
GENERIC RESULTS AND CONCLUSIONS OF RE-EVALUATING THE FLOODING PROTECTION IN FRENCH AND GERMAN NUCLEAR POWER PLANTS

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Abstract: Although the event which occurred at the Blayais site on December 27, 1999 did not lead to a dangerous situation for the local population or the environment, it clearly demonstrated the possible occurrence of modes of degradation of the safety level affecting all the units at a site. As a result, a number of projects were established by the French and German operators that were designed to extract useful lessons concerning the flooding risks at the Blayais site, as well as to upgrade all sites equipped with pressurized water reactors, both in France and Germany.

This report presents, on the basis of the circumstances observed at the Blayais site during the course of the flood event of December 27, 1999 (which was the subject of a presentation by IPSN at the Eurosafe 2000 Conference), an evaluation of the initiatives aimed at improving the safety of both the French and the German units from an external flooding risk perspective.

The safety approaches used in both countries have not been compared.

1. INTRODUCTION

The flooding event that occurred at the Blayais site, though it did not lead to a dangerous situation for the local population or the environment, clearly demonstrated the possible occurrence of modes of degradation of the safety level affecting all the units at a site. As a result, a number of projects were established by the French and German operators that were designed to extract useful lessons concerning the flooding risks at the Blayais site, as well as to upgrade all sites equipped with pressurized water reactors, both in France and Germany.

This report presents, on the basis of the circumstances observed at the Blayais site during the course of the flood event of December 27, 1999 (which was the subject of a presentation by IPSN at the Eurosafe 2000 Conference), an evaluation of the initiatives aimed at improving the safety of both the French and German units from an external flooding risk perspective.

2. DESCRIPTION OF THE FLOODING AT THE BLAYAIS SITE

2.1. Initial state of the Blayais NPP units

Prior to the changes that occurred during the night of December 27, 1999, the status of the units was as follows:

- Units 1, 2, and 4: 100% full power
- Unit 3: cooling system shut down following refueling.

2.2. Events

2.2.1. Partial loss of external power supply

According to data collected by the operator of unit 4, beginning at 7:30 pm on December 27 1999, the site suffered the loss of auxiliary 225 kV power supplies over the four units at the site, as well as a loss of the 400 kV power grid at units 2 and 4. The load shedding design that allows the units to self-supply with electrical power after disconnection from the grid failed, and this led to an automatic shut-down of these two units. As a result of the loss of these external power sources, the diesel generators associated with these two units were called upon and carried out their function while waiting for the return of the 400 kV power grid. The return of this source occurred around 10:20 pm. The 400 kV line which supplied units 1 and 3 remained available during the course of the event.

2.2.2. Flooding history

During the night from December 27 to 28, 1999, a flood crest traveling up the Gironde and caused by the confluence of the rising tide with exceptionally strong winds resulted in the partial submergence of the Blayais site. According to data obtained from the site, this flood probably started on December 27 around 7:30 pm, i.e. two hours before the tidal peak (tidal coefficient of 77).

At 10:00 pm, a high water alarm for the Gironde, received at the Richard observation station, was transmitted to unit 4. This alarm triggered the activation of operating procedure "I CRF". It is noteworthy that the information concerning the high level of the Gironde was not transmitted to units 1, 2, and 3, as is mandated by the corresponding alarm manual. Moreover, the operating procedure I CRF of the Blayais site, the document used by the operators in the control room, does not mention the necessity of setting in motion the Level 2 internal emergency plan (PUI), while the document describing the internal emergency plan makes this procedure a necessary condition for the triggering of the Level 2 PUI.

The water influx submerged the platform, and the inflows were noted along the north-west side of the dike. With the passage of the water, the upper section of the armor-stone protection was eroded away on the side facing the Gironde. The water elevation at the site reached approximately 30 cm in the north-west corner of the site.

Only units 1 and 2 were seriously impacted.

The water tended to flow preferentially within the main gallery of the site through the handling ports in the plates at the top of the gallery, as well as through the spaces left open at the level of the deformed sheet metal. This main site gallery, located outside the buildings, almost completely encircles them. These water influxes are also characterized by the presence, at the entry ports, of sheets of insulation material derived from the facades of

the administration building damaged during the storm. The general site gallery comprised the critical vector for the flooding of the rooms in units 1, 2, 3, and 4.

The flow rate that reached this gallery under the influence of a 30 cm water elevation could be estimated at 40,000 m³/h. This value is corroborated by a calculation of the amount of water pumped from the rooms (approximately 90,000 m³ pumped out from 27/12/99 to 1/1/00) and by the fact that the presence of water at the site was confirmed for approximately 2 hours.

Among the areas flooded in units 1 and 2 were:

- the rooms containing the essential service water pumps. In unit 1, the essential service water pumps in track A were lost because their motors were flooded;
- the technical galleries, particularly those running near the fuel building and linking the pumping station to the platform;
- several rooms containing feeder equipment. The presence of water in these areas also resulted indirectly in the loss of use of certain distribution panels;
- the floor of the fuel building of units 1 and 2 containing the compartments for the two low-head safety injection pumps and the containment spray pumps. The pumps were deemed by the operator to be totally unavailable. The systems to which these pumps belonged are the back-up systems of the installation which are intended for use particularly in loss-of-coolant accidents.

3. DEVELOPMENTS CONCERNING THE SITUATION FOR FRENCH NPP

3.1. Generic lessons

In the light of the observations carried out during the flooding of the Blayais site, a number of lessons might be drawn relating to all the sites. IPSN asked that these lessons be incorporated within the program of actions established by Electricité de France.

