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European Clearinghouse:

Report on External Hazard related events at NPPs

Summary Report of an European Clearinghouse Topical Study

Benoit Zerger
Manuel Martín Ramos
Miguel Peinador Veira

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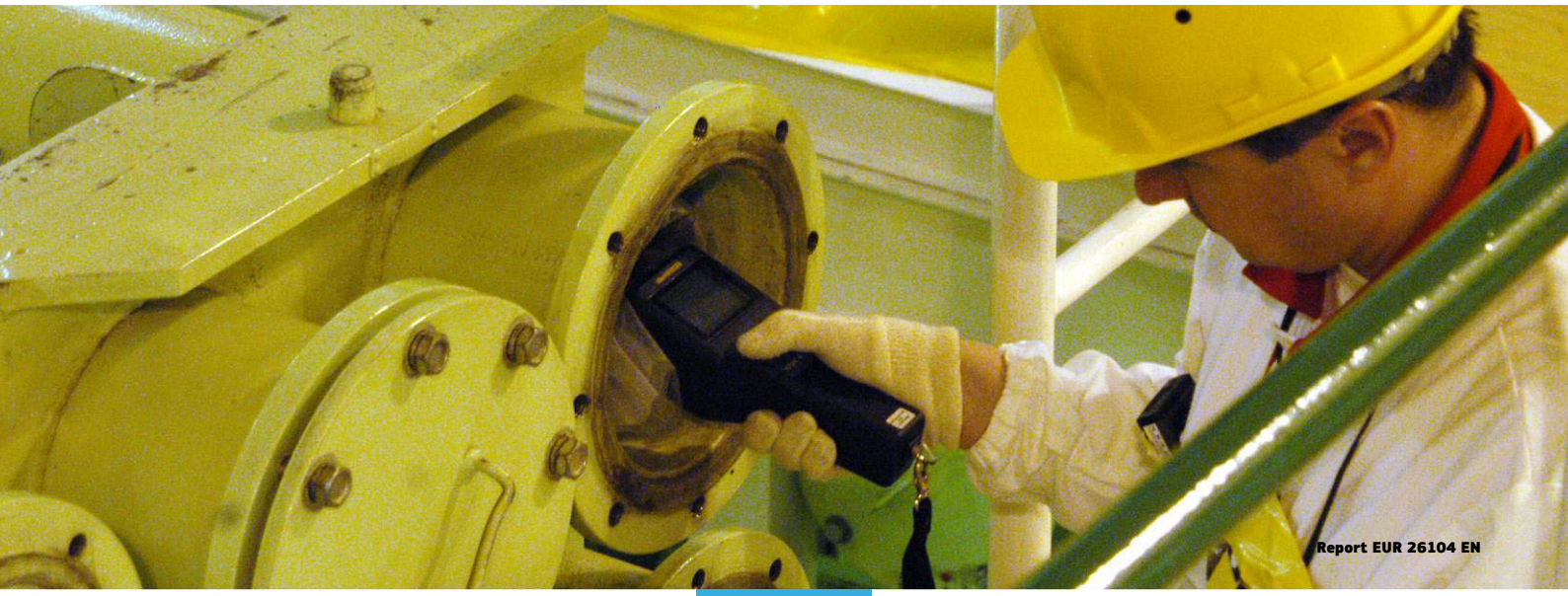

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Contact information
Miguel Peinador Veira
Address: Postbus 2, 1755 ZG Petten, the Netherlands
E-mail: Miguel.peinador-veira@ec.europa.eu
Tel.: +31 22 456 5176
Fax: +31 22 456 5637

http://iet.jrc.ec.europa.eu/
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LIST OF ACRONYMS

