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Risk analysis of external hydrological hazards with flooding potential for a German nuclear reference site

Keywords

flooding, hydrological hazards, hazard combinations, Probabilistic Safety Assessment (PSA), risk analysis

Abstract

Probabilistic Safety Analyses (PSA) are a supplementary analytical tool used worldwide more and more in order to quantitatively assess the effect of hazards on the overall result regarding the safety of industrial installations, in particular nuclear power plants. In that way PSA provides a reliable basis for decisions on the necessity and the benefits of safety improvements.
In the recent past, the existing methods and tools with respect to determining the site-specific risk of nuclear power plants have been comprehensively extended and further enhanced. The focus of extending the existing PSA methods was on external hydrological hazards with flooding potential. For systematically considering hydrological hazards within PSA a systematic approach has been developed.
The paper demonstrates the extended approach in the example of a nuclear power plant site with different flooding risks.

1. Introduction

One important aspect of a site specific assessment to be carried out for an industrial installation such as a nuclear power plant (NPP) is a systematic and comprehensive consideration of the entire risks resulting from external hazards.
Since the overall number of external hazards, natural as well as man-made ones, is quite large, the extension of the methodology for assessing hazards including combined hazards within a PSA has been stepwise applied for different classes of hazards. One highly important external hazards class is the so-called "flooding and other hydrological hazards (Hazards Class B)" (cf. [1], [2], and [3]).
The PSA model extension follows a systematic three-step approach outlined in the *Figure 1*.

- Step 1:
  In a first step a hazards screening has to be carried out. As mentioned in [2] and [3], a stepwise systematic and as far as reasonably practical screening of individual hazards and hazard combinations has been developed and applied. This approach covers a qualitative screening step and a quantitative one.

For those hazards and hazard combinations remaining after screening, the PSA plant model for the plant site under investigation has to be extended. This again is a stepwise process.

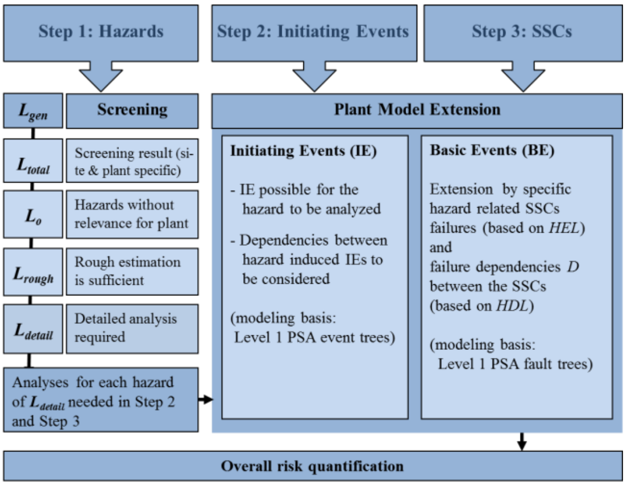

Figure 1. Overview of the risk assessment approach for hazards developed by GRS, from [3]

- Step 2:
  This extension includes an analysis for considering plant and site specifically all initiating events (IEs) resulting from these external and internal hazards including hazard combinations. Accordingly, the potential hazards induced initiating events need to be identified and screened out with regard to their significance. It is essential to investigate if the IEs identified need to be modeled as common cause initiators (CCI) and to what extent the hazard induced IEs do occur simultaneously or nearly simultaneously. Such initiators shall not be screened out, but have to be included in the extended PSA model.
  After identification of the potential IEs induced by the hazards, a screening of these IEs with regard to their safety significance for the plant under investigation has to be conducted under consideration if and in how far the hazard induced IEs remaining after that screening occur quasi simultaneously and need to be considered in the PSA model as common cause initiating events.
- Step 3:
  The third analytical step covers the extension of the PSA plant model by extending the list of basic events (BE) by the potential unavailability of SSCs depending on the hazard impact for each individual hazard and hazard combination remaining after screening in order to identify those items which may functionally fail – the so-called hazard equipment lists *HEL* - and the corresponding failure dependencies - the so-called hazards dependency lists *HDL*, both as defined in detail in [1]. In this context, it is important to mention that, for limiting the analytical effort, these lists have to be reduced according to their risk significance by qualitative arguments and quantitative criteria.