Furthermore, IPSN has studied, for all the sites in the French nuclear system having the same type of reactors as those at Blayais, all the data used for shoring their platforms, with regard primarily to the application of the fundamental safety regulation (RFS 1.2.e). These data relate particularly to the tide levels involved, the influence of natural phenomena taken into account, the maximum flood-tide levels, the supplementary margins to be retained.

This study was based primarily on:

- the elements which appear in the latest versions of the safety reports for each site,
- studies underway at certain sites, particularly the Fessenheim site, with regard to their review of safety issues,
- lessons which may be learned from the flooding circumstances at the BLAYAIS site.

According to the fundamental safety regulation (RFS 1.2.e) applicable to the protection of nuclear power plant sites from external flooding risks, this protection is ensured mainly by:

1. The shoring of the platform supporting the buildings which shelter safety-related equipment at a level at least equal to that of the maximum flood level, plus a margin of safety (the corresponding level is referred to as the maximum design flood level).
2. The closure of the potential pathways for water ingress into the chambers sheltering materials related to the maintenance of the installation in a safe condition located below the level of the platform shoring.

With regard to retroactivity, in the case of those sites commissioned prior to the coming into effect of RFS 1.2.e on April 12, 1984, this regulation stipulates that those sites not meeting the first criterion must in any event conform to the second criterion above and that complementary measures must be proposed to ensure a level of protection equal to that required by RFS 1.2.e. Furthermore, certain sites are in specific locations that require the consideration of flooding risks because they are near a canal whose water level is above that of the platform elevation.

The study carried out by IPSN into external flooding risk for the sites where pressurized water reactors are installed consisted of the following:

- Firstly, classification of the sites according to their formal classification into the possible categories as inferred from application of RFS 1.2.e

- Secondly, study of the elements associated with each site to identify pertinent questions that may arise within the context of a review of the measures instituted for the prevention of flooding risks or for the limitation of the consequences of a flooding event. This study leads to the determination of themes proper to each site which merit further investigations for ensuring an effective protection of the installations insofar as risks of external flooding are concerned. The themes identified are as follows:

- for sites whose protection is not ensured through the platform design, but by the use of other measures such as diking, review of the geometry and the structural resistance of such dikes;
- in the case of those sites where protection is not ensured by the platform shoring, but by other measures such as the triggering, in cases of emergency, of specific protective functions mentioned in the manual of procedures, H5 (activated by a flood alert system), a complementary study of these protective functions in order to assess their sufficiency;
- in the case of those sites whose protection is ensured by the platform shoring, but which have a narrow safety margin between the maximum design flood level and the platform level, study of the sufficiency of this margin, particularly regarding possible terrain packing and/or the assumptions behind the calculation of the maximum design flood level;
- the re-assessment of the maximum design flood level, notably with respect to uncertainties in the natural phenomena;
- study of the vulnerability of the pumping station. It is a fact that at a number of sites, access to the pumping station is located below the level of the platform;
- study of the risks associated with the presence of canals near the site, where the water level is above the platform elevation;
- study of the effectiveness of the flood warning system;
- study of the risk of potential isolation of the site in the event of flooding of the surrounding areas.

At the conclusion of this analysis, a classification of French sites was produced, together with the identification of ten sites for which the procedures currently in force should be re-examined.

3.2. EDF Action Program

In 2000, Electricité de France put forward its global action plan, together with themes for the design review. This design review is based on study of the safety reports, the site reports, site investigations, and specific studies.

On the basis of a number of Electricité de France documents released in 2000, the correlation was made between DSIN and IPSN requirements and the Action Plan presented by Electricité de France. Overall, the principal requirements for the prevention of flooding risks will be addressed by issuing directives for modifications.

The first stage of the Action Plan entails the collection of as much information as possible for the design review, and the validation of a methodology and actions to be initiated with regard to the four themes mentioned above.

Among the themes in the design review, the following four areas may be highlighted:

- hydrology, calculation of the maximum design flood level;
- fixed or mobile protection works for the platform, the units, and especially, the pumping stations;
- warning systems;
- operating procedure, equipment required for switching to and maintaining an emergency shutdown condition.

3.3. Assessment of the EDF Program

3.3.1. SHORT-TERM ACTIONS

In June 2000, Electricité de France published the initial results of an inquiry for all the sites. This inquiry aimed at:

- inspecting the condition of civil engineering works;
- verification by the relevant sites, of the constructive measures, mobile resources, warning procedures, existing H5 procedures;
- verification of the effectiveness of the organizations in ensuring the water-tightness of handling openings and slabs;
- initiation of overhauling operations deemed necessary by the sites.

3.3.2. ACTIONS IN THE ACTION PLAN

The Action Plan implemented by Electricité de France has been the topic of discussions between DSIN and Electricité de France since March 2000. Certain issues directly related to methodology aspects have not yet reached total agreement and will be the subject of an appeal for guidance to the members of the standing committee responsible for reactors in December 2001. As a result, there remains, taking into account the discussions held to date, a certain number of issues still undecided, and which await the judgment of the members of the standing committee.

