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Development of a library based tool for screening external hazards and hazard combinations

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Abstract

For a meaningful and efficient probabilistic risk analysis of external hazards and event combinations involving such hazards those hazards with significant risk potential need to be identified and considered for detailed analyses. Such a site and plant specific screening approach for external and internal hazards based on a hazards library covering all types of hazards is under development at GRS. The paper provides insights on the approach and first examples of application.

1. Introduction

One of the major aspects of a site specific assessment to be carried out for a nuclear power plant (NPP) is a comprehensive consideration of the entire risks resulting from external hazards.

In a first step, all the hazards which may occur at the site being investigated need to be identified. This requires a compilation of potential hazards including possible combinations of hazards. Based on this compilation of generic hazards a site specific list of hazards to be addressed in the analysis is derived based on a screening process taking into account regulatory requirements as well as site and plant specific insights.

For probabilistic risk assessment (also called probabilistic safety assessment, PSA), in a second step, those hazards and hazard combinations to be considered for the specific site have to be classified with respect to the depth of the probabilistic analyses to be carried out. This classification covers three hazard categories: (i) hazards with a negligible contribution to the overall risk, (ii) hazards with a risk contribution low enough that a rough quantitative assessment is sufficient, and (iii) hazards which need in-depth probabilistic analysis.

Based on the Level 1 PSA model available for internal events, a systematic approach for in-depth probabilistic analyses of hazards and their combinations is provided. In this context, two lists of those structures, systems and components, which can be impaired in their required function resulting in a risk increase, are prepared: one containing the equipment Hazards Equipment List, *HEL*), the other one covering the dependencies to be considered for the corresponding hazard (Hazards Dependencies List, *HDL*).

In addition to the general approach for performing site specific PSA, an approach for modelling dependencies in the behaviour of NPP structures, systems and components (SSCs) according to failures caused by hazards has been developed. In addition, a generic dependency model has been built demonstrating how the dependencies identified can be modelled in the fault trees.

2. Library based tool for screening external hazards

For a complete risk assessment of external hazards, a three step approach as depicted in *Figure* 1 is needed. In a first step, the hazards´ screening needs to be performed.

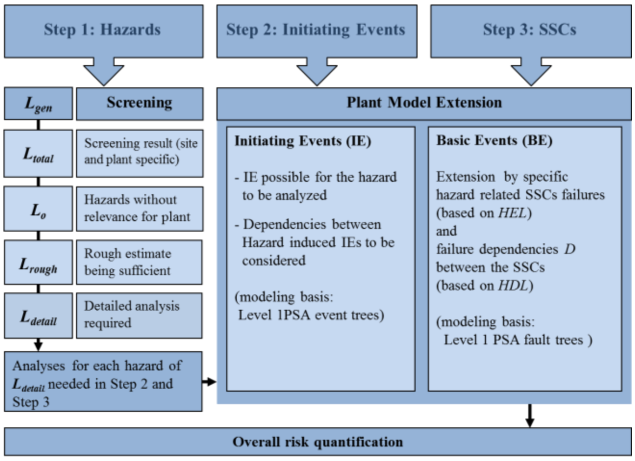

Figure 1. Hazards risk assessment approach by GRS

In a second step, the plant model has to be extended to consider all initiating events (IE) from those external hazards site and plant specifically to be addressed. In a third step, the list of basic events (BE) in the plant model needs to be extended by failures of those plant structures, systems and components (SSCs) related to those external hazards considered as well as the corresponding failure dependencies (cf. *Figure* 1).

Screening of external hazards requires in a first step to generate systematically and comprehensively a complete generic list of all potential hazards. To a large extent, this has already been done in the frame of the international project of the European Commission (EC) named ASAMPSA_E [1]. GRS has adapted and completed this approach based on a kind of library for the entire hazards, considering not only external but also internal hazards, which are needed particularly when generating hazards combinations to be taken into account in the analysis.

The general screening approach as developed by GRS (see also [3]), which covers a qualitative and quantitative part, is outlined in *Figure* 2.