EDG	Emergency Diesel Generator
ESWS/CCWS	Essential Service Water System / Component Cooling Water System
GIC	Geomagnetically Induced Current
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit mbH
CWS	Cooling Water System
IAEA	International Atomic Energy Agency
INES	International Nuclear Event Scale
INPO	Institute of Nuclear Power Operations
IRS	International Reporting System for Operating Experience jointly operated by IAEA and OECD/NEA
IRSN	Institut de Radioprotection et de Sûreté Nucléaire
LOOP	Loss Of Off-site Power
NPP	Nuclear Power Plant
OECD/NEA	Nuclear Energy Agency
OEF	Operating Experience Feedback
PSA	Probabilistic Safety Analysis
WANO	World Association of Nuclear Operators

1 INTRODUCTION

External phenomena are a significant source of hazards to nuclear power plant operation, and thus it is important to investigate the existing operational experience in this kind of events. The objective is to determine the adequacy of protection of nuclear power plants against external hazards and the effectiveness of corrective actions, as well as to provide recommendations on how to prevent or mitigate the impact of external phenomena on NPP operation.

IAEA Safety Guide NS-G-1.5 [1] defines external events as "events that originate either off the site or within the boundaries of the site but from sources that are not directly involved in the operational states of the nuclear power plant units, such as fuel depots or areas for the storage of hazardous materials handled during the construction, operation and decommissioning of units located at the same site".

The interpretation of this definition may vary in different countries. In some cases, some events which cannot be considered as external events but which can give interesting insights (as the case of the rupture of large water pipes related to flooding hazard) have been retained.

This Summary Report presents the results of a comprehensive study [2] performed by the European Clearinghouse on Operating Experience Feedback of NPP with the support of IRSN (Institut de Sûreté Nucléaire et de Radioprotection) and GRS (Gesellschaft für Anlagen und Reaktorsicherheit mbH). It addresses both natural origin and man-induced external events. An important exception is the earthquake hazard, which has not been studied in this report as other extensive reports have already covered the matter. However, in the case of tsunamis resulting from earthquakes, these events have been taken into consideration.

It is worth to note that the study [2] was started in 2010 and therefore it does not address the Fukushima accident.

2 METHODOLOGY

Three different event report databases have been searched in order to analyze the operating experience of events related to external hazards, namely

- The International Reporting System for operating Experience (IRS), operated jointly by the IAEA and the OECD/NEA. The IRS is a worldwide system containing 3700 incident reports at the time of preparation of this study. Events are reported on a voluntary basis, and the reporting criteria vary with countries.
- SAPIDE database, operated by the IRSN in France. It contains more than 10.000 events reported by French nuclear power plants under French regulations.
- VERA database, operated by GRS in Germany. It includes about 6.000 events reported by German plants under German reporting criteria.

All databases were searched using keywords and other specific searching tools, yielding a list of potentially relevant events. Reports of these events were reviewed individually to determine the actual cause, thus obtaining a screened list of relevant events.

After screening, the relevant events were classified into one of the following groups:

- Extreme weather conditions. This group includes events related to extreme ambient temperature (low or high), strong winds (including tornadoes, typhoons, hurricanes, etc.) or intense water precipitation without flooding.
- Extreme heat sink conditions. This group refers to events in which the temperature or the level of the heat sink (i.e. river or sea) is extremely low or extremely high, in a way that can severely affect the adequate reactor cooling in different situations.
- Flooding. This group includes any kind of power plant building flooding from external origin (river, dam, tides, tsunamis, etc.). Also included are floods caused by system failure / piping breaks whenever the cause of the system failure is related to the external environment.
- External fires.
- Lightning strikes.
- Fouling of the water intake. These are events of biological origin (ingress of sand, vegetable debris, seaweed, fish, etc. in the water intake structures) usually impacting the availability of the ultimate heat sink.
- Corrosion or chemical fouling caused by external environment. These events include those originated by salinity or pollution of the environment, by corrosion due to external water retention or by chemical fouling linked to the external environment.
- Man-induced events. Any incident caused accidentally by human activity external to the plan, as well as any malevolent act is included in this category.
- Solar magnetic disturbances.