3.3.2.1. "TECHNOLOGY/SAFETY" AREAS

The safety analysis carried out dealt with the following areas:

1. Content and thoroughness of the area covered.
2. Maximum design flood: methodology for the determination of the maximum design flood.
3. Additional contingencies: measures for taking into consideration and methodology for determination of phenomena having a potential for generation of extreme flood events.
4. Additional contingencies: methodology for consideration of event combinations and the uniformity of protection against all flooding risks.
5. Warning systems: principles of implementation, and definition of devices appropriate to the sites, and to the nature of the contingencies involved. For each site, given the risks of external flooding that are involved, it was necessary either to evaluate the suitability of the warning systems installed, or to make arrangements relative to the site itself, if the installation of a warning system is not feasible. Furthermore, procedures have been envisaged aimed at the perennial nature of the arrangements involved in the warning system.
6. Procedures H5 and ICRF or equivalents: study of changes in the documents related to site operation (protocols such as H5, ICRF, S-SEO, GC3). In the case of those sites unable to make use of warning systems, it was proposed to rework the operation manuals, or even the design of certain equipment to address the following:
 - the possible occurrence, before switching units to an emergency shutdown condition ($P > 45$ bar), of loss of the cooling water concomitant with the loss of external power supplies;
 - the execution of all the planned actions despite the presence of the contingency (see actions conducted locally, in particular).
7. Procedures H5 and ICRF or their equivalents: definition of safe emergency shutdown conditions which the facilities should achieve.
8. Maintenance of a safe emergency shutdown condition: definition of the systems and equipment necessary for achieving and maintaining safe emergency shutdown conditions.
9. Maintenance of the safe emergency shutdown condition: constraints associated with the re-supply of the emergency feedwater storage tanks. Based on observations made during the night of 27/12/99 at the Blayais site, it was necessary for all sites to have information to evaluate performance of the re-supply circuits for the emergency feedwater storage tanks of the various units, especially during the re-supply phases by gravity feed. Moreover, it was necessary to assess the feasibility of alignments that would allow the use of various means of re-supply in the presence of a event or a shutdown of the water station.
10. Water pathways: methodology for the study of water pathways.
11. Equipment protection: methodology and criteria associated with measures of protection to be applied, maintaining over time of the nature of the protection devices.
12. Equipment protection: principles for the use of fixed or mobile pump systems, problems associated with their power supply and their discharge pathways.
13. Protection of equipment/control devices: measures for dealing with the question of centralized alarms and efficient detection of water in the chambers.
14. Protection of equipment/control devices: measures for prevention and detection of faults in electrical isolation.
15. Discharge and procedure: study of the impact of cutoff of the nuclear auxiliary building ventilation system in the event of source switchover.

16. Discharge: principle of study and prevention of discharge risks from ICPE.

3.3.2.2. "TECHNOLOGY/SAFETY" AREAS - OTHER TOPICS

The safety analysis carried out dealt with the following topics:

1. Potential loss of external sources: study of the measures to take to prevent the loss of external power supplies in the event of floods or storms and impact of the experience feedback from the Blayais site on the initial assumptions contained in the Generalized Grid Incident document.

Electricité de France indicated that it retains the loss of external electrical power as one of the potential consequences of flooding, and is evaluating its impact. A disconnect value of 1 to 3 days, depending on the site, has been estimated for the duration of this loss.

As to the prevention of such losses in external power supply, Electricité de France has confirmed that the studies it carried out aimed at ensuring that the first substation as well as the transformers at the site remain available in the event of flooding in order to ensure operation of a supply line (main or auxiliary).

Finally, aspects associated with the storm (strong winds, protection of the electrical pylons, ...) will be the subject of a separate technical review. Electricité de France confirms that the review aims to separate the short-term processing of aspects related to the flooding alone from those related to the storm.

2. Potential consequences of the contingency: study of phenomena associated with a storm other than external flooding (flying debris);

3. Protection of the cooling water or the pumping station: study of the measures that can be taken to prevent the occurrence of a total loss of the heat sink in the event of a flood;

4. Complementary situations: study of the combined loss of the heat sink + loss of off-site power for all the units at one site in terms of control or particular measures;

5. Operating technical specifications: study of the interfaces with the operating technical specifications, particularly in the case of the safety injection system and containment spray system. During the progress of the incident at Blayais, the application of the operating technical specifications associated with the unavailability of the safety injection system, requiring switchover to a maintenance outage condition, led to serious discussions leading to the decision not to follow the RGE protocols. Because of this, the relevance of the emergency shutdown conditions outlined in the operating technical specifications for cases involving unavailability of the safety injection system and/or the containment spray system was re-examined.

6. Civil engineering: study of the behavior of civil engineering works under the effect of hydraulic loads (stability and watertightness);

7. Equipment protection: study of the harmful effects of water on the resistance of submerged equipment;

8. Maintaining a safe emergency shutdown condition: study of the impact on steam generator operation when using non-degassed water;

9. Consideration of internal hazards: evaluation of issues related to the prevention of internal flooding risks and the conformity of units to safety requirements;

10. Examination of the sufficiency and coherence of the measures adopted for all external hazards and initiation of a review on margins in terms of how vulnerability is sensitive to assumptions taken into account when sizing units with respect to these hazards.

3.3.2.3. "ORGANIZATION AND CRISIS MANAGEMENT" AREAS - EDF ACTION PLAN

The safety analysis carried out dealt with the following areas:

1. Guidelines of national scope (PUI model, availability of emergency premises and resources, resources and competencies necessary to address incident situations impacting several units at the same site, ...).
2. Protective measures for persons that must intervene locally.
3. Accessibility / isolation of the site.
4. Re-evaluation of the protection of sites - Initial results.

3.3.4. SUFFICIENCY OF THE SAFETY LEVEL ATTAINED

In 2001, IPSN put forward the results of a review on information that would allow the members of the standing committee to estimate the sufficiency of the protective measures against external flooding that Electricité de France planned to implement at 19 sites equipped with pressurized water reactors.

