Report on flooding of Le Blayais power plant on 27 december 1999

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Abstract: A flooding occurred at "Le Blayais" Nuclear Power Plant on the 27th of December 1999, revealing a potential mode by which the safety of all the units of a single plant could be jeopardized. This flooding has led Electricité de France to define a study programme whose goal is both to draw the lessons of this event and to improve the safety of the French Nuclear Power Plants regarding the flooding risks.
Firstly, the sequence of events and the management of the situation during the flooding will be presented. Then, the Electricité de France study programme and the actions undertaken in order to ensure the protection of the plants, especially those already implemented on "Le Blayais" site, will be detailed.

1 INTRODUCTION

This report describes the flooding which occurred at « Le Blayais » Nuclear Power Plant on 27 December 1999 and the consequences it had. It also describes the resulting action taken by the Institute for Nuclear Safety and Protection and the preliminary lessons which can be learned from the incident.

2 LAYOUT OF THE "LE BLAYAIS" SITE

2.1 Location of the site

The site of « Le Blayais » Nuclear Power Plant, which comprises four 900 MWe pressurised water reactors, is located in the county of Gironde, 50 km north-west of Bordeaux. The installations are located on the banks of the River Gironde in a swampy area. The position of the site on the estuary of the River Gironde is shown in Illustration 1.

2.2 Site hydrology

Assessments made to estimate the high water levels of the Gironde have shown that at the site, the effects of the sea are more important than those of the river. Therefore, the approach adopted for quantifying these levels is that used for coastal sites.
The high water level depends on the tides and the local relief and meteorological conditions. The level used for designing the site protection system is 5.02 m above the French national datum level. It corresponds to the level reached by the highest tide (coefficient 120), increased by a certain value to make allowance for local relief and meteorological conditions (winds, areas of low pressure etc.); this value is obtained by extrapolation on the basis of water levels recorded over several decades.
The reference tide monitoring station for the « Le Blayais » site is located at Pauillac, 2.5 km upstream. The positions of the sensors are shown in Illustration 1.
The site is surrounded by a dike (Illustration 2). The dike is made of earth and is protected on the River Gironde side by a pile of stone blocks. Alongside the River Gironde, its height is 5.2 m above the national datum, and its height is 4.75 m at the sides.
The levels of the site platform and the layout of the reactors are shown in Illustration 3.
Recent studies carried out by Electricité de France led to a reassessment of the water level to be taken into account as regards protection of the site; the new level was set at 5.46 m above the national datum. In these conditions, EDF had planned to increase the height of the dike to 5.70 m above the national datum; work which had been due to begin in 2000 was postponed until 2002 by EDF.
Some water levels recorded in the River Gironde can be given by way of example:

- maximum level measured at Pauillac prior to 27 December 1999: 4.12 m above the national datum on 28 March 1979,
- maximum level measured at Pauillac on 27 December 1999: 4.46 m above the national datum (it should be remembered that all the tide sensors were put out of service by the storm of 27 December 1999).

Investigations carried out on the « Le Blayais » site after the storm of 27 December 1999 showed that the water had jumped over obstacles from 5 to 5.30 m.

3 DESCRIPTION OF THE FLOODING

3.1 Initial state of the units on 27 december 1999

Following the disruption caused during the night of 27 December 1999, the state of the units was as follows:

- Units 1, 2 and 4: operating at 100% rated capacity,
- Unit 3: shut down after refuelling, with cooling by the decay heat removal system.

3.2 Sequence of events

3.2.1 Partial loss of off-site power supplies

According to the information obtained from the nuclear operator, loss of the 225 kV auxiliary power supplies and loss of the 400 kV grid for Units 2 and 4 occurred as early as 19:30. Attempts to switch the units to house load operation to enable them to continue powering their auxiliaries following disconnection of the grid failed, causing these two units to shut down; the diesel generators of both units started up and operated correctly pending reconnection of the 400 kV grid, which occurred at around 22:20. The 400 kV line powering Units 1 and 3 continued to be unavailable.
Illustration 4 shows the site electricity network, as well as the points at which the power supplies failed.

