



## Original Article

# Identification and Analysis of External Event Combinations for Hanhikivi 1 PRA



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## ABSTRACT

Fennovoima's nuclear power plant, Hanhikivi 1, Pyhäjoki, Finland, is currently in design phase, and its construction is scheduled to begin in 2018 and electricity production in 2024. The objective of this paper is to produce a preliminary list of safety-significant external event combinations including preliminary probability estimates, to be used in the probabilistic risk assessment of Hanhikivi 1 plant. Starting from the list of relevant single events, the relevant event combinations are identified based on seasonal variation, preconditions related to different events, and dependencies (fundamental and cascade type) between events. Using this method yields 30 relevant event combinations of two events for the Hanhikivi site. The preliminary probability of each combination is evaluated, and event combinations with extremely low probability are excluded from further analysis. Event combinations of three or more events are identified by adding possible events to the remaining combinations of two events. Finally, 10 relevant combinations of two events and three relevant combinations of three events remain. The results shall be considered preliminary and will be updated after evaluating more detailed effects of different events on plant safety.

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## 1. Introduction

Fennovoima's nuclear power plant, Hanhikivi 1, Pyhäjoki, Finland, is currently in design phase, and its construction is scheduled to begin in 2018 and electricity production in 2024. To apply the construction license, a design-phase probabilistic risk assessment (PRA) shall also be developed. The PRA of a nuclear power plant shall include all initiating events that could endanger the safe operation of the plant, including external events related to natural phenomena and man-made hazards. These external events could occur simultaneously and cause more severe consequences than single events. The

importance of external event combinations has been identified in international guides and in the Finnish YVL guides, but methods for identifying event combinations and evaluating their probabilities are not presented. The objective of this paper is to develop a practical method for identifying event combinations and providing rough probability estimates for the relevant events. This method is applied in practice to the Hanhikivi nuclear power plant site, and thus the outcome of this paper is the list of relevant external event combinations with preliminary probability estimates for the Hanhikivi site. The probability estimates presented in this paper are preliminary and based on simplified methods. The most

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important event combinations should be evaluated in more detail later when the plant design evolves.

The single external events relevant at the site have been identified earlier. Furthermore, the probabilities (hazard curves) of the single events have been estimated with the support of Finnish Meteorological Institute and Swedish Meteorological and Hydrological Institute. These evaluations are used as input information for this work.

## 2. Material and methods

### 2.1. Guides and standards

The Finnish nuclear regulatory guides—the YVL guides—present no specific requirements related to the evaluation of combined external events. The YVL guide B.7 related to internal and external events states that the dependencies between natural phenomena shall be considered in the PRA [1]. External event combinations are not mentioned in the YVL guide A.7 related to PRA [2]. In the international guides and standards, the combined external events are rarely mentioned. The International Atomic Energy Agency SSG-3 states that external event combinations shall be considered, but no methodologies are described or referred [3]. A short method description for combined external event evaluation is given by Knochenhauer and Louko [4].

### 2.2. Methods

The method for creating a list of relevant event combinations for the PRA of Hanhikivi 1 plant is presented in Fig. 1. The method includes similar elements to those described by Knochenhauer and Louko [4].

A list of relevant single events with probability estimates shall be available prior to analyzing event combinations. Based on the single events, combinations of two events are identified and analyzed. A large share of the two-event combinations can be excluded using the following screening criteria. (1) Independent events: some of the selected events

have no dependency with any of the other selected events and can be excluded from further event combination analysis. (2) Seasonal variation: some events have a strong seasonal variation and events occurring in different seasons cannot form a relevant combination. (3) Exclusive preconditions: certain events require specific preconditions related to weather and sea conditions, and events that have opposite preconditions cannot form a relevant combination. (4) Similar effects: the effects of some events are very similar, and it can be stated that if the first event has occurred, no further consequences are caused by the second event. These event combinations do not need to be considered. However, the event combination might still be relevant if the combined effect is significantly greater than the effect of a single event.

After the obvious irrelevant combinations have been excluded, the remaining two-event combinations shall be considered one by one. A combination of events is assumed relevant only if the occurrence of the events is dependent. If two (rare) events occur independently, their combined occurrence can be estimated so improbable that the combination can be considered insignificant. Two types of dependencies are looked for: (1) fundamental dependency, the occurrence of events is related to same basic phenomenon or events are created by the same mechanism and (2) cascade-type dependency, the first event may inflict or strengthen the second event, increase its probability, or worsen its effect.

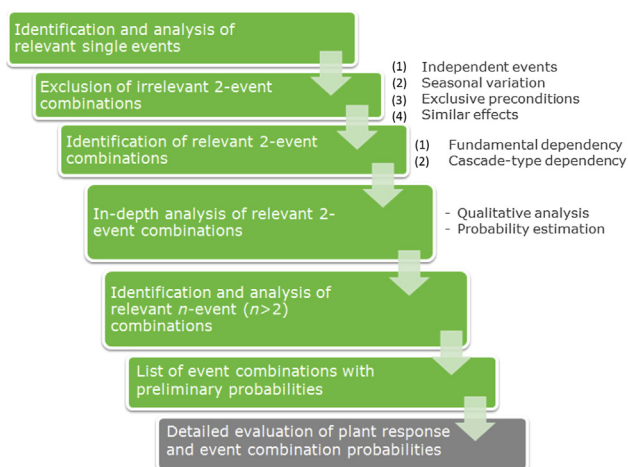
All the identified potentially relevant combinations of two events are analyzed in detail. If a combination is still considered relevant after qualitative assessment, the probability of the event combination is determined by using the probability estimates of the single events. The event with a lower probability is assumed to have occurred and the conditional probability for the other event to occur simultaneously is estimated. An event combination may be considered a relevant initiating event if it exceeds the general cutoff frequency ( $10^{-8}/y$ ) used in the PRA. However, a lower cutoff frequency ( $10^{-9}/y$ ) shall be applied if the conditional core damage probability after the event combination is assumed to be close to 1.

After the list of relevant two-event combinations is completed, event combinations with more than two events are identified by recognizing groups of events that are all dependent on each other. In practice, the two-event combinations (Events A and B) are browsed through, and in each case it is evaluated if an additional event (C) can be found that has a dependency with both events A and B. Similarly, event combinations including more than three events can be identified.

## 3. Results

### 3.1. Single event analysis

The relevant single external events that possibly need to be included in the Hanhikivi 1 PRA have been identified earlier by Helander [5]. (1) Meteorological events: air humidity, down-burst, freezing rain, high or low air temperature, lightning, rain, snow, strong wind, trombs (tornadoes). (2) Sea-related events: algae or other organic material, frazil ice, high or low seawater level, high seawater temperature, meteotsunamis,



**Fig. 1** – Identification and evaluation of event combinations in the Hanhikivi 1 probabilistic risk assessment (PRA).

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