The partial flooding of the BLAYAIS site clearly demonstrated the risk that an external flooding event could lead to damage on multiple equipment items throughout the units of a site, and thus put into question the existing measures, especially the warning systems, site protection measures, protection of safety-related equipment, and the procedures for the control and management of the situation.

The observations made during the incident caused Electricité de France to launch a far-reaching program of investigations aimed at reinforcing the lines of defense in such a way as to maintain the units in safe shutdown condition even in the event of site flooding. To date, the design review of the risk of external flooding and its impact on unit safety initiated by Electricité de France for all French sites has, at the end of 2000, led to the definition of an Action Program to be implemented at all the sites in the coming years. As indicated above, this program is presently the subject of an inquiry.

The conclusion of the inquiry now in progress should enable one to judge if the Action Program engaged is adequate for a satisfactory level of safety to be achieved.

On this subject, the various stated objectives can be recalled.

In terms of the overall risk objective, INSAG-3 has set as a goal for the existing power plants a probability figure for severe damage to the core of approximately 10^{-4} per year of operation. This overall objective for risk assessment combines initiators inside the facilities, as well as internal and external hazards. Insofar as radiological consequences are concerned, the objective set by INSAG-3 represents a reduction by at least a factor of 10 from the probability of significant discharges to the outside of the site requiring a rapid off-site intervention, by implementing measures for the management and attenuation of serious accidents.

With regard to the information appearing in French regulations, the briefing letter SIN #1076/77 dated 11/07/1977 states that "*in general, the sizing of facilities within a unit housing a pressurized water reactor should be such that the overall probability that this unit can be at the center of unacceptable consequences should not exceed 10^{-6} per year [...]. It is proper to consider that this class of events must be effectively taken into account if the probability of such events leading to unacceptable consequences is greater than 10^{-7} per year*".

With regard to the risk of external flooding, during the RFS 1.2.e inquiry before the standing committee on 05/01/84, it was pointed out that, given the impossibility of arriving at a probability level for the initiating event of less than 10^{-3} per year, primarily because of the data available in France, a margin of 15% is added to the flow rate in order to lower the frequency at which the level is exceeded to an order of magnitude of less than 10^{-4} per year. RSF 1.2.e states that *"In order to ensure a certain homogeneity between the probabilities of different risks due to external hazards and taken into account in sizing the nuclear facilities, a margin of safety is fixed on an overall basis as being the water level corresponding to an excess flow rate equal to 15% of the flow rate of the estimated 1000-year flood"*.

There appears to be, therefore, a certain amount of difficulty in estimating the probability of reaching the risk objective for external flooding.

From a deterministic point of view, for a given site, taking into account the nature of the contingency it faces, it is possible to identify three lines of defense that come into play for external flooding events, vis-à-vis the occurrence of unacceptable consequences for the units.

I - The warning system installed. As a general rule, when its installation is possible, the warning system is designed in such a way so that units may be switched over to a safe emergency shutdown condition before the contingency takes place. It should be noted that for certain facilities or certain contingencies, the anticipation of the contingency is not possible. In such cases, another line of defense is necessary.

II - Protection of the site in a way aimed at limiting the height of water arriving at the site, using passive means of protection and/or pumping.

III - Providing resistance to the water encroachment through the buildings or the chambers housing important safety-related equipment aimed at maintaining a safe emergency shutdown condition of the reactor. The list of such equipment constitutes one of the major discussion points with Electricité de France in the design review now being studied.

It should be noted however that the overlapping of these three levels of protection can be questioned, particularly with regard to the intensity of the contingency. In fact, for a site where protection levels are established with reference to a certain intensity of contingency (I0) to which a probability level is assigned (P0), if the protection of the site and the protection of the chambers containing important safety-related equipment are defined without adequate margins, it must therefore be noted that for a higher intensity of contingency (I) whose probability P would be thus less than P0, there would be no way to limit the consequences of the contingency.

The estimation of the unit safety level thus requires evaluating the existing margins in terms of protection vis-à-vis a contingency of intensity greater than the intensity used in sizing in order to avoid a "cliff effect".

Although the possibility of producing for each site a probabilistic study in association with an external flooding event is very interesting, it does not appear to be feasible in the foreseeable future.

Because of this fact, IPSN has proposed to use the following method for each site:

- characterize the contingency taken into account in sizing the various levels of protection and try to assign it a probability of occurrence,
- evaluate the three levels of protection proposed,
- estimate the margins provided by the proposed protection levels. This therefore entails estimating the quantity of additional water that the site could accommodate if a contingency of higher intensity than the design intensity occurs before a cliff effect appears, characterized by the loss of safety equipment,

- evaluate the sufficiency of the margins by expert judgment. This evaluation may be based on a trial simulation using a probability of occurrence of the contingency that is the maximum that the site can tolerate before a cliff effect appears.

In response to this trial by IPSN, Electricité de France has agreed to present:

- the conservative aspects chosen, in particular for contingency characterization or combinations of contingencies,
- the margins chosen in sizing the various prevention measures implemented (warning system, site protection, protection of the chambers containing safety-related equipment).

3.4. French conclusions

The partial flooding of the Blayais site that occurred on December 27, 1999 has led to a large-scale re-examination of the measures to prevent and limit the consequences associated with all contingencies or combinations of contingencies which could lead to external flooding of any of the 19 French sites equipped with pressurized water reactors.

An Action Program was therefore launched by Electricité de France. The evaluation of this program has been, since the beginning of 2000, the subject of an inquiry which will be finalized by a judgement requested from the members of the reactor standing committee. The committee will meet to deal with this matter on December 20, 2001.

The study of implementation of this program throughout all sites in France equipped with pressurized water reactors will extend to the year 2003.