Wherever an external event was initiated by the combination of different external phenomena, the phenomenon having the main impact was considered with regard to the classification into a particular group.

For every group of events, the report summarizes the lessons learned as well as the recommendations which can be drawn from the operating experience.

The annual frequency, the distribution of the events in time, and the linear trends calculated must be interpreted more as a description of the available data rather than as an actual trend. One of the reasons is the limited number of events reported, in the first place, and, in the case of the IRS, the fact that events are reported on a voluntary basis, as stated above.

3 MAIN FINDINGS

This section presents the main results of the quantitative analysis performed on the events identified.

The search for incidents in the IRS yielded 421 event reports, from which 87 were retained after screening. In the case of SAPIDE and VERA databases, the search yielded 112 and 36 applicable events respectively. Given to the different nature of the databases, only simple statistical analyses were performed on the data to gain some insight into the distribution of the events by type and the trends through the years.

3.1 Distribution by group of external event

Figures 1 through 3 show the distribution of the events according to the types described in the previous section, for every database.

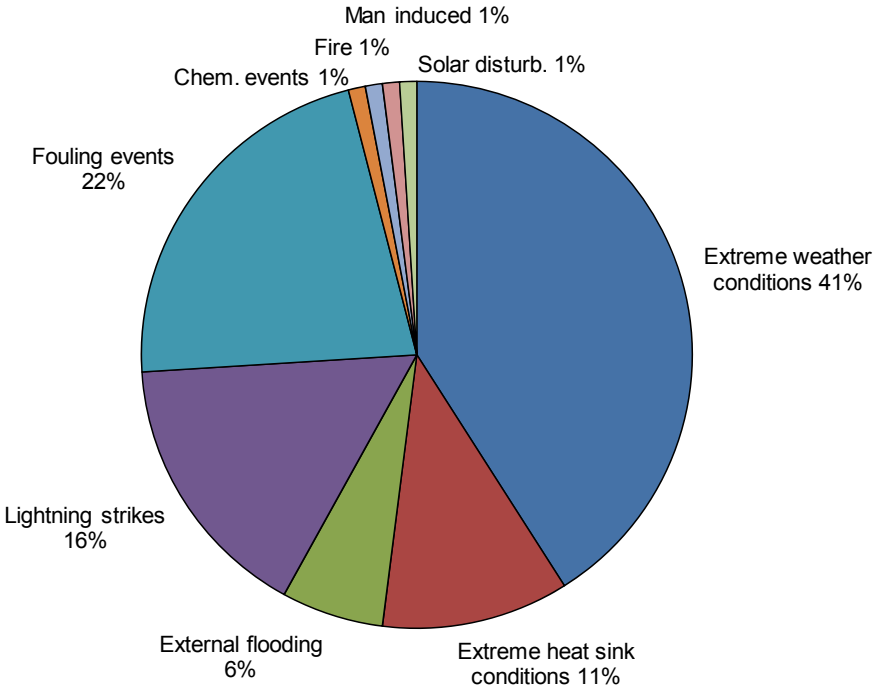

Figure 1 – Distribution of external hazard related events reported to the IRS

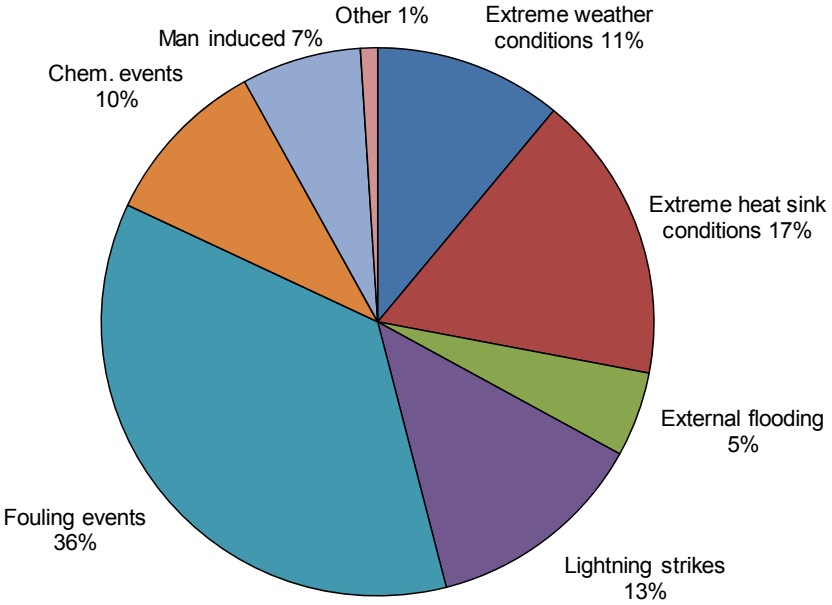

Figure 2 – Distribution of external hazard related events in France

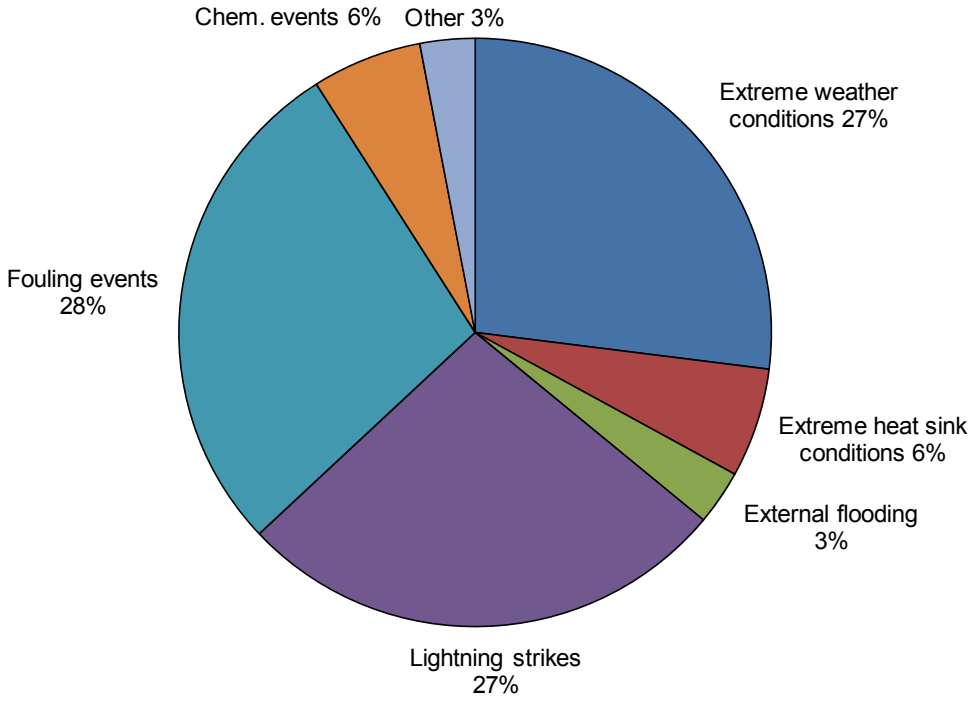

Figure 3 - Distribution of external hazard related events in Germany

In all three databases, four categories of external events comprise most of the incidents, namely fouling events, extreme weather conditions, lightning strikes and extreme heat sink conditions.

3.2 Trends in time

The classification of the significant events by year of occurrence yields the time frequencies shown in figures 4 through 6.