3.2.2 Flooding of the site

In the night of 27 to 28 December 1999, high waves, caused by a combination of tide and exceptionally high winds, moved up the River Gironde and partly submerged the « Le Blayais » site. According to the information provided by the nuclear operator, flooding began at around 19:30 on 27 December 1999, i.e. two hours before high tide (coefficient 77).
At 22:00, an alarm indicating the high level of the River Gironde at the Richard observation station (see Illustration 1) was sent to Unit 4. The alarm caused operating procedure I CRF to be applied. It would appear that the information on the high level of the River Gironde was not sent to Units 1, 2 and 3, contrary to what is stipulated in the corresponding alarm sheet. Furthermore, procedure I CRF of the Le Blayais Nuclear Power Plant used by operators in the control room makes no mention of the need to put the Level 2 On-site Emergency Plan into operation, whereas the document describing the On-site Emergency Plan states that this procedure is one of the conditions for putting the plan into operation.
Strong waves submerged the plant platform, with water entering mainly on the north-west side of the dike. The waves moved the rocks, protecting the dike, and part of it was washed away alongside the River Gironde (Illustration 5). The water reached a depth of around 30 cm in the north-west corner of the site (this value was obtained by observing branches which were caught in the access gates (Illustration 6).
Units 1 and 2 were severely affected by incoming water. Conversely, Units 3 and 4 were affected to a far lesser degree.
The points at which the water entered Units 1 and 2 were identified by the presence beside the holes of insulating panels from the administration building which was damaged during the storm (Illustration 9). The water tended to run along the general site gallery through the panel handling holes above the gallery and in the empty spaces where the metal plating was distorted (Illustrations 7 and 8). This general gallery is located outside the buildings and almost completely surrounds them

(Illustration 10). The rate at which the water entered the gallery and filled it to a depth of 30 cm can be estimated at between 20,000 and 40,000 m^3/h. This value is corroborated by the estimate of the volume of water pumped from the facilities (around 90,000 m^3 of water were pumped out between 27 December 1999 and 1 January 2000), and by the fact that water was observed on the site for around two hours.
Of the facilities which were flooded in Units 1 and 2 (Illustrations 10 and 11), the following should be noted:

- the rooms containing the essential service water pumps. The essential service water system of each unit comprises four pumps on two independent trains (A and B); each pump is capable of providing the entire throughput required. In Unit 1, the essential service water system pumps of Train A were lost as a result of immersion of their motors;
- some utility galleries, particularly those running in the vicinity of the fuel building linking the pump house to the platform;
- some rooms containing outgoing electrical feeders. The presence of water in these rooms indirectly led to the unavailability of certain electrical switchboards;
- the bottom of the fuel building of Units 1 and 2 containing the cells of the two LHSI pumps and the two containment spray system pumps. The nuclear operator considered that the pumps were completely unavailable. The systems to which these pumps belong are the engineered safety systems of the installation which are designed mainly to compensate for breaks in the primary system.

Illustration 12 illustrates the roles of the aforementioned systems. The essential service water system operates during normal operation of the units to cool the reactor auxiliaries and when the reactor is shut down to cool the decay heat removal system during accident situations in order to remove the decay heat by heat exchange in the containment spray system heat exchangers.
The route taken by the water in Unit 1 is shown in Illustration 13.