4. RECENT SITUATION AT GERMAN NPP

4.1. External Flooding Protection

4.1.1. Open questions in view of weather changes and the Blayais event

Against the background of the consequences of the extreme thunderstorm in December 1999 in France - resulting in the flooding event at the French nuclear power plant (NPP) Blayais - the BMU (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) organised a so-called federal state survey to the design of German NPP against external flooding (see chapter 4.1.2). The question arising from this survey is if such an event can also happen in Germany. All German NPP sites have been examined insofar.

The survey concerns 14 German NPP sites under operation (fig. 4.1), 5 of these with two NPP units. There are 9 river sites without and 5 river sites with tidal influences.

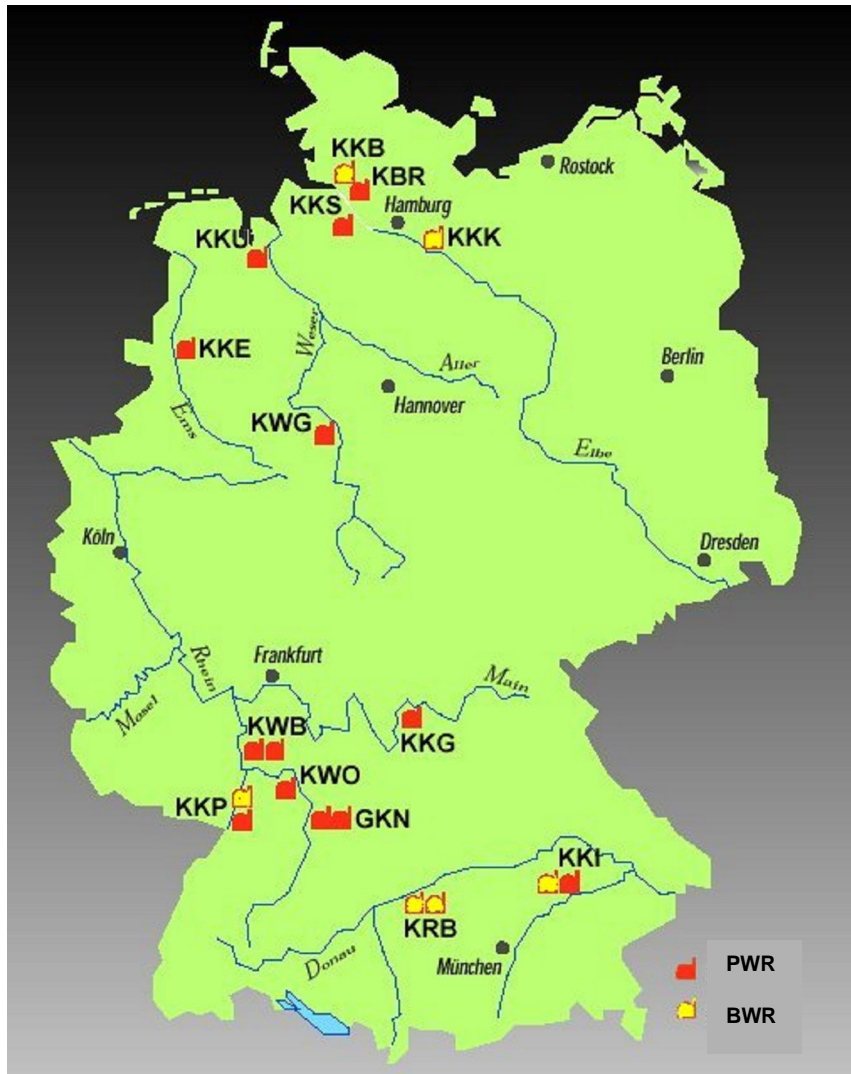


Figure 4.1: German NPP sites

With regard to the transferability of the event at the French NPP Blayais, the following questions have to be answered for German NPP:

- Are the deficiencies found in the methodology to determinate the design basis flood or in dike constructions also applicable to German NPP sites with tidal influence?
- Can an external flooding of subterranean pipe and cable ducts be excluded or have the borders and connections between flooded ducts and buildings with safety related components a sufficient stability and tightness?
- Is the quality assurance of the measures taken in German NPP against flooding sufficient?

In addition to the question of flooding protection for each German NPP, another problem has been arisen analysing the flooding event of the NPP Blayais. What about the weather development during the last years? The question is, if meteorological parameters such as rainfall, occurrence frequency and impact of maximum flooding water levels, storm force, etc. have been changed significantly during the last decades and if therefore the

determination of design water levels is obsolete, particularly for older NPP designed to earlier standards.