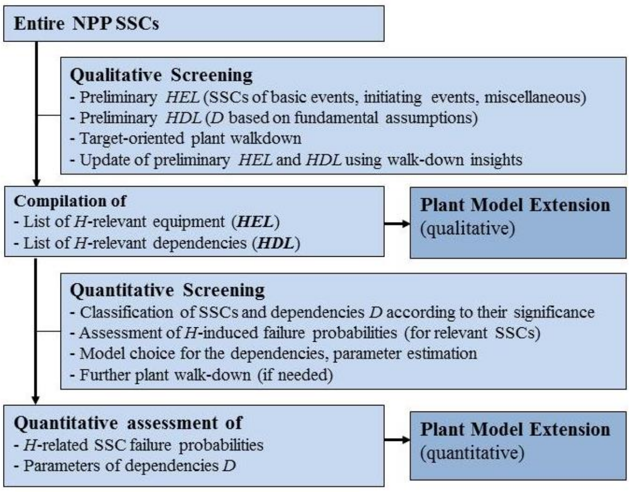

Figure 2. Screening steps for hazards and hazard combinations, from [3]

Based on the library tool, those external hazards are selected which have to be considered for analysis of the NPP site under investigation.

The library tool is again applied in order to select those hazard combinations which site and plant specifically need further analysis, e.g., for consideration of event combinations involving external hazards either as initial event with a consequential hazard occurring or as a consequence from another anticipated event, or occurring independently of another event at the same time.

In the following, the library based screening for hazards and hazard combinations is outlined.

2.1. Hazards library

Major input for the Hazards Library is a generic compilation of the entire potential hazards. For each hazard detailed information characterising the hazard itself as well as the potential consequences of the hazard impact, such as the deterioration of items important to safety, resulting initiating events, etc. have to be stored in the Hazards Library. Moreover, as far as available insights from the national as well as international operating experience regarding the respective hazard and/or hazard combination shall be also collected and considered in the Hazards Library. As a result, a list of the site and plant specific individual hazards as well as possible combinations of hazards is obtained, see *Figure 3*.

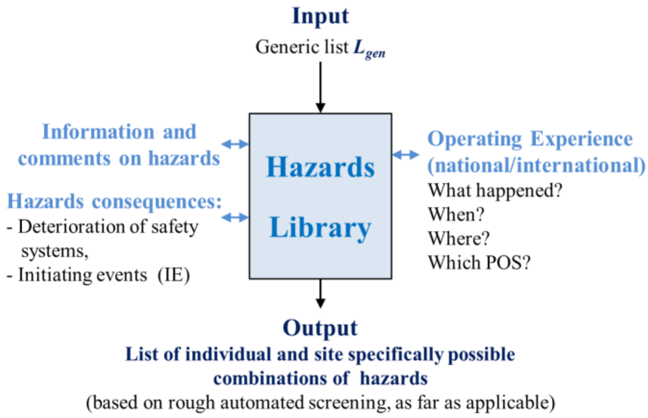

Figure 3. Overview of the Hazards Library tool

The Hazards Library contains in general the following classes of hazards:

I. External hazards
   1. Natural hazards
      - Seismic hazards (Class A)
      - Flooding and other hydrological hazards (Class B)
      - Meteorological hazards (Class C)
      - Extra-terrestrial hazards (Class D)
      - Biological hazards (Class E)

- Geological hazards (Class F)
- Natural fires (Class H)

2. Man-made hazards (Class Z)

II Internal hazards (Class I)

The Hazards Library consists of several tables containing information to be correlated generically as well as for the plant site to be investigated for selection of those hazards, for which a simplified or a more detailed in-depth analysis needs to be carried out.

The primary table for the entire individual hazards selection sorted by hazard classes contains the following information:

- Hazard ID;
- Nomenclature1 to n;
- Short title of the hazard;
- Detailed hazard title;
- Hazard characterization:
  - Duration (min, hours ,days, longer);
  - Protection possible (U: unpredictable; P: predictable, protection is possible before the event starts);
  - Event progression possible (R: progressing rapidly; G: progressing gradually, protection is possible during the event sequence);
- Detailed remarks;
- References concerning the hazard;
- Conjunction with operating experience;
- Conjunction with site parameters;
- etc.

Other information stored in tables is:

- Initiating events (IE) for different types of reactors and plant operating states (POS);
- List of potential types of damage for the entire SSCs;
- Compilation of site parameters relevant for the analysis, such as:
  - Type and number of nuclear installations at the site;
  - Site specific conditions with respect to the hazards;
  - etc.
- Compilation of events from hazards observed from the nuclear sites´ operating experience;
- Compilation of available Hazards PSA;
- Additional literature providing background information on the individual hazards.

The information contained in the Hazards Library can be used as basis for the screening. In this context, more detailed information regarding the screening of hydrological hazards developed by GRS and other ASMPSA_E institutions can be found in [1], [2], and [4].

2.2. Screening of individual external hazards

Before starting the plant specific screening, the site specific hazards screening has to be carried out. Site specific hazards screening as well as screening of scenarios to be analysed follow in principle the same screening approach. The screening approach as outlined in *Figure 2* consists of two screening steps based on the Hazards Library, a qualitative and a quantitative step.