4 MANAGEMENT OF THE SITUATION IN THE EMERGENCY REPONSE CENTRES

4.1 Setting up and action of the emergency reponse teams

From 22:40 onwards on 27 December, the Regional Directorate for Industry, Research and the Environment, the *préfecture* through the Regional Directorate and the Nuclear Installations Safety Directorate were regularly kept informed of the situation; at around midnight, the Regional Directorate for Industry, Research and the Environment informed the engineer from the Institute for Nuclear Safety and Protection who was on call of the power supply problems at « Le Blayais » Nuclear Power Plant. At 3:00 on 28 December, the plant emergency response teams were called out to assist those already in place. In parallel to this, the plant informed the headquarters of Electricité de France and the Regional Directorate for Industry, Research and the Environment. At 3:15, the national emergency response teams of Electricité de France were mobilised.
At 3:30, the Nuclear Installations Safety Directorate was informed by the headquarters of Electricité de France.
At 6:30, the headquarters of Electricité de France directly informed the management of the Institute for Nuclear Safety and Protection of the power supply problems at « Le Blayais » Nuclear Power Plant and asked that a technical team be put together in its emergency response centre to collaborate with Electricité de France emergency response teams. At 7:45 on 28 December 1999, work began to put together a team of experts at the Institute for Nuclear Safety and Protection Emergency Response Technical Centre in Fontenay-aux-Roses.
Given the situation, the Level 2 On-site Emergency Plan was put into operation at 9:00 at the request of the Nuclear Installations Safety Directorate, and a complete emergency response team (comprising 25 individuals) was set in place at the Emergency Response Technical Centre.

An emergency response team was present in this centre at all times from 9:00 on 28 December to 21:00 on 29 December; the team on duty during the day was replaced by another team during the night of 28-29 December. On 30 December, a smaller team continued to observe the situation from the emergency response technical centre and it was not until around 18:00 that the centre officially ceased to operate. During this period, the Institute for Nuclear Safety and Protection sent around 30 messages to the Nuclear Installations Safety Directorate, including 12 on 28 December informing it of the technical situation and the risks that would result from further failures.

Thus, on the morning of 28 December, which was the most critical phase of the flooding, the Institute for Nuclear Safety and Protection estimated that Unit 1 would have had over 10 hours to take action prior to core meltdown in the event of failure of the emergency feedwater system (Illustration 12) which removes the decay heat caused by radioactive decay. This system, which comprises two motor-driven pumps and one turbine-driven pump — only one pump is needed to cool the reactor — showed no signs of failing during operation.

During the three days, the emergency response team had to give prognosis taking into account the fact that a lot of equipment on two Units were not available and could therefore not be recovered in the short term until it had been cleaned or repaired. Consequently, the situation was specific and managed without using any computerised tool but only on the basis of the knowledge of the members of the team. Only the information given by the Site Computer System was used for identifying the damaged equipment. Among the team members, some had been involved in the probabilistic studies performed by the Institute for Nuclear Safety and Protection and were familiar with the different problems to be solved and that concerned : the time before core melt on the morning of 28 December in the case of additional failure, the best state for the plants during the short and medium terms taking into account the Y2K problem which can occur.

4.2 Management of the situation by the emergency response teams

The accident situation involving Units 1 and 2 was managed in four stages:

- shutdown: between 27 December and late morning on 28 December, the units, which had shut down automatically at around 23:00 and 0:30 respectively, switched from operation at rated capacity, when the reactor coolant has a pressure of 155 bar and a temperature of 280°C, to a shutdown state in which the pressure had dropped to around 30 bar and the temperature to 160°C; at the end of this stage, the decay heat to be removed amounted to no more than 15 MW;
- identification of all the paths by which water was entering the site and pumping out of flooded rooms: these operations were completed in the evening of 29 December 1999;
- recovery of Train A of the essential service water system of Unit 1: this work began once all the water had been pumped out of the flooded rooms and was finally completed on 4 January 2000 when all the essential service water pumps had been restored to their original condition (one pump was available as early as 30 December 1999);
- repair of one safety injection pump and one containment spray pump for each unit on 4 January 2000 (with no exhaustive requalification).

