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

IRSN

E. VIAL – V. REBOUR – JM. MATTEI – A. GORBATCHEV

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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 operator that was 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 in France.

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, an evaluation of the initiatives aimed at improving the safety of the French 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).

4. CONCLUSION

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 judgment requested from the members of the reactor standing committee. The committee met to deal with this matter on December 20, 2001.

The committee approves the Electricité de France methodology consisting of:

- first, defining the principles for re-evaluating external flooding risks together with the relevant arrangements,
- secondly, applying these principles and arrangements to each site and showing that the margins adopted are sufficient for achieving an acceptable safety level.

Subject to the proposals for studies adopted by Electricité de France being followed through and taking into account some additional recommendations, the committee considers that the principles adopted by Electricité de France in the "External flooding" action plan are satisfactory and capable of meeting the concerns expressed after the flooding of the Blayais site.

The committee would like an evaluation regarding the application of the "External flooding" action plan on the sites to be submitted to it at the end of 2003 to enable it to give a final judgment on the adequacy of the measures associated with each site.

Moreover, the committee considers that it would be useful to undertake a review of RFS I.2.e.

The study of implementation of the program throughout all sites in France equipped with pressurized water reactors will extend to the year 2005.