A schematic overview of the approach for the plant model extension by hazards is given in the following *Figure 2*.

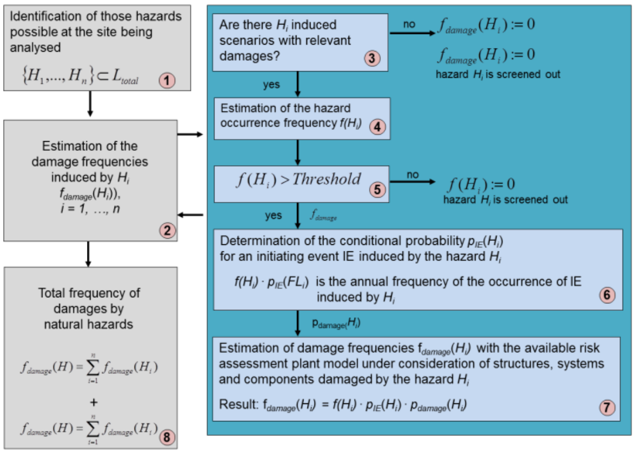

Figure 2. Extension of the PSA plant model for hazards, adapted from [1]

2. Screening of external hazards with flooding potential

For external hazards with flooding potential, from all hazard classes the hydrological ones with flooding potential have to be identified.
From the Class B hazards in the following *Table 1*, those hydrological hazards with flooding potential have been identified in order to perform the site and plant specific screening for the reference plant. These are the individual hazards with flooding potential B1 to B6a, B7a, B8, B9a, B10 to B14, and B16.

Table 1. Class B - flooding and other hydrological hazards, from [4]

Hazard	Type of Individual Hydrological Hazard
B1	Tsunami
B2	Flash flood by local extreme precipitation
B3	Flooding by melting snow
B4	Flooding by extreme precipitation outside the plant boundary
B5	Extreme groundwater increase
B6a	High water level due to obstructions in the course of the river
B6b	Low water level due to obstructions in the course of the river

Hazard	Type of Individual Hydrological Hazard
B7a	High water level by natural changes in the course of the river
B7b	Low water level by natural changes in the course of the river
B8	Flooding by high fresh water waves due to volcanism, land or snow slide
B9a	High water level with wave formation due to failure of water control or retention systems (e.g., dams, dykes, etc.)
B9b	Low water level with wave formation due to failure of water control or retention systems (e.g., dams, 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 (of rivers, lakes, oceans) by erosion due to strong water flows or sedimentation
B17	Water flotsam (mud, debris, etc.)

2.1. Individual flooding hazards screening

For the reference plant site, a screening of individual hazards with flooding potential - B1 to B6a, B7a, B8, B9a, B10 to B14, and B16 – has been carried out.

As the reference site is a riverine site far away from any coastal area, individual hazards which can only occur at maritime locations and potential tidal influence, such as the hazards B1, B10 to B14 and B16 have been directly screened out qualitatively. In addition, B5 (groundwater increase) has also been screened out qualitatively due to results from the siting hazard analysis. B17 (debris according to flooding) does not have itself a potential for flooding but may increase the effects of flooding. This could be screened out as individual hazard as well.

For those individual hazards remaining after the qualitative screening step, a quantitative screening had to be carried out, requiring to conservatively estimate the ranges of their occurrence frequencies and comparing them to cut-off frequency values corresponding to given screening criteria.

As a result for the reference plant, from the remaining external hazards with flooding potential, B2, B3, B4, B6a, B8, and B9a, only B2 (flash flood), B3 (flooding from melting snow) and B4 (flooding from extreme precipitation) remained after quantitative screening according to the German screening criteria and the plant design against flooding hazards (details see [2]).

2.2. Flooding hazards combinations screening

For a state-of-the-art comprehensive Hazards PSA, hazard combinations have to be included in the analyses. This requires a qualitative and quantitative screening of the different types of hazard combinations which have to be assumed following the same approach as for individual hazards.