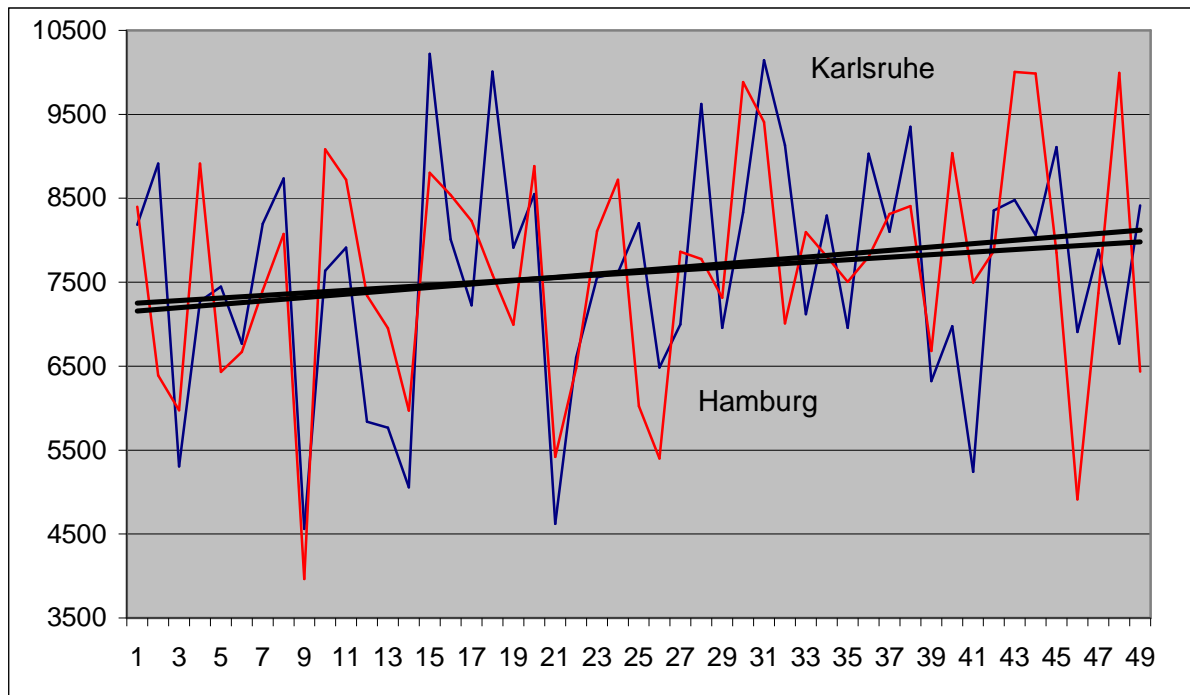


Figure 4.2: Development of the annual rainfall in 0.1 mm during the last 50 years for two selected NPP sites

In Figure 4.2, time series of rainfall for two characteristic NPP sites in Germany are depicted [1]. A slight increase can be realised. Figure 4.3 is taken from [2] visualising that the mean annual high tide for the sites Husum and Cuxhaven (close to the NPP KKS, KKB and KBR) shows an increase of 0.27 cm/a.

It is stated in [3] that a change regarding the occurrence frequency of storms and the wind speed could not be proven for a long time period. Should there be the impression that especially the wind speed has increased during the last years, arguments are given that this fact can be assigned to short period oscillations within the climate system.

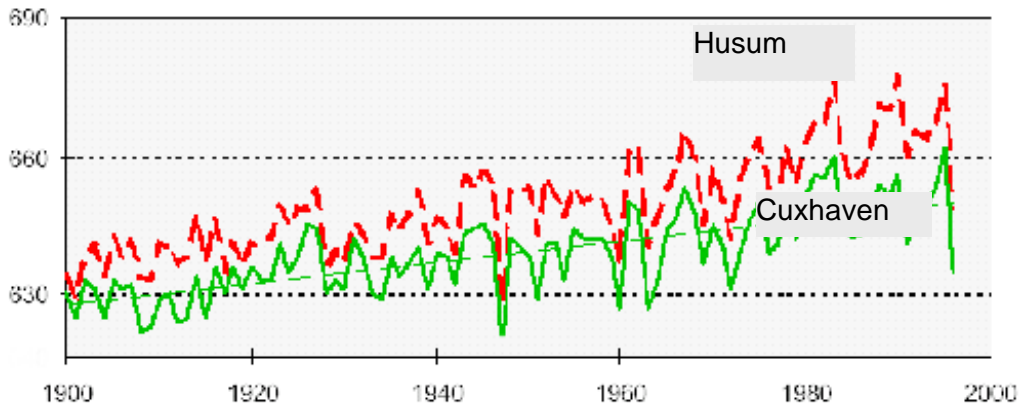


Figure 4.3: Development of the mean annual high tide in cm

In principle, the weather changes are not as significant that the determination of design flooding has to be questioned at time being. The current requirements regarding the protection of German NPP against flooding and the design flooding which has to be taken into account are formulated in the safety requirements of KTA 2207 [4]. The design flooding is defined as an event with a probability of $1.0 \cdot 10^{-4}$ per year that the water level will be exceed the design value. In fact, that design value cannot be calculated by historical data due to changes in the geological formations (land, coast areas, rivers) as well as in the meteorological conditions during a period of 10.000 years. The design value represents a probabilistic estimation for a maximum water level during the lifetime of a NPP. The validity of this estimation depends on the quality of modelling with a sufficient number of relevant influence parameters. It remains the task that this design value has also to be verified for older NPP when the model has been developed. All of the flooding protection measures have to be checked if they withstand the impact of that design water level. Otherwise, reconstruction measures are necessary.

4.1.2. Insights from the evaluation of design load characteristics and protection measures applied to German NPP

The questions of the BMU organised federal state survey to the design of German NPP against external flooding are:

1. Determination of the design flooding

- What was the method to determine the design flooding? Which influence quantities were taken into consideration?
- In how far was the superposition possibility of extreme tidal flood and storm-determined wave height taken into account in case of the determination of the design flooding for rivers with tidal influences (Elbe, Weser)?
- Was the design flooding assessed probabilistically? If yes, which annual frequency was applied?
- Which design water level was specified in the vicinity of the NPP sites? Was a freeboard taken into account?

2. Amount of protection measures and combination of loads

- Is there a concept for the protection of safety significant plant equipment against damage or failure due to flooding, so that the components can fulfil their safety

functions in case of flooding combined with other loads as mentioned in the next question?

- Which combinations of loads were included determining the measures against flooding?