To remove the water from the flooded rooms, the power plant used its own pumps and those of the fire services in the vicinity. The water pumped out was released into the River Gironde through the sewage system which flows into a tank with a capacity of several thousand cubic metres, meaning that the plant laboratories could determine the activity of the water before releasing it into the river. The nuclear operator put a figure on the activity per unit volume of the water released into the River Gironde and the Office for Protection against Ionising Radiation also carried out its own measurements. During this period, the values of activity per unit volume due to tritium remained below the detection threshold (with the exception of one unconfirmed measurement of 180 Bq/l) and were therefore lower that the limit for release water, i.e. 1000 Bq/l for tritium.

5 ACTION TAKEN BY THE INSTITUTE FOR NUCLEAR SAFETY AND PROTECTION

5.1 Assessment by the Institute for nuclear safety and protection of safety at the units at Blayais nuclear power plant after the flooding

The information which follows is the result of technical exchanges which have been underway with Electricité de France since 27 December 1999. Experts from the Institute for Nuclear Safety and Protection went to the plant several times.

5.1.1 The situation to end of January

5.1.1.1 Units 1 and 2: On 30 December 1999, Electricité de France asked the Nuclear Installations Safety Directorate for permission to maintain Units 1 and 2 in what is known as the *"normal shutdown state with cooling by the steam generators",* until all the plant electrical systems (off-site supplies and electrical switchboards) had been completely recovered. In the light of a comparison of how the accident sequences might develop in the different states possible, the Institute for Nuclear Safety and Protection was of the opinion that keeping Units 1 and 2 in this state was preferable from a nuclear safety point of view, and the Nuclear Installations Safety Directorate granted Electricité de France its permission accordingly.
On 3 January 2000, Electricité de France indicated its intention to partially restore one train of the low pressure safety injection system and one train of the containment spray system (Illustration 12), to provide a sufficient degree of reliability to bring the units into the refuelling outage state so that the state of the units could be thoroughly investigated and the aforementioned systems completely overhauled. The Institute for Nuclear Safety and Protection thought it reasonable to aim for a state where all the operations required for completely restoring the installations affected by the flooding could be carried out (inspections, repair of structures and equipment, tests for checking that the equipment challenged in the context of safety functions was operating satisfactorily).
On 7 January 2000, on receipt of a favorable answer from the Institute for Nuclear Safety and Protection, the Nuclear Installations Safety Directorate gave the go-ahead for Units 1 and 2 to be switched to the refuelling outage state.

5.1.1.2 Units 3 and 4: Unit 3 was kept in the normal cold shutdown state with cooling by the decay heat removal system. Once the 225 kV auxiliary power supply had been restored on 29 December 1999, Unit 4 was reconnected to the grid on 30 December 1999.

5.1.2 The situation in the short term

The Institute for Nuclear Safety and Protection considered it necessary that Electricité de France devise compensatory measures for the entire site as quickly as possible (installation of a reliable flood alert system, implementation of a procedure, repair of the dike, elimination of paths which could be taken by floodwater, for example by blocking penetrations and installing pressure-resistant doors, prevention of flooding of the compartments containing the equipment needed to reach and to maintain a safe state) and implement them.
Furthermore, the Institute for Nuclear Safety and Protection deemed it necessary that Electricité de France devise a programme for the systematic and thorough inspection of the state of the installations and systems of the units.

At the end of January 2000, Electricité de France has carried out all the inspections required to show that all the damage to Units 3 and 4 had been repaired and that improvements were realised (new alert system, repair of the dike, repair of openings).
On receipt of a favorable answer from the Institute for Nuclear Safety and Protection, the Nuclear Installations Safety Directorate gave the go-ahead for Unit 3 to be switched to nominal power state.
The Units 1 and 2 have been maintained in cold shutdown state for refuelling. At the beginning of May, the Unit 2 was restarted and it is foreseen to restart the Unit 1 at the end of May.
The different following works have been performed.

Alert system

- An improved alert system has been installed.