In order to reduce the number of combinations to be investigated, the identification of hazard combinations for the plant site under investigation start from those individual hazards, which have not been screened out qualitatively.

Three categories of hazard combinations have to distinguished:

- Category 1: combinations of consequential hazards;
- Category 2: combinations of correlated (by a common cause) hazards;
- Category 3: combinations of unrelated hazards (occurring however simultaneously).

In this context, it is important to make an assumption, how related (consequential or correlated) hazards are treated to avoid double counting. GRS has chosen to treat combinations of related hazards as part of the analyses for the initial hazards (e.g., a seismically induced fire in the Seismic PSA and not in the Fire PSA). In addition, higher order event chains of more than one consequential hazard (e.g. seismically induced flooding with consequential explosion) should only be built and screened, if the lower order combinations have not been screened out quantitatively.

It is also important to keep in mind that external hazards cannot occur as consequence of internal ones and that various external hazards cannot occur as consequence of other external hazards.

These general assumptions have reduced the number of combinations of hydrological hazards with other hazards to undergo the screening process for the reference plant site significantly.

Combinations of the six individual hazards B2 to B4, B6a, B8 and B9 having remained after qualitative screening, with other hazards resulted in the following combinations of the three categories not screened out qualitatively:

- *Category 1*:
  - B3 or B4, the external flooding hazards of longer durations can induce I2 (“internal flooding”) hazards.

    - B2, B3, B4, B8, or B9a can in principle result in B17 ("water flotsam") at the reference plant site.
- *Category 2*:
    - B2, B3 and B4 can occur as correlated events from the same root cause or together with the meteorological hazard C1 ("precipitation"), correlated for example by extreme weather conditions. In addition, B2 ("flash flood") or B4 ("extreme precipitation") can occur correlated to F1 ("subaerial slope instability").
- *Category 3*:
    - An independent but simultaneous occurrence of one of the flooding hazards B2, B3, B4, B6a, B8, or B9 together with any other hazard without any common cause is generally very unlikely. Investigations therefore are only carried out if at least one of the combined hazards has a longer duration. For the reference plant site this has resulted in a longer list of combinations which have not been qualitatively screened out.

In the frame of the quantitative screening applying the same screening criteria as for individual hazards, a majority of hazard combinations has been screened out by frequency for the reference plant site.
The following hazard combinations remained for detailed analysis after quantitative screening:
While all category 1 and 2 combinations of related hazards (consequential ones as well as correlated ones) could be screened out, the following two category 3 combinations have remained: flash flood B2 occurring independently at the same time as the longer duration flooding hazards from snow B3 or other extreme precipitation B4.
These combinations have been addressed in the detailed analyses.

3. Detailed PSA analyses for hazards with flooding potential at a reference plant site

For the individual hazards B2, B3 and B4 and the category 3 hazard combinations B2+B3 and B2+B4, the PSA plant model of the reference plant has been extended and detailed analyses have been carried out. Since the reference plant model already covered B3 and B4, no extensions and changes in the plant model were necessary for those hazards.
Flash flood had so far not yet been investigated. Therefore, a site-specific hazard analysis with regard to the risk of flash floods has been performed first.