3. Preventive measures against flooding

- What are the constructional measures? It has to be distinguished between permanent and temporary measures of flood protection.
- Was a dike break assumed determining the measures for flood protection?
- How is the accessibility of the NPP site ensured during flooding?
- What are the organisational and administrative measures of flood protection? Are there corresponding measures given in the instruction manual?

4. Periodic inspections and testing

- Are there periodic tests for equipment for flood protection? Are the tests performed regularly and what are the periods? What is the extend of examination and what have been the results?
- Was the protection against flooding assessed in the framework of the periodic safety assessment of the NPP? What results were important and which measures were derived?
- Are there new flooding analyses for the site and what are the results?

5. Transferability of insights regarding the flooding event at the NPP Blayais

- Is it possible to exclude similar events such as at the NPP Blayais regarding the flooding protection at the site or are there needs for specific measures?

The GRS was instructed by the BMU to analyse the survey answers. Some of the generic results are given below.

It is the major goal of the German NPP design against flooding to maintain a safe state of operation up to the design water level (design flooding) depending on constructional, organisational/administrative and temporary measures in consideration of the site characteristics. The survey revealed the result that the requirements of the KTA safety Standard 2207 [4] for the design flooding have been taken into consideration by the design for the newer NPP. For most of the other sites it could be demonstrated that the design meets the requirements of [4]. KTA 2207 is valid by a version from the year 1992 and has been taken as a basis for the assessment of the survey answers. However, at the time being it has to be mentioned in this context that these standards are in an upgrading process. For four of those NPP sites with tidal influences another method - a non-probabilistic approach - was used to determine the design flooding. The design flooding was calculated using dike break scenarios which were superposed by conservative site assumptions (river high water, extreme tidal flood, etc.). For those NPP it could be additionally stated that the protection against flooding is sufficient using the requirements of [4] as criterion.

The amount of protection measures in case of flooding is defined in [4]. It covers all the plant equipment required to shut down the reactor safely, to keep the reactor under shut down conditions, to remove decay heat, and to prevent the release of radioactive material. This safety significant plant equipment has to be protected in such a manner that their safety related function is not jeopardised, even not in combination with other loads. The survey indicates that for most of the NPP sites the amount of protection measures is kept by the safety concept realised at the respective plant. In some cases, the safety concepts refer to a design flooding differing from the requirements in KTA 2207 [4]. Due to a lack of information regarding the methods for the determination of the design water level, no final assessment is possible.

In the following, some remarks on the preventive measures against flooding can be found. There is a permanent constructional protection against flooding at most of the NPP in Germany. Some of the protection measures mentioned as answer of the survey are listed below:

- heightening of the whole NPP site,
- heightened location and arrangement of important safety significant plant equipment,
- flooding-safe boundary for safety significant plant equipment,
- sealing against water pressure,
- watertight design of penetration assemblies.

One important question of the federal state survey was, if there are dikes near the NPP site and if a dike break has been assumed designing the flooding prevention measures. There are 9 NPP sites without tidal impact but only three of them with dikes. The plants near these rivers are protected by a dike, but a dike break directly at these sites can be excluded due to geographical characteristics (replenishment behind the dike). As a worst case, if there is a dike break close to the site, in case of two sites the NPP would be an island because of the large size retention possibility of the surrounding area. At one site, there is a barrage. The design assumption of a break of this nearby barrage resulted in heightening of the whole NPP site.

There are 5 sites with tidal impact. It was a design assumption for three of them that the dike abruptly breaks in the vicinity of the site shortly before the zenith of the flooding is reached. It is pointed out by the utilities that this assumption is very conservative because of two reasons: The dikes close to the NPP sites are specifically resistant constructed and, on the other hand, no credit has been taken of relieves by (more likely) dike breaks afar the sites.

In KTA 2207 [4], it is emphasised that the accessibility of the site and the plant supply by operating media agents must be ensured during the design flooding. Analysing the answers of the federal survey, it appears that the accessibility is warranted.

In case of the organisational and administrative measures of flood protection, the question arises how the necessary measures are considered in the instruction manual and the respective other written directives. The answers of the following two questions are of special interest:

- What about the involvement of the NPP in the official flooding announcement system? Is the water level measured by the utility itself?
- Is there a water level threshold to shut down the reactor?

There are some sites without description of measures against flooding in the instruction manual. In some cases written instructions are potentially not needed because of the site altitude above the design flooding and the protective constructional measures, which are permanently existent at the respective plants.

Analysing the causes for the flooding of rooms with safety related equipment at the NPP Blayis the question arises for German NPP, if the quality of sealings and partitionings (e.g. near doors, penetrations, ducts or miscellaneous openings within or between buildings) is sufficient. Above all, it is a matter of unchanging quality of the equipment. This can be checked by periodic testing or in-service inspections. The survey gives indications that the technical (permanent and temporary) equipment of flood protection is tested periodically, but the numbers and type of tests and the test periods is not uniform and differ from plant to plant. The seal-tightness is tested by visual inspections in most cases. In the frame of the survey, there were no reports on safety significant indications revealed by in-service inspections. The equipment is maintained as soon as a minor indication attracts attention.

It has to be mentioned that for all operating German NPP new analyses have to be carried out at the time being. Most of these analyses are performed within the periodic safety reviews. In most cases, the analyses could confirm the provisions to flood protection from the licensing procedure by comparison with the state-of-the-art. In addition to the probabilistic determination of the water level by the design flooding, a probabilistic assessment of the consequences of flooding events has been carried out for some NPP. It can be stated that the contribution of the initiating event "external flooding" to the core damage frequency is negligible.