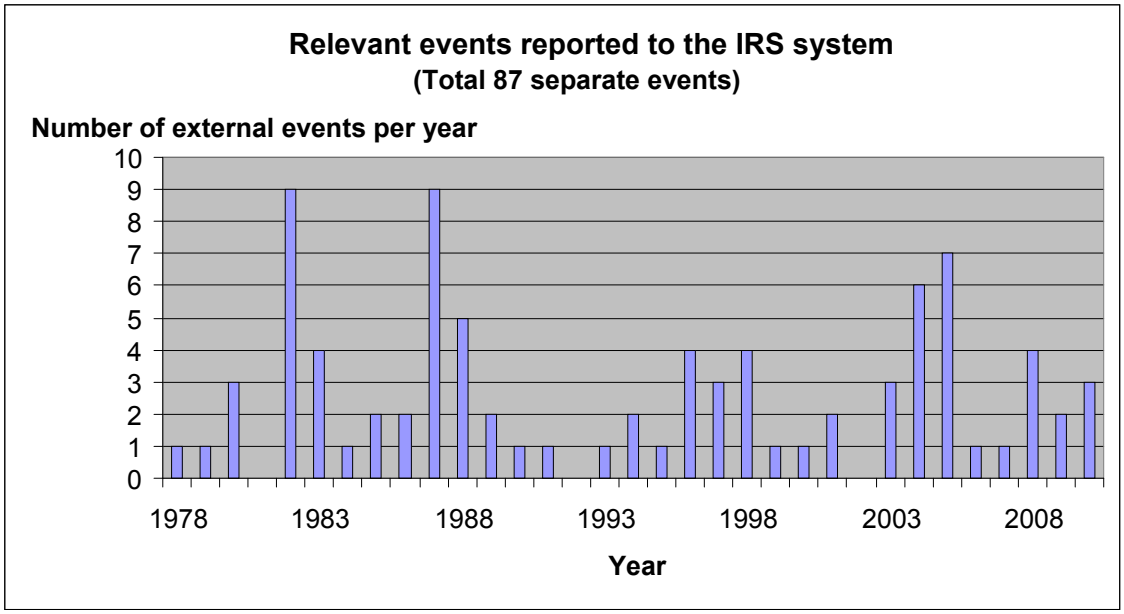

Figure 4 – Time distribution of external hazard related events reported to the IRS

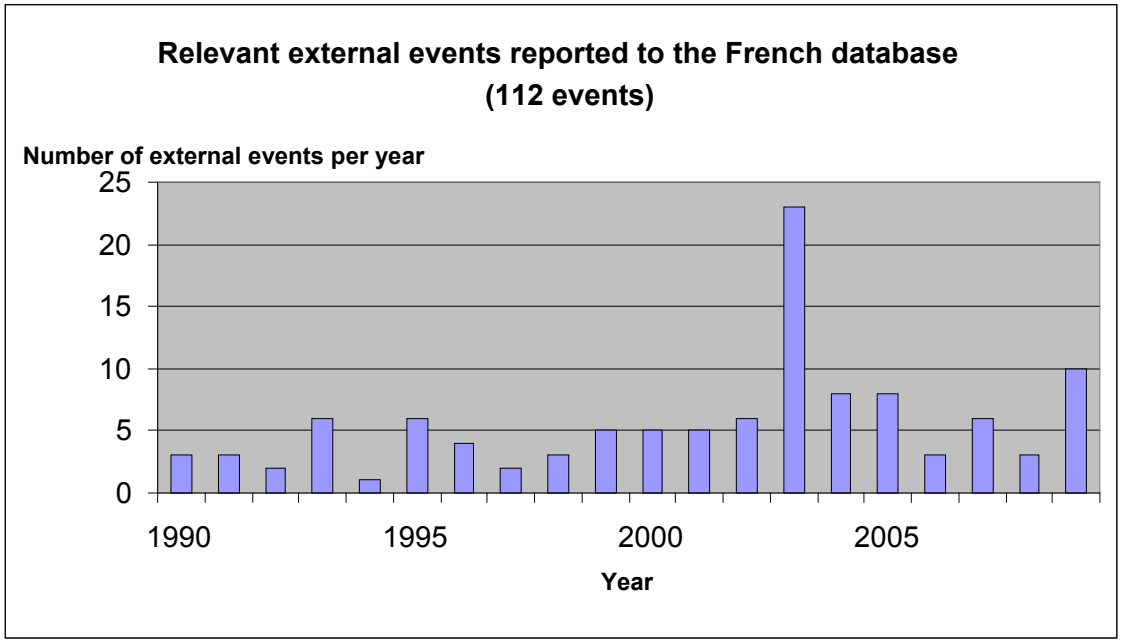

Figure 5 – Time distribution of external hazard related events reported in France