3.1. Hazard occurrence frequency estimations

For the flooding hazards B3 and B4 occurrence frequencies had been estimated and updated in the frame of the Periodic Safety Review (PSR) of the reference plant. These have been reviewed with respect to completeness and plausibility and have been used for further analyses.
For the flash flood hazard B2 (and the combinations of B2 with B3 or B4) occurrence frequencies have been estimated in detail based on the corresponding operating experience. The analysis of the international operating experience from nuclear power plants with flash floods revealed the result that such events had neither been reported from the reference plant site within 28 reactor years (ry) of commercial operation, nor from other German nuclear plant sites (representing approx. 730 ry) nor in the international event databases from IAEA (e.g. INES and IRS, representing more than 17.000 ry) with regard to the risk of flash flood events.
A mathematical, so-called super-population approach (details see [5]) has been applied using a two-stage Bayesian approach for generating generic distributions based on observations from the operating experience from the plant being analysed. The distribution describes the variability of the observed parameter (e.g., the occurrence frequency of B2) over the whole operating experience as a-priori state of knowledge and is coupled with the plant specific observations.
As a result a mean value of E-03/ry (with a standard deviation of 1.9 E-03/ry) has been estimated for the reference plant.
This result has been further supported by observations from flash floods in the near past in an area in Germany with quite similar geological and structural conditions. For these flash floods the water levels measured have been categorized into three groups and the corresponding occurrence frequencies calculated. The result is as follows:
- Group 1, water level < 1.0 m (two thirds of the flooding events): f_{mean} = 6.7 E-04/ry;
- Group 2, 1.0 m ≤ water level < 1.5 m (one third of the flooding events): f_{mean} = 3.9 E-04/ry;
- Group 3, 1.5 m ≤ water level (none of the flooding events): f_{mean} = 3.2 E-05/ry.

3.2. Reference plant protection concept against external flooding hazards

Longer Duration Floodings B3 or B4

For riverine sites, the flooding protection concept preferably considers scenarios resulting from the river water regime. The reference site is designed against a flooding of a 10,000 years return period with an exceedance probability of 1 E-05/a resulting in a flood protection level of a given level (called NPP level 0) over ASL (*a*bove *s*ea *le*vel). For the design basis flooding of 1.66 m over the NPP 0 resulting in a safety margin of about 0.84 m. Dams, dykes or other structural protection means are not present according to the design. The protection is provided by passive means through the given height of the plant and openings in the buildings. According to the operating manual, the temporary placing of flood partitions at openings to buildings is foreseen as active means to limit the water ingress. For the flooding hazards B3 and B4 a long pre-warning period of more than 30 h is available being sufficient for temporary flood protection measures and to trip the reactor, since the water level increase is quite slow. Moreover, a majority of buildings structures, such as reactor building (RB), auxiliary building (AB), electrical building (EB), emergency diesel building (EDB), etc., are either protected by structural means or by temporary measures to be taken. Turbine building (TB) and switching buildings (SB) are not protected against the design basis flooding (DBF). The required function of all items needed to meet the nuclear safety goals as well as the function of the auxiliary and the backup transformers are protected against the DBF.

Permanent flooding provisions are present for various buildings, pipework und channels. In case of a flooding alarm, only the entries of two high voltage switching buildings (SBs) and the EDB, the AB and the nuclear waste storage building (NWSB) need to be protected by temporary flood partitions, which either are already permanently installed and have only to be leak-tight closed or have to be mounted. In case of some soil movement by flooding the coverage load of channels and pipework has to be kept constant, e.g. by sandbags, in order to avoid water ingress. The temporary measures follow clear procedures in the plant operating manual. The closure of doors, water locks and flood partitions are typically performed by the well-trained on-site fire brigade. Minimal amounts of water intruded can be diverted by pumps being present.

Flash Flood B2

Different flash flood events that occurred in the more recent past have indicated that more likely local precipitations may result in endangering the plant safety in the future. Extreme precipitation events have occurred in Germany for example in Miltzow in 1968 with 200 $l/(m^2h)$ and in Muenster in 2014 with 292 l/m^2 within approx. 7 h. Such an event with about 200 $l/(m^2h)$ precipitation can be no longer be excluded in various parts of Germany including the region of the reference site.

In case of extreme local precipitation the surroundings are also affected, therefore water flowing to the plant site due to the topographic conditions needs also to be taken into account. For the reference site, this is in principle possible via a smaller waterway adjacent to the plant site with a non-negligible slope in the direction of the plant. The basin area of the waterway has been estimated to be approx. 13.5 km^2. A very rough pessimistic estimate based on only few available data results in water ingress of approx. 750 m^3/s under the assumption of about 70 – 90 % of the water reaching the plant area. Under the pessimistic assumptions that nearly no water is drained off the plant area, that the entire roof drainages release water on the plant ground, and that the plant area free of buildings represents about half of the total site, local water levels of 0.2 m after 15 min up to 0.8 m within 1 h could not be excluded in case of a flash flood resulting from a precipitation as in Miltzow. However, the data base available is extremely limited; therefore the uncertainties of this estimate are very high. For an as much as possible realistic probabilistic analysis the data base needs to be extended under consideration of site specific topographic data. The pessimistic rough estimation has however been used for model validation with the following results:

In case of such a B2 hazard the plant area will be flooded with a water level higher than the designed level of the plant. The flooding will occur within a much shorter time period than for B3 or B4 flooding hazards. The TB not protected against flooding will be flooded resulting in the failure of the main cooling water supply and the main condensate system with a consequential unavailability of the main heat sink. A simultaneous failure of main cooling water supply and main heat sink can result from the loss of the cooling of the main feedwater pumps. In case of such transients, the reactor protection criteria lead to a turbine trip and a reactor scram. Further analyses provided the result that a failure of the main feedwater supply (T4) can be analysed as bounding scenario.

The time period available for taking temporary flooding protection measures according to the plant operating manual is much shorter than for B3 or B4 because of the shorter pre-warning period.

Combinations of B2 with B3 or B4

For the simultaneous occurrence of a flash flood B2 with a longer duration flooding hazard B3 or B4, which cannot be excluded, it has to be checked if such a combination can lead to a water level on the site reaching or exceeding the protection level for a design basis flooding. The pre-warning period for such a scenario is much shorter than for the individual hazards B3 or B4 requiring that temporary protection measures will be taken within a very short time period. Such scenarios are covered by B2.

The reference plant is protected against design basis flooding events B3 and B4. For flooding events exceeding the corresponding water level, a pre-warning period of 30 h corresponding to a water level increase of 0.5 m during this period can be conservatively assumed. During this time period, temporary measures can be successfully taken.

In case of flash flood hazards B2 the time for pre-warning is much shorter. Local extreme precipitation events can be only predicted a few hours in advance with high uncertainties. Corresponding severe weather warnings for the region (e.g., more than 40 l/m^2 within 1 h or more than 60 l/m^2 within 6 h) by the DWD (German: Deutscher Wetterdienst, for German Weather Service) are available at the reference site and noticed. However, the time for measures to be taken is very limited.

For further analyses it is assumed that temporary measures have to be taken before the heavy rain starts. While some measures can be taken within minutes, others need definitely more than 30 min. Therefore the time available from the DWD warning to the start of precipitation is highly important. This period is assumed to be approx. 2 h.

The resulting pessimistically estimated maximum water level may locally reach a little more than 1.5 m within 60 min. In case that a water level of 1 m will be exceeded the temporary flood protection measures have to be assumed to be failed in the PSA.

In case of flash floods, the original flow direction may change. This, together with the waterway location, may result in the following two alternative flow directions:

- **Alternative A:** The above mentioned buildings (SBs and EDB) are affected due to debris and blockages on the plant area. In addition, the EB can be affected if the water level exceeds 1.5 m.
- **Alternative B:** Only the AB is affected. For water levels exceeding 1.5 m the auxiliary cooling water buildings (ACWB) and the emergency cooling water pump station (ECWPS) can be affected.

Without detailed knowledge on the plant specific water levels and local flow conditions the occurrence probability of both alternatives is assumed to be 50 % of the total one for B2.

In case of an event combination of B2 with B3 or B4, a linear water increase of about 2 cm/h as for B3 or B4 as individual hazards can be assumed as a first rough estimate. The following scenarios of such combinations have to be considered:

- The flash flood starts before the river flooding has reached the first water level (0.5 m below NPP level 0 at the intake building. This scenario is covered by B2 scenarios.
- The flash flood starts after the river flooding has reached the level 0.5 m below NPP level 0 at the intake building, but before the river starts flooding the site (< 0.00 m (NPP level 0)). This scenario is equivalent to B2, but the criteria for taking temporary measures are already given by B3 or B4. Therefore, the time available for taking measures against B2 is longer, and B2 represents a bounding scenario for this one as well.