4.1.3. Recent developments concerning the requirements of the KTA Standards

At the time being, the KTA Standard 2207 [4] is under revision. Two of the substantial modifications and innovations of the draft [5] are listed as follows:

Even in the draft of the new standard, the design of the protection of NPP against flooding emanates from a rare flooding event with an exceeding frequency of 1.0 E-4/a , but it is underlined that the methods used to determine the design water level must be different for river sites without and for sites with tidal influences. For river sites without tidal influence, the design water level can be assessed using the flood flow of the river with the given exceeding frequency as basis. For river sites with tidal influences, an extreme tide caused by storm (storm-tide) must be assumed. Therefore, it is prescribed to determine statistically the storm-tide water level with an exceeding frequency of 1.0 E-2/a plus a site-specific addend. In conclusion, a storm-tide must be covered with an exceeding frequency of 1.0 E-4 . In the supplement of [5], state-of-the-art methods are given to determine the design water level.

The loads due to the design flooding must be combined with other loads. The respective chapter of load combinations of [4] has been revised. The following combinations have to be considered in case of the design flooding:

- external loads of normal usage (e.g. dead load, live load, operational loads, earth thrust, wind load),
- loads due to the design flooding (e.g. static water pressure due to the design water level, streaming water, waves, upswing, flotsam, ice pressure),
- loads of events as a consequence of the design flooding (e.g. undermining, erosion).

4.2. Internal flooding protection

4.2.1. Goals and realisation of protection measures at German NPP

Using the international operating experience, there are the following main reasons for internal flooding:

- leaks or breaks of water-carrying pipes,
- faulty control of water-carrying pipes,
- human errors during preventive and corrective maintenance,
- consequential failures due to other events.

For safety related purposes, internal flooding events are particularly to be analysed in the following NPP buildings or part areas:

- Rooms within the reactor building, but outside the containment (e.g. the reactor annulus of pressurised water reactors),

- service water pump rooms and other rooms or buildings with safety related equipment, if a impact by the flooding water is possible.

For a better understanding, it should be added that the definition of the hazard "internal flooding" does not involve loss of coolant accidents (LOCA) with flooding of the containment. The so-called LOCA events are separately analysed.

Primarily, the following preventive measures against flooding have to be mentioned for German NPP:

- Particular specifications and safety margins for the design of water-carrying systems and components with a large potential for flooding,
- constructional and spatial separation of redundant safety trains,
- measures for detection, sealing, or isolation of leakages,
- sealing of the relevant buildings against ground and surface water,
- sealing of the relevant buildings or rooms against entering water from other buildings or rooms,
- quality assurance during operation and maintenance.

4.2.2. Safety relevance and results of PSA

As a result of the above mentioned federal survey to external flooding, it has been demonstrated that for all operating German NPP new analyses regarding flood protection have been performed or are being carried out at the time being. These analyses within the frame of periodical safety reviews cover also investigations with respect to plant internal flooding events. In the following, a brief description of the major three results is given..

The first example is taken from the German Risk Study [6]. Investigations showed that above all a flooding of the reactor annulus may jeopardise the nuclear plant safety. Flooding of the reactor annulus is possible, if a leak occurs in the service water system. The occurrence frequency of a large leak is approximately 5.0 E-3/a . If a service water pump delivers to full capacity (approximately 3000 t/h), flooding which may cause the failure of safety related components has to be expected within less than 15 minutes. Several backfitting measures are available, serving to improve the detection of leaks and to prevent flooding of the reactor annulus. Thus, for example, the individual quadrants of the reactor annulus are separated from each other by ground thresholds. Each quadrant is continuously monitored by water level indicators. Also as a result of these measures, in total a very low occurrence frequency of less than 3.0 E-7/a results for an uncontrolled leak sequences initiated by a leak in the service water system.

The second example given comes from a topical PSA of one of the most recent German so-called "Konvoi-type" pressurised water reactor (PWR)s. The four quadrants of the reactor annulus are also separated by ground thresholds and the pumps of the service water system are located in separate compartments. There is only the fire extinguishing system, which could be the reason for a potential flooding of the reactor annulus. The leak occurrence frequency of this system inside the reactor annulus is assessed to be 3.0 E-5/a . The respective core damage frequency is lower than 3.0 E-8/a , if the leak remains undetected, otherwise the core damage frequency can be neglected.

In most cases it could be demonstrated that the initiating event "internal flooding" can be neglected, because there is no relevant contribution to core damage. However, the next example shows that this assumption has to be verified.

A recent examination of an older PWR shows that the hazard "internal flooding" can substantially contribute to the total core damage frequency (CDF). In this case, the danger results from a potential leak of the service water system in the reactor auxiliary building. In consequence of such a leak, the water pressure can be so high that the locks between the reactor annulus and the auxiliary building cannot resist. The reactor annulus would be

consequentially flooded. Measures have been taken in the plant affected to eliminate the deficiency and to reduce the frequency for the course of the event.

4.3. Generic conclusions of GRS

With regard to external flooding, plant specific reviews of the methods for determination of the design water level are required for NPP in Germany. The methods discussed within the frame of the recent upgrading process of the German nuclear Safety Standard KTA 2207 could be the basis for a state-of-the-art safety assessment. Furthermore, a uniform procedure for periodic testing and in-service inspections with respect to the quality of equipment and measures against flooding seems to be necessary.

With regard to plant internal flooding protection, several PSA studies have shown results with different safety relevance. It therefore makes sense to consider the event "internal flood" in all future PSA.

5. GLOBAL CONCLUSION

At the present time, a detailed comparison of the different approaches used in Germany and in France has not been performed. Consequently, no global conclusion is provided.

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