○	X
9	Water temperature	○	○	○	○	○	○	○	X

* ○: satisfy,
×: not satisfy (going to qualitative screening),
△: need to check design standard, site condition, and etc.

5. Conclusions

This study proposed hazard screening method and criteria for natural hazard PSA. Qualitative screening criteria proposed to consider potential natural hazards that may occur due to climate change. It is expected that the proposed criteria will be possible to screen more diverse natural hazards. Quantitative screening criteria using the design-basis natural hazard frequency were proposed. The design-basis natural hazard frequency, the quantitative screening criteria proposed in this study, is a conservative criterion based on the safety assessment in NPP sites. Therefore, when the PSA method for potential natural hazards will be developed in the future, it is necessary to screen the hazard based on CDF.

In addition, since the frequency and intensity of natural hazards may have different values for each site of NPP, it is necessary to check the site.

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REFERENCES

[1] ASME/ANS, Addenda to ASME/ANS RA-S-2008 Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications, ASME/ANS RA-Sb-2013, NY, 2013.
[2] SKI, Guidance for External Events Analysis, SKI Report 02:27, Helsinki, Finland, 2003.
[3] IAEA, Treatment of External Hazards in Probabilistic Safety Assessment for Nuclear Power Plants, IAEA Safety Series No. 50-P-7, Vienna, Austria, 1995.
[4] EPRI, Identification of External Hazards for Analysis in Probabilistic Risk Assessment, EPRI Report 1022997, Palo Alto, CA, 2015
[5] ENSI, Guideline for Swiss Nuclear Installations Probabilistic Safety Analysis (PSA): Quality and Scope, ENSI-A05/e, Brugg, Switzerland, 2019.