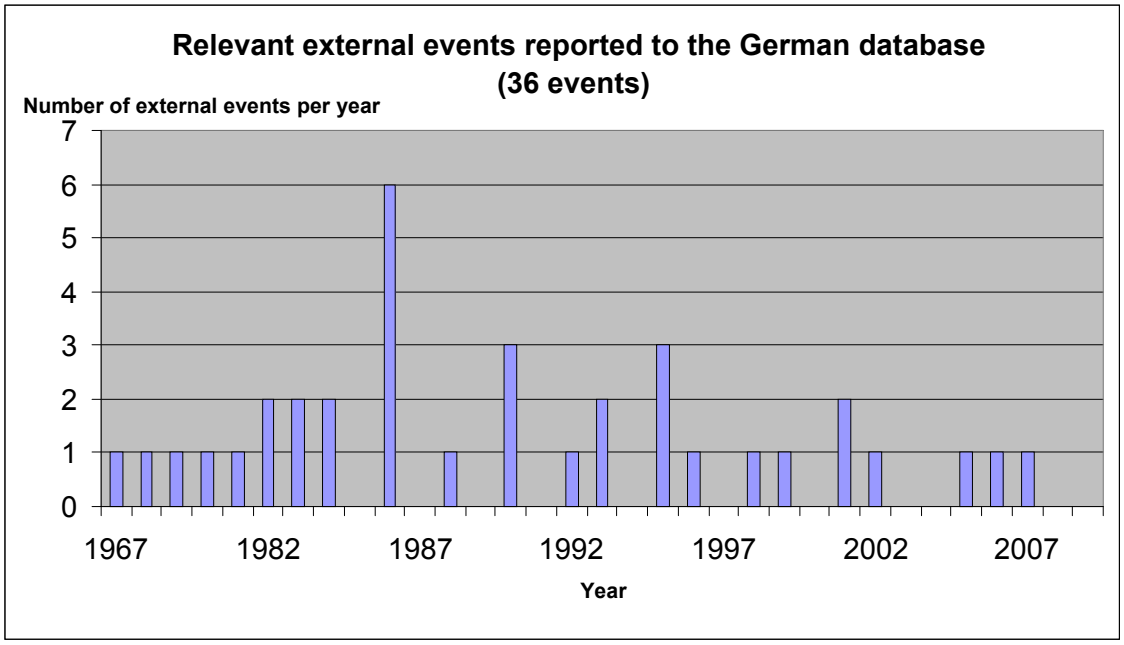

Figure 6 – Time distribution of external hazard related events reported in Germany

In some years, the high frequency can be explained by specific climate conditions experienced in particular areas of the world, as for example the cold weather in North America in 1982 (7 events), the cold weather in Russia in 1987 (6 events) or the hot and dry conditions in France during the summer of 2003 (16 events).

No clear trend can be identified in these figures, though in the case of the SAPIDE database a slight increasing trend might be suspected.

4 LESSONS LEARNED

This section presents the main lessons learned raised from the analyzed event reports for each category of external hazards.

4.1 Extreme weather conditions

Most events included in this category were related to freezing and ice caused by very low ambient temperatures as well as to strong winds or precipitations. The most important lessons learned from these events are summarized below:

- In cold days, instrument lines may freeze due to local low temperatures (portions of impulse lines close to openings in the building or adjacent to metal parts, like supports, not insulated). This in turn may lead to spurious signals or misleading information for the operators.

