EXTERNAL EVENT SCREENING APPROACH TO IDENTIFY RELEVANT DESIGN EXTENSION HAZARDS FOR NPP

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The nuclear accident in Japan resulted from the combination of two correlated extreme external events (earthquake and tsunami). The consequences (flooding in particular) went beyond what was considered in the initial plant design. Such scenarios can be identified using probabilistic methods that complement the deterministic approach for beyond-design accidents. External events are considered as natural or man-made hazards to a site and facilities that are originated externally to both the site and its processes with the potential of causing initiating events at the plant, typically transients like loss of offsite power. Simultaneously, external events may affect safety systems required to control the initiating event and, where applicable, also back-up systems implemented for risk-reduction. The aim of the screening analysis is to identify from an exhaustive list of external events those single and combined external events which are relevant to the plant and the site with regards to their potential of affecting the plant safety.

This paper presents a screening analysis methodology to identify relevant external events and external event combinations. In line with the WENRA Position paper, this approach provides valuable input information for the identification of single external events and their combinations to create Fukushima-like rare and severe external hazards which may need to be addressed additional to the general design basis as design extension hazards by realistic analyses rather than conservative. In order to identify relevant external hazards for a certain nuclear power plant (NPP) location, a site-specific screening analysis is performed, both for single events and for combinations of external events. The analysis is based on a systematic identification of relevant external event combinations which includes earthquake-induced external events and takes into account deterministic justification of the design basis for external events including beyond design external events.

As a result of the screening analysis, risk significant and therefore relevant (screened-in) single external events and combinations of them are identified for a site. The screened-in events are further considered in a detailed event tree analysis in the frame of the Probabilistic Safety Analysis (PSA) to calculate the core damage/large release frequency resulting from each relevant external event or from each relevant combination.

The analysis identifies potential threats given by hazards inducing initiating events, which are not considered in the safety demonstration of the plant, such as e.g. the loss of the offsite power combined with prolonged plant isolation. Under this situation, the offsite support, e.g. delivery of diesel fuel oil, usually credited in the deterministic safety analysis may not be possible in this case. As the Fukushima events showed, the biggest threat is likely given by hazards inducing both effects. Such hazards may well be dominant risk contributors even if their return period is very high.

I. INTRODUCTION

The accident at the Fukushima Daiichi nuclear power plant on 11th of March 2011 resulted from the combination of two correlated extreme external events triggered by an exceptional magnitude earthquake which led to an automatic shutdown of the plant and loss of offsite power supply. The earthquake triggered a major tsunami that devastated the site by flooding and resulted in severe damages to the plant leading to both loss of emergency power supply and a loss of the heat sink. The sequence of events lead to a critical situation on three reactors (units 1 to 3) and on the spent fuel pool of unit 4 challenging the plant stuff and the emergency response team to recover cooling capabilities in a situation where the off-site power supply has required about 11 days to be effective and massive radioactivity releases to the environment. This major event has been classified by the Japanese Safety Authority at the maximum level on the INES scale (level 7).

The Fukushima event revealed the safety relevance of rare but extremely severe external hazards, exceeding the design base of a nuclear power plant (NPP). The plant safety may especially be threatened by so called cliff–edge effects when loads from external hazards exceed the load assumptions considered in the design of safety-related systems, structures and components. A number of initiatives have been undertaken in many countries and at international level in order to take into account the lessons learned from this accident for the improvement of nuclear reactors design and the organization to manage radiological accidents. Most of the countries operating nuclear reactors have launched systematic reassessment of the safety margins of their nuclear fleet under severe natural hazards, usually called stress-tests.

In the frame of this reassessment also the methods applied for the analysis of external events and the approaches to define and verify the design bases of the plant have been reviewed, as well for identifying relevant external hazards as beyond design accident especially for severe hazards and any their combinations. The main findings of this review are outlined in this paper. The screening approach to identify relevant external events and external event combinations is presented. In line with the WENRA position paper (Ref. 1), this approach provides valuable input information for the identification of single external events and their combinations to create Fukushima-like rare and severe external hazards which may need to be addressed additional to the general design basis as design extension hazards by realistic rather than conservative analyses. The approach is based on a systematic identification of relevant external event combinations including earthquake-induced external events and takes into account deterministic justification of the design basis for external events including beyond design external events. In line with (Ref. 2) the systematic identification of the plant features for coping with design extension conditions (beyond design basis accidents) in order to assure the robustness of the defence in-depth and to avoid cliff edge effects the approach is used to identify vulnerabilities in the defence-in depth and safety margins which require improvements of the robustness of the plant.