Procedure

- A procedure has been implemented to be able in case of possible flooding defined by the alert system to bring and to maintain the plants in a safe state.

Dike

As far as the dike is concerned, Electricité de France has defined three stages:

- initial repair by 21 January 2000 (to a height of 5.2 m above the national datum),
- on May 2000, review of the water level to be considered making allowance for the flooding which occurred on 27 December 1999 without allowance to the effect of the heavy wave and erection of the corresponding dike,
- at the end of 2000, review of the water level to be considered for determining the final protections of the site, making allowance for the flooding which occurred on 27 December 1999 and to the effect of the heavy wave.

Flooding of rooms

A number of routes were taken by the floodwater. Flooding spread mainly through the general site gallery, doors, pipe penetrations in masonry structures and hoppers. The following have been assessed:

- the ways in which rooms are flooded through the general site gallery. In the wake of the flooding, Electricité de France has investigated a certain number of sensitive points (hoppers in pumping station pump rooms, for example),
- the initial installation, or installation as a result of modifications, of openings between trains (Essential Service Water System galleries, for example) or between items of equipment in the same train (cells of Essential Service Water System pump cells) calling into questions the original arrangements made to protect against fire or flooding,
- door strength. At certain access points, the leaktightness of doors and their ability to withstand pressure have been reviewed not only in terms of challenges corresponding to fire but also in terms of leaktightness and strength at a certain depth of water in the event of flooding,
- the strength of the various hoppers, given the loads and constraints which may be applied to them,
- the characteristics of the recirculation line penetrations leading to the fuel building on the sumps in the containment of the safety injection system and the containment spray system.

Protection of the equipment needed to bring and to maintain the Units in a safe state

In case of possible flooding of the site detected by the alert system, provisions will be installed against every door of the main buildings to avoid entrance of water inside.

Behaviour of structures

The following have been assessed:

- possible degradation of the structures, even though there was no obvious damage associated with the flooding (apart from the dike),
- strength of joints between buildings,
- the consequences of flooding of the Containment Instrumentation System gallery under the reactor building as regards the strength of the equipment it contains,
- the strength of the waterstop joint under the basemat.

Repair of systems

Following technical discussions with the Institute for Nuclear Safety and Protection, Electricité de France used the exhaustive list of rooms affected in Units 1, 2, 3 and 4 and targeted all the equipment to be covered for restoring completely the installations and to propose the corresponding requalification programmes to be run.

Furthermore, the chlorine content in the water has been analysed. A content of 300 mg/l was recorded, which corresponds to the characteristics of the River Gironde and makes the water slightly corrosive. The Institute for Nuclear Safety and Protection considers it necessary to assess the impact of this finding on equipment, particularly electrical equipment, on the sheaths protecting cables from fire and on the strength of supports (anchoring plugs etc.).

Electricité de France has analysed each item of equipment in turn (cables, stops, sheaths, fire detectors, heat lagging etc.) to be able to establish its expected resistance to flooding and a design or modification programme intended to guarantee this resistance and, where appropriate, allow lessons to be learned as regards the qualification of materials.

5.2 Investigations to be carried out

The partial flooding of « Le Blayais » Nuclear Power Plant raises a number of issues regarding the state of the units but also calls into question the design bases used to reduce the consequences of external flooding and, by extension, the consequences of any internal or external events in all French plants equipped with pressurised water reactors.

Electricité de France is reviewing the design bases for all its units in the light of observations made after the « Le Blayais » flooding and the lessons which can be learned from it, and will propose modifications where appropriate (see Section 6).

The following sections deal with the issues which should be reviewed in the light of the flooding of 27 December 1999 and give the preoccupations highlighted by the Nuclear Installations Safety Directorate on the basis of the assessment made by the Institute for Nuclear Safety and Protection.