In the first, qualitative screening step, a qualitative site specific selection of all hazards takes place. In the second, quantitative screening step, those hazards having remained after the qualitative screening undergo a quantitative screening by frequency based on screening criteria to be defined either on a national basis by regulatory requirements or by the analysts considering recent best practice from international activities.

The screening approach is then repeated for the selected hazards which have to be analysed for the site of the plant under investigation. Again the two screening steps are carried out.

For each of the hazards not screened out, two different lists have to be compiled:

(i) a hazards equipment list (*HEL*), $HEL = \{SSC_1, \ldots, SSC_n\}_H$, for each hazard not screened out, with the following characteristics:
   - For a given hazard *H* the corresponding *HEL* contains the entire SSCs being vulnerable to the impact of the hazard *H*.
   - Additionally, the failure or unavailability of such a SSC should contribute to the hazard induced risk.

(ii) a hazards dependencies list (*HDL*), $HDL = \{D_1, \ldots, D_m\}_H$, with $D_i = \{A_i, S_i, c_i\}$, characterized follows:
   - For a given hazard *H* the corresponding *HDL* contains all dependencies among the hazard induced failure behaviour of SSCs, which need to be considered.
   - Generally, a dependency *D* can be characterized as a triple of the set of dependent SSCs *S*, the common property of the elements of *S* (as reason for the hazard induced dependency) *A*, and a correlation factor *c* representing the strength of dependency.

First, a preliminary rough *HEL* is generated covering the basic events (BE) with their associated SSCs, the initiating events, and miscellaneous additional information, as well as a preliminary *HDL* with the dependencies *D* based on fundamental assumptions), and a target-oriented plant walk-down is performed. As a result of insights from the plant walk-down, the preliminary lists *HEL* and *HDL* are updated. The result of the qualitative screening is a compilation of the final hazards equipment list *HEL* and hazards dependencies list *HDL*. These lists can be used to extend the plant model qualitatively.

In the frame of the quantitative screening, the SSCs in the HEL and the dependencies *D* in the HDL are classified according to their significance for the analysis before an assessment of the hazard induced failure probabilities of the relevant SSCs can be performed. In this context, the model for characterizing the dependencies in the plant model has to be chosen and the corresponding parameters have to be estimated. If necessary, another plant walk-down will take place in order to confirm the screening results. The result of the second screening step is a quantitative assessment of the hazard related failure probabilities of the relevant SSCs and the parameters characterizing the dependencies *D.* These estimates are applied for extending the plant model quantitatively.

2.2. Screening of event combinations with external hazards

Since the number of individual external hazards does already exceed 100, the generation of a complete matrix of hazard combinations of correlated hazards or event chains of more than two correlated hazards would be too time consuming and not very easy to perform systematically. It has therefore been decided to start the screening of event combinations with external hazards after the site specific hazard screening for the individual external as well as internal hazards.

For the essentially lower number of individual hazards having remained after screening, for which in addition also the plant specific event scenario screening has been performed and the related information is already available, in a first step, again a qualitative screening of physically possible event combinations is carried out.

External hazards cannot occur as consequence of internal ones; this reduces the number of combinations already significantly. Moreover, various external hazards cannot occur as consequence of other external hazards, e.g., seismic as consequence of a hydrological event (e.g., heavy rainfall) but only at the same time. The frequency of such combinations, however, is very low and can be quantitatively screened out for many sites.

An example of a matrix showing combinations of Class B external hazards combinations is provided in *Figure 4*, the corresponding matrix of those combinations remaining for further analysis is shown in *Figure 5*.

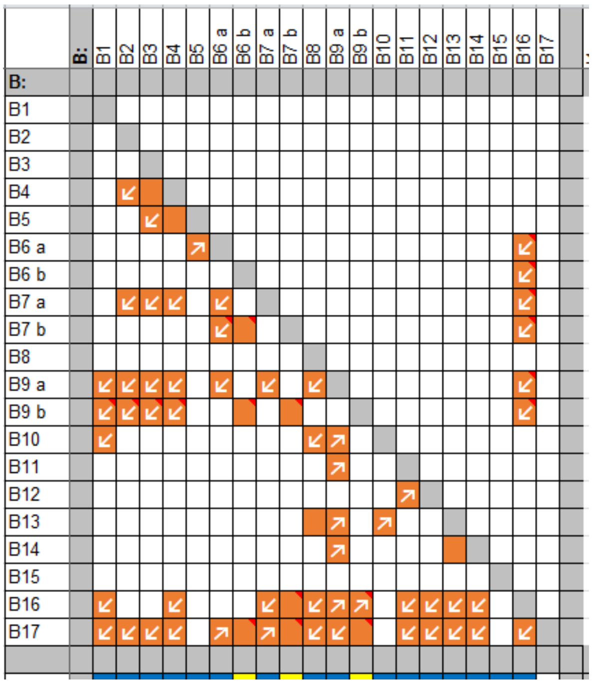

Figure 4. Excerpt of the combination matrix for exemplary combinations of Class B external hazards before screening, based on [1]