Benefit has been taken from the contribution to the European Project ASAMPSA_E in which the methodologies for the assessment of external hazards and their combination as well as their effects on NPPs have been updated in order to consider the current state of the art knowledge including the use of probabilistic and advanced deterministic methods to assess the plant safety in relation to extreme events. Lessons learnt from the Fukushima accident about the possibility of a severe accident with radiological consequences due to failures with a common cause relevant for other site location and types of reactors have been reviewed and evaluated in order to take benefit for the reinforcement of the approaches for the identification, screening and the detailed probabilistic analysis of external events to consider extreme events in a more comprehensive and systematic approach.

II. CONSIDERATION OF EXTERNAL HAZARDS FOR DETERMINISTIC AND PROBABILISTIC ANALYSES

As a consequence of the Fukushima event the following deterministic external hazards considerations are of concern:

- The design basis load case to be considered in the design of Systems, Structures and Components (SSCs) (e.g., Design Base Earthquake and Design Base Flooding) and
- The design extension load case ("Design Extension Hazard", DEH) for which it shall be shown under best-estimate assumptions that fuel melt can be prevented or that the radiological consequences of fuel melt can be controlled by a proper containment function.

As the definition of a DEH may raise a need for important and expensive design modification it is advisable to identify those hazards and hazard combination at an early design stage. An example of such a design extension hazard is given by the consideration of a crash of large commercial air plane on the plant. In order to identify relevant external hazards for a certain NPP location, a site specific screening analysis is performed, both for single and for combinations of external events. The screening analysis identifies relevant single and combined external hazards, which are natural or man-made events which originate externally to the site and its processes and which have the potential of causing initiating events at the plant, typically transients (e.g., loss of offsite power). Simultaneously, external hazards may affect safety systems required to control the initiating event and, where applicable, also back-up systems implemented for risk-reduction. The screening analysis of external events is performed to

- Identify external hazards for which a Design Extension Approach might be applicable and
- Identify the relevant external hazards for the detailed probabilistic analysis.

Screening analyses of external events performed at AREVA are based on the approach provided by the SKI guidance report (Ref. 3) and have been performed as part of the PSA for new plant designs and for installed based projects.
As a result of the screening analysis, risk significant and therefore relevant (screened-in) single external events and combinations of them are identified for a site. The screened-in events are further considered as events to which a Design Extension Approach might be applicable. A detailed event tree analysis is performed for each screened-in external event in the frame of the PSA in order to calculate the core damage frequency (CDF)/large early release frequency (LERF) resulting from each relevant external event or from each relevant combination. An overview of the screening process for external event based on the approach of the external events PSA is presented in Figure 1.