The flash flood starts after the river has started to flood the site ($\geq$ 0.00 m (NPP level 0)). The water level for such B2+B3 or B2+B4 scenarios is higher than for B2 only. The for B3 roughly estimated water level of 0.84 m will increase to 0.96 m and will not exceed the 1 m level provided by the temporary protection means. Even if for B2 a water level of more than 1 m is postulated, the increased level from the combinations will remain below 1.5 m (protection level for the ACWB and ECWPS) or 1.53 m respectively (protection level for the EB). Due to the longer pre-warning period of more than 30 h, this combination scenario is less severe than B2.

3.3. Potential flooding areas and hazard equipment lists

For the hydrological hazards with flooding potential the above mentioned buildings need to be analysed with respect to potential flooding areas (details see [1] and [3]). For the different flooding scenarios, in each building potential flooding areas have been identified and the corresponding dependency lists *HDL* (see [2] and [3]) have been provided. The following flooding areas have been identified in those buildings flooded at the same time (depending on Alternative A or B and on the water level):

- TB and supply systems building (SSB) at water levels < 1.0 m and flood partitions for other buildings set and/or closed;
- TB, SSB and AB at water levels < 1.0 m and flood partitions not set for AB but closed for EDB;
- TB, SSB, AB and EDB at water levels < 1.0 m and flood partitions not set and/or closed for AB and EDB;
- TB, SSB, SBs and EDB at water levels between 1.0 m and 1.5 m and flash flood flow direction to one of the SBs;
- TB, SSB and AB at water levels between 1.0 m and 1.5 m and flash flood flow direction AB;
- TB, SSB, SBs, EDB and AB at water levels between 1.5 m and 3.1 m and flash flood flow direction to one of the SBs;
- TB, SSB, AB, SBs, and ACWP and ECWPS at water levels between 1.5 m and 3.1 m and flash flood flow direction to the AB.

Model simplifications concern the number of building levels to be considered.

3.4. Model extension for external flooding hazards

Basis for the extension of the Level 1 PSA plant model for the reference plant was the event and fault tree modelling of transients during power operation of the plant in the existing PSA plant model. In order to consider events from external hazards with flooding potential in total eleven analytical cases have been analysed.
For items important to safety in flooded buildings a flooding induced failure is generally postulated, if the water level reaches their location in the building.

Event Tree Extensions

The event sequences were extended for the flooding scenarios resulting in five analytical cases for B2:

- Case 1: At a postulated water level of 1.0 m water is intruded in the TB, the SSB, the AB, and – if the flood partitions are not closed in time - in the EDB. Two alternatives have to be distinguished:
  - 1a: due to meteorological warnings approx. 2 h before, the partitions for the EDB have been closed. The required manual actions have been probabilistically assessed.
  - 1b: The possibility of closing the partitions has not been considered.

  Moreover, it is assumed that the required function of cables and pipework is not affected. SSB flooding causes failures of several pumps with the plant being manually tripped (transient T7_FL). TB flooding causes a loss of main feedwater and main heat sink (T4_FL). This transient is the basis for case 1.
- Case 2: In addition to case 1, at a water level between 1.0 m and 1.5 m, in one of the SBs some safety related circuit breakers are flooded. Therefore, a loss of offsite power (LOOP) is pessimistically postulated (T1_FL).
- Case 3: In addition to case 1, at a water level between 1.0 m and 1.5 m, the AB (without items important to safety) is flooded. Like in case 1, the TB flooding causes loss of main feedwater and main heat sink (T4_FL).
- Case 4: In addition to case 2, at a water level between 1.5 m and 3.1 m the EB is flooded resulting in the failure of a variety of components finally resulting in case of LOOP (T1_FL).
- Case 5: In addition to case 3, at a water level between 1.5 m and 3.1 m, ECWPB, ACWB and the cooling tower are flooded resulting finally in T4_FL.

In the event sequence analyses the corresponding accident measures modelled in the exiting PSA for the reference plant have been considered. These measures require manual actions to be carried out in the EFB, which needs to be accessible. This is ensured by a water-tight connection from the reactor building.