- The combination of high inside air humidity and low walls temperature can lead to excessive condensation and failure of electrical equipment. This can be caused in particular by erroneous design of ventilation systems.

- Frost spreading inside NPP buildings can lead to equipment/piping break by bulge

during ice formation. Important leakages can occur during unfreezing.

- After a loss of offsite power due to an external event, such as strong wind, the automatic initiation of emergency systems might need to be disabled to undergo functionality tests prior to reactor start up. In this situation, it is important to ensure that procedures and training are suitable for manually aligning all emergency cooling systems in case a second LOOP happens with automatic initiation disabled.

- Grid disturbances prior to a LOOP event may trigger repeated automatic preventive startups of EDG equipment. These repeated startup signals might exhaust the start-up compressed air, rendering the EDG inoperable when the LOOP actually takes place. The EDG automatic control should be designed in such a way that this situation is precluded.

- Any operation, maintenance or construction activities which imply a modification of the freezing protections should be assessed properly prior to the activities and every time the activities are extended, with regards to the freezing risk.

- Not properly fixed metal objects, in case of high wind, can lead to a short-circuit by creating a link between two phases of high-voltage lines.

- The chillers design should consider the combination of low cooling water temperature with low heat load (in addition to high cooling water temperature with high heat load) in order to ensure the chillers operability in extreme weather conditions where this combination is likely to occur.

- High wind blowing in the direction of a cooling-tower can create important water movements in cooling-tower ponds which can lead to CWS pump tripping by “low water level” protection.

- Cleanness of NPP buildings and roofs on completion of repairs, and on a regular basis must be ensured by organizing and performing appropriate monitoring of building roofs, storm drains ducts and debris-retaining grids.

- Total loss of unit power events and unit stability with extended frequency and voltage oscillations conditions should be assessed and appropriate corrective actions (including automatic changeover set points, protections & interlock settings and personnel actions) should be envisaged to assure specified cool down and allocate one of the units for operating to meet the in-house power requirements.

- Additional instructions and procedures should be given to personnel responsible for operating ventilation systems as to the mode of operation of the intake systems at below zero external air temperatures, to prevent overcooling of the air in the parts of the NPP served by these ventilation systems. Equivalently, hot ambient air conditions should be taken into consideration to avoid high temperature in the rooms where safety equipment is located.

4.2 Extreme heat sink conditions

Emergency or post shutdown cooling functions can be compromised if abnormal conditions exist in the ultimate heat sink, usually the sea, a river or a lake. These abnormal conditions may be caused by high or low temperature or by high or low level. However, the review of the operational experience has shown that most safety significant events were related to low temperatures of the heat sink with ice buildup and eventually

water intake clogging or malfunctioning.

Most important lessons learned follow.

- Cold weather and ice formation may clog and make unavailable the normal water intake. By-pass cooling water lines can help in case the normal water inlets are not operable.

- For NPPs located in cold areas, the design should take account of the formation of frazil ice in the water intake channel and include adequate protection and warming systems. In addition to design provisions, the plant operation should consider that the formation of frazil ice can be a very fast phenomenon and thus should provide appropriate surveillance and operational procedures, for instance early recirculation of hot water to reheat water in cold conditions before ice formation.

- Adequate and reliable instrumentation and monitoring systems should be implemented to early detect sudden changes in the conditions (temperature, flow) of the heat sink.

- It is important to comply not only with safety requirements for climatic hazards, including frazil ice, but also to assess regularly the adequacy of protective measures against these risks. This assessment should consider particularly the risk of common cause failure induced by the use of devices common to the entire plant.

4.3 Flooding

- Room division, which ensures system reliability in case of common cause failure, can be compromised with unblocked passages between rooms supposed to be independent. Room division should be restored after working activities (drilling for cable introduction, for example) and periodic controls about room division should be carried out to notice and correct potential non-compliances.

- Consequences of NPP site isolation in case of external flooding should be studied in order to ensure emergency staff arrival.