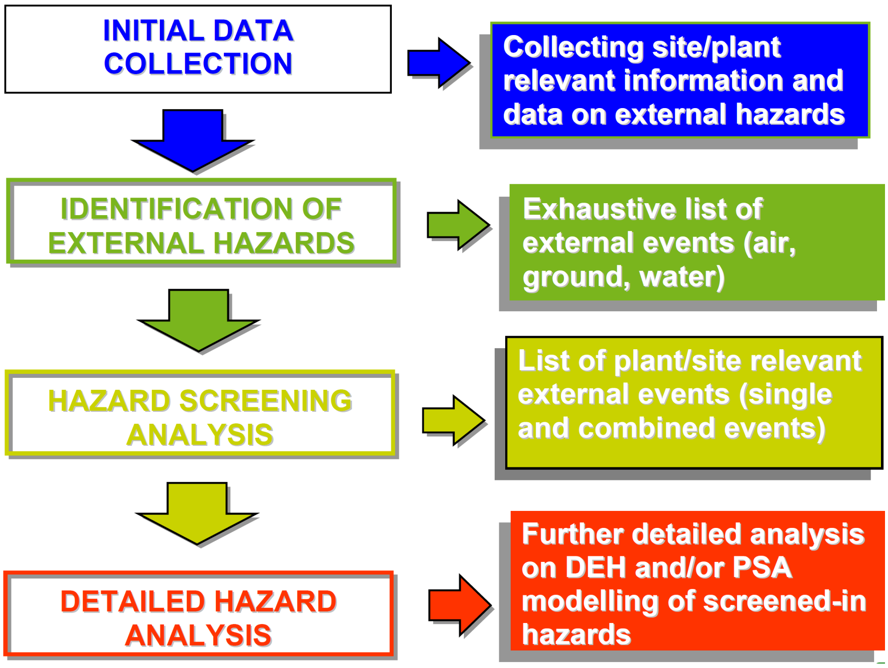

Fig 1: Overview of the Screening Process for External Hazards

As a first step collection of relevant site information and data on external hazards for the site is performed in order to

- Identify external hazards potentially relevant to the plant and to the site and
- Provide the necessary input information to perform the screening analysis of external events.

External hazards may in particular have one or more of the following effects to be considered in the safety demonstration (Table 2.2. in SKI guidance report (Ref. 3)):

Based on the initial data collection, potential external events to be considered in the screening analysis are identified in order to create an exhaustive list of external hazards. Grouping the various types of external events is useful for structuring the information presented and for performing a tentative completeness check of the identified events. Based on SKI guidance report (Ref. 3) and Annex 1 of IAEA SSG-3 (Ref. 4) a generic event grouping into natural and man-made external events, cross grouped via air, water and ground based external events is considered. Applying the generic event grouping relevant external events are derived and documented in an exhaustive list of events that constitute as a basis of the external events screening analysis.

TABLE I. IMPACT TYPES TO BE CONSIDERED FOR THE SCREENING

Impact type	**Description**
Structure / Pressure	The external event affects safety-related structures and may disable the safety functions contained.
Structure / Missile	
HVAC (Heating, Ventilation, Air Conditioning)	The external event affects HVAC functions and may cause partial or total loss of safety systems relying on heating or cooling. Alternatively, the event may affect the plant through the ventilation system, e.g., corrosive gases.
Ultimate heat sink	The external event affects the ultimate heat sink and by this the capability of the residual heat removal from the core via secondary or primary cooling.
Power supply	The external event affects the plant grid connections and may cause loss of offsite power.
External flooding	The external event causes flooding of buildings or structures and may disable the safety functions contained.
External fire	The external event causes fire in buildings or structures and may disable the safety functions contained.
Electric	The external event affects safety functions by creating electrical or magnetic fields.
Other direct impact	In a few cases, the event may work in a way that is not covered by the general categories. Examples are plant isolation or toxic impact on personnel.

III. SCREENING ANALYSIS OF EXTERNAL EVENTS

The screening analysis of external events is performed, in order to limit the number of events to be analyzed to those events which have the potential of a relevant impact to the plant and to the site. The methodology applied in the screening analysis, which is based on (Ref. 3), involves the following steps for screening single and combined external events:

III.A. Relevancy screening (site relevant external events)

The relevancy screening is based on general information about the strength of the potential external event and its relevancy at the site. The purpose of the task is to screen out those potential external events, either single or combined, which are not relevant to the site, which means that they cannot occur at the site or in its relevant surroundings or that their maximum possible strength at the site is evidently too low. The task will result in a list of potential site relevant external events. The following screening criteria are used (see Chapter 5 of (Ref. 3)).

Distance	The potential event cannot occur close enough to the plant to affect it vulnerably. Examples of use: Volcanic phenomena could be screened out by the distance from areas where volcanic activities have taken place (if applicable to the site).
Inclusion	The potential event is included into another event which is more representative to the site Example of use: Continuous land rise takes place e.g., on the coast of Botnia. This event is slow and may be included in the event low sea water level.
Applicability	The potential event is not applicable to the site Example of use: Events like Low Temperatures, Extreme snow, White frost are not applicable for tropic site locations.