Fault Tree Extensions

For the extended fault tree analyses for the analytical cases 1a, 1b, 2 to 5 the fault trees of the existing PSA for the reference plant are used for the transients T1 and T4. The extensions cover failures of components considered in the event trees, which are located in buildings assumed to be flooded. Depending on the analytical case, the probabilities of the corresponding basic events are assessed to be P = 1. For assigning components to their locations the Level 1 PSA plant model (the RiskSpectrum© model of the reference plant PSA) and the PSA data base of the plant are applied. According to that process, the rooms or plant areas have been considered, which contain components including their corresponding cables relevant for PSA (represented by basic events).

3.5. Results of the flooding PSA

Flash flood scenarios with flooding the site with water levels of 1 m (case 1a) result in a loss of main feedwater and main heat sink (transient T4_FL). The unavailability of the emergency diesels for feedwater and of the emergency feedwater system by such type of common cause failure (CCF) dominate the result for frequencies of hazard states estimated to be in the order of E-07/ry. In addition, the failure probability of closing the flood partitions of the EDB and the failure probabilities of the manual actions for accident management measures provide the highest contributions to core damage, which is nevertheless very low with values in the order of E-08/ry.
Case 1b with the partitions of the EDB not closed provides nearly the same result for hazard states and a slightly higher core damage frequency (CDF) than for case 1a.
The results for case 2 with flooding levels between 1.0 m and 1.5 m are very close to those for case 1a, while for case 3 again the transient T4_FL is initiated. The resulting CDF is however nearly one order of magnitude lower than for cases 1 and 2.
Case 4 with flooding levels between 1.5 m and 3.1 m cause again transients T1_FL resulting in lower damage state frequencies but due to the unavailability of some measures again CDF in the order of E-08/ry. The dominating factor in this scenario is the unavailability of some manual actions.
The results for the less frequent, but worse case 5 scenario provide significantly lower hazard and core damage frequencies dominated by the unavailability of emergency diesels and other components of the emergency feedwater system as well as those manual

actions to be taken which are no longer successful in this case.

Normal riverine flooding hazards B3 and B4 are already covered in the licensee´s PSA for the reference plant. A bounding assumption there is that the TB flooding results in a LOOP. The PSA plant model did not have to be modified. This case 6 scenario provided a CDF in the order of E-09/ry.

For combinations of independently at the same time occurring riverine floodingevents B3 or B4 and flash flood hazards B2, which cannot be totally excluded to occur, the pre-warning period for B3 and B4 is in minimum 30 h and for B2 only 2 h. If the river level reaches a critical threshold, the reactor needs to be tripped and brought in a state “cold stand-by”. In this case, the flash flood does affect only the core cooling after the trip. If the flash flood occurs before such a critical river water level is reached, B2 scenarios are bounding because of the much shorter pre-warning periods for flash floods than for the combinations but the same consequences for the plant.

4. Conclusions and outlook

For an as far as possible systematic but also comprehensive consideration of the entire possible external hazards and hazard combinations to be anticipated site and plant specifically for a given plant site, an extension of PSA methods was and is necessary. GRS has therefore developed an approach starting with a suitable qualitative as well as quantitative hazards screening covering individual hazards as well as hazards combinations.

As a second step of the approach, which has been validated for hydrological hazards with flooding potential, the Level 1 PSA plant model for estimating frequencies of core or fuel damage by such hazards has been extended, identifying potential flooding areas in the plant buildings and generating hazard equipment lists (*HEL*) for equipment sensitive to flooding hazards and the corresponding hazard dependencies lists (*HDL*) for flooding hazards.

Based on this step, the event and fault trees have been systematically extended for those hazards and hazard combinations remaining after screening for the reference plant and implemented in the PSA plant model. In a final step, plant frequencies of hazard and damage states have been calculated for the plant under investigation.

The approach for the PSA extensions is being adapted for other external and internal hazards including hazard combinations and tested for a multi-unit, multi-source nuclear site.

Moreover, by means of some tools for a systematic, at least semi-automatic screening under development, parts of the extension can be simplified saving time and resources and reducing failure sources in the approach. In the near future, it will be possible to adapt the general approach tested for one reference plant site to other sites and plant types, not only in Germany following German nuclear safety goals and assessment criteria, but also from other countries and industries.

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