5.2.1 Limiting the risk of external flooding at french nuclear power plants

The general principles for the protection of the Nuclear Power Plants against flooding of external origin are defined in the french Basic Safety Rule (RFS 1.2.e) whose respect is considered as being in conformity with the french technical regulations.

According to this Basic Safety Rule, protection is mainly provided by:

1. setting the platforms supporting buildings housing safety-related equipment at a design basis flood (DBF), i.e. a level at least equal to the highest water level, plus a safety margin.
2. blocking of paths by which water could enter facilities housing equipment used to maintain the installation in a safe state, when these paths are located below the platform level.

As regards the action to be taken at plants built before Basic Safety Rule 1.2.e came into force on 12 April 1984, the rule stipulates that plants which do not comply with the first criterion should nonetheless comply with the second, and that supplementary steps should be envisaged to ensure a level of protection equivalent to that of Basic Safety Rule 1.2.e. Furthermore, in the case of certain plants with special features, reviews will have to be made of the risk of flooding due to their proximity to canals whose water levels are higher than the levels of the platforms.

The data used to position the platforms of all the Nuclear Power Plants in France, which have the same type of reactors as those at « Le Blayais », will have to be reviewed, particularly as regards application of Basic Safety Rule 1.2.e. The data considered are tide levels, the influence of the natural phenomena taken into account, the levels reached when rivers burst their banks and the extra margins to be used. The Institute for Nuclear Safety and Protection has studied the data used to position the platforms of all the Nuclear Power Plants in France and suggests that certain issues be examined in more depth.

The examination carried out by the Institute for Nuclear Safety and Protection on the risk of external flooding at plants with pressurised water reactors consisted in:

- dividing the plants into categories obtained from the application of Basic Safety Rule 1.2.e,
- examining the elements corresponding to each site to determine which issues could be raised in the context of a review of the steps taken to prevent flooding or limit the consequences should flooding occur. This examination resulted in the identification of issues specific to each plant which had to be investigated further to ensure that the installations would be effectively protected from the risk of external flooding. The issues are as follows:
  I. in the case of plants where protection is provided not by the position of the platform but by a dike, the geometry and strength of the dike have to be reviewed,
  II. in the case of plants where protection is provided not by the position of the platform but by the implementation, in the event of an emergency, of special protective measures detailed in Procedure H5 (activated by a high water level warning system), these protective measures will have to be studied in more depth to determine whether or not they are adequate,
  III. in the case of plants where protection is provided by the platform position but with a low margin between the design basis flood (DBF) and the platform level, it has to be investigated whether this margin is adequate, particularly as regards the possible settling of the ground and/or the hypotheses used to calculate the design basis flood (DBF),
  IV. the design basis flood (DBF) will have to be recalculated, particularly when there is a degree of uncertainty surrounding natural phenomena,
  V. the vulnerability of the pumping station will have to be looked at. In many plants, certain points of access to the pumping station are located below the platform level,
  VI. the risks corresponding to the presence of canals close to the plant whose water levels are higher than those of the platform will have to be examined,
  VII. the effectiveness of the flooding alert system will have to be studied,
  VIII. the risk of the plant becoming isolated in the event of flooding round about it will have to be investigated.

Finally, the following conclusions can be drawn from the division of the plants into four categories according to the two criteria described above which result from the Basic Safety Rule 1.2.e:

- Chooz, Civaux and Cattenom Nuclear Power Plants comply with Criteria 1 and 2 above, with margins.
  This is confirmed by examination of the characteristics of these plants. However, it remains to be confirmed that the pumping stations of the three plants are not vulnerable,
- at Bugey, Cruas, Flamanville, Golfech, Nogent, Paluel, Penly and Saint Alban Nuclear Power Plants, the platform of the nuclear island is above the design basis flood (DBF).
  It has been observed that the current margins between the design basis flood (DBF) and the platform level are very low in certain cases. Consequently, additional studies will have to be carried out to confirm that there is an adequate margin, despite the uncertainty which may exist concerning certain parameters, especially the current level of the plant buildings, making allowance for any settling which might affect them. For these plants, special investigation should be carried out into the alert systems. Furthermore, it would be useful in the medium term to review the safety levels of coastal sites by making allowance for swell effects. Review of the flooding risks at these plants could be useful at times.
  As regards compliance with the second criterion, the examination carried out reveals that checks should be made to ensure that there is no risk of flooding in the pumping station.
- At Belleville, Chinon, Dampierre, Gravelines, Le Blayais and Saint-Laurent NPP, the nuclear island platform is below the design basis flood (DBF).
  The hypotheses used to calculate the design basis flood (DBF) of the plant involved should be re-assessed so that the values can be confirmed or updated. The current levels of the plant buildings should also be examined, bearing in mind that they may have been affected by settling.
  Furthermore, all the special arrangements taken, including alert and access systems and the protection of equipment in the event of flooding (particularly in the pumping station), should be

assessed, making allowance for the results of the review mentioned above, either to show that the current arrangements are perfectly adequate or to improve them.
Studies of equipment protection should focus on flooding as a result of an increase in the level of the water table.
It would also be useful to review the design basis flood (DBF) values at coastal sites by making allowance for swell effects and, if need be, to identify improvements to be made to the pumping station.

- Fessenheim and Tricastin Nuclear Power Plants are located near canals whose water levels are higher than the platform levels.
  In the case of these plants, it should be confirmed that the dike is earthquake resistant and its vulnerability to percolation should be examined. The percolation rate should be reassessed given the review of the hydrogeological characteristics and whenever countermeasures have to be taken.

5.2.2 Generic lessons to prevent and mitigate external flooding at french nuclear power plants

5.2.2.1 Alarm system:

The effectiveness of the entire alarm system should be analysed, particularly its ability to detect the risk of flooding of the plant. It would seem particularly appropriate to examine the equipment used (tide sensors, wind measurements etc.), the reliability of the information provided by the organisations contacted (Météo France), the parameters monitored and the criteria triggering the alarm, as well as the way in which the alarm was managed and the strategy adopted as regards unit operation.
Furthermore, the consistency between the various documents dealing with emergency situations will have to be analysed.
This analysis should cover all plants with alarm systems, to determine whether or not they are suitable.

5.2.2.2 Safety systems:

5.2.2.2.1 Leak collection and drainage system:

Detecting the presence of water in rooms
During the flooding, many of the outgoing feeders of the leak collection system which powered the level sensors had to be disconnected to keep the electrical switchboards available, even though the availability of this system is particularly important in the context of flood management. As a result, the design approach should be reconsidered and the need for improvements should be assessed by means of a safety analysis focusing on the equipment affected.
Design of draining devices
The flooding at « Le Blayais » NPP showed that :

- flooding and loss of the off-site power supplies could occur simultaneously, whereas very few of the drainage pumps are emergency-supplied,
- some inconsistencies can exist both between the redundant design of safety systems and the provisions implemented to protect them against the internal hazards (as it is the case at "Le Blayais" site for the Essential Service Wtaer System) and between the provisions implemented to deal with different internal hazards.

These points should therefore be investigated.

5.2.2.2.2 Auxiliary feedwater supply of steam generators:

The incident once again revealed the importance of the steam generator water supply. In this respect, the two following points should be particularly reviewed :

- the provisions taken to protect the Auxiliary Feedwater System against a flooding, as far as the system cables were flooded at "Le Blayais" site,
- the reliability of the Auxiliary Feewater System and the one of its deionised water supply, especially when all the Auxiliary Feewater System tanks have to be simultaneously refilled.

5.2.2.2.3 Effect on electrical equipment:

During the incident, some of the Power System switchboards had insulation resistance problems.