The number of event combinations remaining after systematic qualitative and quantitative screening is non-negligible but low enough for further analysis in the frame of PSA.

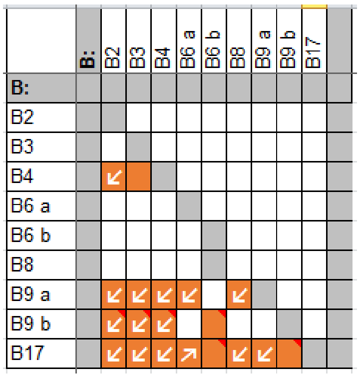

Figure 5. Excerpt of the reduced combination matrix for exemplary combinations of Class B external hazards

3. Site specific screening example

For a reference NPP site in Germany the hazard screening has been performed, e.g., for Class B flooding and hydrological hazards. Class B hazards cover the following individual hazards:

– B1: Tsunami;
– B2: Sudden flood by local extreme precipitation;
– B3: Flooding by melting snow;
– B4: Flooding by extreme precipitation outside the plant boundary;

- B5: Extreme groundwater increase;
- B6: High (B6a) or low (B6b) water level due to obstructions in the course of the river;
- B7: High (B7a) or low (B7b) water level by natural changes in the course of the river;
- B8: Flooding by high fresh water waves due to volcanism, landslide or snow slide;
- B9: High (B9a) or low (B9b) water level with wave formation due to failure of water control or retention systems (e.g., damns, dykes, etc.);
- B10: Seiche;
- B11: Tidal bore (running extremely river-up);
- B12: Tidal high water, spring tide;
- B13: Storm induced waves and monster waves;
- B14: Storm surge;
- B15: Corrosion resulting from contact with salt water;
- B16: Instability of coastal areas by erosion due to strong water flows or sedimentation;
- B17: Water flotsam (mud, debris, etc.).

The plant site to be investigated is a riverine site, therefore B1, B5, B7, and B10 to B16 could be qualitatively screened out. For the remaining Class B hazards the quantitative screening gave, based on the site specific information in the Hazards Library the result that only the hazard B2 "sudden flooding by local extreme precipitation" will remain for further in-depth probabilistic analysis to be carried out in the frame of PSA.

As a consequence, the screening of hazard combinations had to be site and plant specifically carried out for this hazard only. For the given site, the hazard B2 may occur in combination with the hazards B4, B9 and B17 (see list above). Moreover, sudden flooding by extreme precipitation (B2) could result in internal flooding, electrical faults with high energy arcing faults (HEAF), plant internal fires and explosions. The B2 induced HEAF may again induce fires and/or explosions as well as fire induced internal explosion or flooding.

The quantitative screening provided the following site and plant specific results: (i) Event chains of more than two hazards resulting from B2 as initial hazard can be quantitatively screened out for the reference plant. (ii) Combinations of sudden flooding by extreme precipitation (B2) with independently at the same time occurring other events or hazards can also be screened out by frequency.

For the remaining individual hazards and hazard combinations the qualitative and quantitative plant specific screening of event scenarios as in principle outlined in 2.2 is ongoing. The results gained within a research and development project funded by the German Federal Ministry for Economic Affairs and Energy (BMWi) will be publicly available in summer 2017.

4. Conclusions

For an effective and systematic probabilistic risk assessment of the entire external hazards and hazard combinations to be anticipated site and plant specifically, a suitable screening process covering a hazard screening, but also an event sequence screening is needed.

Based on insights from the international project ASAMPSA_E launched by the European Commission, GRS has developed an own screening approach based on a hazards library covering the manifold types of external as well as internal hazards and hazard combinations. The general approach is in final development stage and has already been successfully applied for flooding and other hydrological hazards. As soon as the general information required for the screening process has been implemented in the Hazards Library, the approach can be applied using site and plant specific information from a German nuclear reference site.

It will be easily possible to adapt the general approach to other sites and plant types as well as to modify quantitative screening criteria depending on the regulatory framework for the site under investigation.

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