III.B. Impact screening (plant relevant external events)

The purpose of the task is to screen out those potential external events, either single or combined, which would not have a considerable effect on the plant structures, cooling, electrical transmission or plant operation, even if maximum impact strength is assumed. As a result of this task a list of plant relevant external events **having the potential to degrade one or more plant safety functions** is derived. The following plant related screening criteria are used for the impact screening (see Chapter 5 of (Ref. 3)):

Severity	The effects of the event are not severe enough to damage the plant, since it has been designed for other loads with similar or higher strength. Example of use: Extreme air pressure can be screened out using this criterion as normal or abnormal events within this category will not affect the plant.
Warning	There is time to shut down the plant or to implement pre-planned measures which would render the event irrelevant. In the first case the functional analysis of event consequences can be restricted to the cold shutdown state. „The assessment of what is a sufficient warning time requires a plant specific approach, and is mainly dependent on the time required for safe shutdown of the plant. However, it also depends on existing procedures, emergency plans, etc. and must be evaluated on a case-by-case analysis.“ (Ref. (3)). Example of use: Flooding at river sites will often occur with enough pre-warning time to perform pre-planned actions to protect the plant by installation of flooding protection means and preventive plant shutdown. (exception might be flooding caused by dam failure)

Screening criteria for the identification of design extension load cases (“Design Extension Hazard“, DEH) may differ from PSA screening criteria when a more conservative approach is required in applicable regulations. Examples for deterministic screening criteria may include:

- Exclude any hazards from the list which are physically not possible for a site (e.g., avalanche),
- Exclude any hazard whose impact is obviously covered by accident conditions already considered in the plant design (e.g., water-based hazards which would at most lead to a blockage of the service water inlet screens when a scenario “Loss of Ultimate Heat Sink” is already a postulated as a design extension load case in the safety analysis.
- Exclude any hazard whose impact is already covered by another screened-in external hazard (e.g., direct impact from heavy transportation may be covered by consideration of air plane crash or explosion pressure wave).

III.C. Event definition

The purpose of the task is to acquire detailed site relevant information on the strength and frequency for each potential plant relevant external event using internal and external information sources (Ref. 3). The task will result in potential plant relevant external events characterized by

- Information on event strength, duration, frequency, etc.
- Potential impact on safety systems/components, availability of external support, etc.

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Note: Experience from ongoing project show that these data are not available completely especially in early project phases, consequently external events screening analysis needs to be updated during the project. Even in later project phases it might be necessary to base the analysis on expert judgment

Especially with regard to the evaluation for low probability events there is a further demand on the development and implementation of suitable methodologies for determining the frequency of occurrence of extreme events with very long period of return, including the combination of extreme events due to limited availability of historical data.

III.D. Plant response analysis

The purpose of the plant response analysis is to identify (Ref. 3):

- The design basis values or best estimate expert judgments of the tolerability of relevant safety functions to the loads associated by the external hazard respectively the combined external hazards
- The expected damage levels for each potential plant relevant external event together with the assisting expertise at plant.

The analysis shall generate the following general information on the plant response to the various external events:

1. First, it must be whether or not the external event has the potential to cause an initiating event to the plant, and which initiating event is most probable to occur (typically a transient or a need for a manual plant shutdown, either immediately or after some time).
2. Secondly, the event must have the potential to degrade one or more safety functions needed to cope with the induced initiating event.
   The kind of impact of the external event on the plant has to be determined. Available protective measures are also to be identified. These measures may especially include structural characteristics, characteristics of active or passive safety features, diversified features not affected by the event and protective or mitigating human interactions as defined in safety analysis and operating procedures.

The major types of interfaces of the plant with the site surroundings relevant for the analysis of plant response to external events can typically be defined via:

- Events affecting the structural integrity of buildings or structures (e.g. aircraft crash, explosions, external flooding or lightning)
- Events resulting in the loss of the main heat sink (e.g. low sea water level, transportation accidents, clogging by ice or organic material)
- Events affecting the plant via ventilation (e.g. ventilation blocking or toxic gases)
- Events resulting in the loss of external power supply (e.g. loss of external grid, severe wind, extreme snow loads)

IV. ANALYSIS OF THE SCREENED-IN EXTERNAL EVENTS

Single external hazards and combination of external hazards are analyzed in detail. This will initially require a more detailed analysis with regard to the protection principles and potential impact. Afterwards it can be concluded whether the event is a candidate event to be considered as

- A Design Extension Hazard (DEH) for which it shall be shown under best-estimate assumptions that fuel melt can be prevented or that the radiological consequences of fuel melt can at least be controlled
- An event for which a detailed event tree analysis is performed in the frame of the PSA.