5.2.2.3 Effect on operation:

Detailed assessment of the way in which Units 1 and 2 were operated in the night of 27 December 1999 could provide valuable information on management of the situation by the operators and the emergency response structures at local and national level, with particular emphasis on the human factor, procedures and organisational structure. This assessment will then have to be completed.
Consideration will have, also, to be given to the appropriateness of the technical specification for operation to the cases of unavailability actually observed, particularly the safe state recommended in the event of total unavailability of the Safety Injection System.

5.2.3 Lessons learned as regards internal flooding

The flooding at « Le Blayais » NPP revealed a potential link with what is known as internal flooding. Therefore, for all the plants where there is a risk of external flooding, including « Le Blayais », the Institute for Nuclear Safety and Protection considers that, in addition to the action suggested in Section 5.2.1 and in order to show that safety-related systems are not vulnerable, there should be an assessment of the margins introduced by the protection devices implemented in the nuclear island to prevent internal events. Should these margins prove to be inadequate, protective devices correctly designed to handle the loadings likely to be introduced by the spread of external flooding to the nuclear island should be implemented.
Moreover, for all the plants, there should be a re-examination of the state of the files on the prevention of the risk of internal flooding, the corresponding analyses carried out and the current state of compliance of the units with the safety requirements.

5.2.4 Lessons learned as regards other external events

By extension, the flooding at « Le Blayais » Nuclear Power Plant could lead to consideration of the appropriateness of the methods commonly used to determine the gravity of what are known as external events (earthquakes, extreme cold etc.). Consequently, the appropriateness and consistency of the measures adopted for the entire range of external events should be examined and modifications proposed where required.
The problems associated with operating team shift turnover and the mustering of emergency response teams at the « Le Blayais » plant during the flooding of 27 December 1999 should be examined in the context of any external event at a Nuclear Power Plant liable to disrupt the surrounding area.

6 ELECTRICITE DE FRANCE STUDY PROGRAMME

Electricité de France has launched a design review covering all its Nuclear Power Plants; this should result in action programmes and specially scheduled independent modifications:

- in October 2000 for plants considered to be a priority,
- during the first half of 2001 for the other plants.

Discussions are currently being held to determine which plants should take priority.
The design review focuses on the following issues:

- Issue 1: listing and review of design hypotheses.
  The aim is to list all the design data and suggest modifications based on methodological study in the following areas:
  - hydrological studies and design basis flood (DBF) calculation,
  - arrangements taken to protect the platform and the units,
  - alarm process,
  - operating procedures and systems required for bringing the units to a safe state and maintaining them there after a flood.
- Issue 2: examination of routes taken by water.
  The aim is to make on-site enquiries as to the various routes taken by water in the event of immersion of the platform and to suggest additional provisions where required.
- Issue 3: control of the structures.
  The aim is to improve the maintenance programme and to include additional examination of the structures.
- Issue 4: H5 procedure.
  The aim is to review all the H5 procedures or their equivalents and suggest modifications where required.
- Issue 5: other lessons from the experience feedback from the incident at « Le Blayais ».
  The aim is to study the observations made during the incident which occurred at « Le Blayais » NPP on 27 December 1999, focusing on the availability of alarms, power supplies, pumping equipment and possible releases.

The study programme proposed by Electricité de France addresses the preoccupations highlighted by the Nuclear Installations Safety Directorate on the basis of the assessment made by the Institute for Nuclear Safety and Protection (see Section 5.2).

7 CONCLUSION

The flooding which occurred at « Le Blayais » Nuclear Power Plant revealed a potential mode by which the safety of all the units of a single plant could be jeopardised.
The Institute for Nuclear Safety and Protection has therefore begun a short and medium term programme to determine the lessons to be learned from the flooding for all plants in France with pressurised water reactors. The study programme proposed by Electricité de France addresses the preoccupations highlighted by the Nuclear Installations Safety Directorate on the basis of the assessment made by the Institute for Nuclear Safety and Protection. The first results of the investigations will be available on October 2000.

List of illustrations