The most common approach for the detailed analysis of external hazards in the frame of the PSA is to perform an event tree analysis and to calculate the resulting core damage / large release frequency from this event. Another approach is to assess safety margins in the design against potential impacts from the respective hazard. The most common example is the seismic margin assessment applied to identify margins in the seismic design of structures and components and to demonstrate robustness against loads from beyond design earthquakes. Margin assessments may support both PSA but also deterministic analysis of design extension hazards. A third approach would be the definition of deterministic load cases and subsequent explicit analysis (mechanical, thermo-hydraulical, etc.) showing that structures and systems can withstand the load case. This approach is applied if the detailed analysis of the PSA shows high risk contribution of the respective external event. In all approaches understanding of associated uncertainties, both epistemic and aleatory is required (Ref. 1). A qualitative uncertainty analysis should be performed discussing the potential influence of assumptions considered. In the frame of PSA the qualitative uncertainty analysis analyzing the epistemic uncertainties by modelling assumptions is complemented by a quantitative uncertainty analysis of the resulting core damage frequency / large release frequency.

Design changes or improvement might be necessary, if

- The robustness of the design cannot be demonstrated,
- The probabilistic target values for the core damage frequency / large release frequency are exceeded,
- The contribution of the hazard to the core damage frequency / large release frequency results in an unbalanced design.

V. CONCLUSIONS

The external event screening analysis is described as a method to evaluate the design against external hazards, especially beyond design external hazards. As a result of the screening analysis those external events are identified which need to be analyzed in detail as a Design Extension Hazard in the probabilistic safety analysis (PSA) or by margin assessments to demonstrate robustness of the design.

Effects from single and combined external events need to be analyzed. Specifically in light of the Fukushima accident the focus is on the identification of relevant combinations of external hazards for which the effect of the combination is more severe respectively has relevant additional effects compared to the single event. Some guidelines (see e.g., in (Ref. 3) and (Ref. 5)) do not allow a screening of certain hazards, especially earthquake, as these hazards are applicable to nearly all sites and specific regulations apply. In consequence these hazards are omitted during data collection and screening. For the identification of potential relevant event combinations this may establish drawbacks as vital information may not be available. It is therefore important to include the full spectrum of hazards in the process.

Correlation mechanisms with the potential for inducing hazards to the plant and effects on safety functions to control transients induced by the combined hazards need to be investigated in more detail. Especially if the screening criterion is based on the low frequency of the event combination, the potential of this combination for inducing a large early release has to be considered. In this case, the screening of the combination should be based on a comparison of the frequency of the combination with the large early release frequency (LERF) and not with the CDF. The effects of beyond design external events may aggravate the performance of possible accident management actions to cope with hazard induced unavailability of safety systems. Such actions are:

- Actions to fill-up water storages and fuel oil storages for beyond design grace times,
- Actions to start back-up systems,
- Actions to recover failed / damaged components.

In addition the Fukushima accident has shown that the analysis of beyond design external hazards must take into account severe damages on the plant infrastructure and the public infrastructure for the analysis in such a way that offsite support, e.g., delivery of diesel fuel oil or make-up water usually credited in safety analyses as available may not be possible or more difficult to be managed. The systematic approach of the external event screening method provides a mean to demonstrate the robustness of the plant to effects of design extension hazards in the frame of the plant response analysis respectively the detailed analysis of such external hazards and combination of external hazards which have been identified as relevant for the plant in the screening analysis. Site specific information and data on strength and frequency of beyond design external events is an important basic input to perform an external event screening analysis. This input is needed as early as possible for new build projects such that any potential site specific issue to be taken into account for the design of the plant against external events is identified in the early phase of the project. Experiences from ongoing projects have shown that it is not always possible to receive this information in adequate level of detail. As a consequence of this, the external hazard screening often involves engineering judgments. Caution has to be paid that the assumptions applied are properly documented to allow a later check, e.g., in the frame of periodic safety reviews if still valid under consideration of the developed state of the art.

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