- Water retention on NPP building roofs combined with the rupture of inter-building sealing joint can be considered as a potential phenomenon of external flooding.

- External events PSA results should be used to understand high seawater level events consequences and to implement adequate surveillance and management procedures.

- It should be ensured that the drainage system is functional and that the water tightness of buildings, penetrations and other openings are checked regularly.

- Adequate measures should be taken to avoid internal flooding caused by pipe break due to different causes (i.e. corrosion, stagnant water sedimentation, freezing and unfreezing, etc.).

4.4 External fires

Only one incident was identified in this category, and no significant lessons learned or recommendations can be issued.

4.5 Lightning strikes

- The plant should be properly protected against lightning strikes. Some examples of protection measures are: wrapping of the conduits containing signal cables for neutron flux measurement in aluminum shield, isolation of static wire associated with high voltage transmission line from power station structural steel, installation of volt traps across the power feed to the auxiliary power supply, installation of low-pass filters on the input of 24 V positive supply, installation of copper conductors, external to containment, from the roof mounted lightning rods directly to ground rods in the earth, or measures to improve grounding of stack and main control panel.

- One of the consequences of a lightning strike may be the generation of spurious signals, hence originating virtually unpredictable events.

- The adequacy of the electric system protection of the plant should be evaluated, analyzing the effect of a lightning strike in the switchyard. In particular it should be verified that the mechanisms in place that would prevent the strike from propagating the voltage surge to safety related electric buses, and instrumentation, etc.

4.6 Fouling of the water intake

- Additional means (updated procedures, cleaning equipment, human resources, protection) should be anticipated against (seasonal) inrush of fish or massive arrival of vegetable material, mud, etc… which may clog the water intake.

- The water intake should also be protected against biological fouling (buildup of colonies of mussels, shells, etc.).

- It is important to be aware, through an early warning system, of an impending potential influx of seaweed into the Cooling Water System (CWS) system (based for instance on tidal, wind direction and wind speed indicators) and the need to be clear on the actions to be taken should a large ingress of seaweed occur. The same holds true for the case of water release from upstream dams.

- Massive and sudden arrivals of materials at the water intake entrance should be taken into account to define periodicity of the inspection and cleaning of coarse screens or rotating drum screens.

- Monitoring maintenance operations, especially analyzing the results of de-silting operations (nature, granularity, amount of removed sediment…) should be implemented.

- Changes in operating practices, (increased flow rate of water pumped from the river) might have impact on silting kinetics.

- Periodicity and methodology of bathymetry measurements should be able to detect a slow silting-up kinetic.

- Regular dredging operations on the intake channel entrance reduce the probability of a total heat-sink loss.

- Sludge particles passing through screens can damage pumps and lead to system failure.

- Study of low flow areas should be carried out during design stage of equipment

containing raw water in order to limit biofouling development and to define mechanical cleaning periodicity.

- Cross section passage reduction due to biofouling causes speed flow acceleration which can lead to a corrosion-erosion phenomenon.

- Sufficient protection measures should be in place to avoid ESWS/CCWS heat exchanger clogging and fouling.

4.7 Corrosion or chemical fouling caused by external environment

- Proper protection of outside electrical components should be ensured against salt contamination.

- On-site pollution should be adequately monitored, considering the site environment (salt, chemical industries, works…).

- Design of watertight joints for piping, which penetrate inside NPP buildings, should not retain rainwater, leading to corrosion development. Deposit corrosion phenomenon should be studied in all equipment containing stagnant raw water, to prevent its formation.

- Concrete piping design should consider saline environment, notably regarding salt impregnation. Stress corrosion phenomenon, notably on saline environment, should also be taken into account for outside equipment design.

- Corrosion kinetic, caused by water passing in different equipment, should be studied in order to adapt their maintenance.

- Minor corrosion dots on equipment surfaces is recommended to be repaired when they are detected in order to ensure system reliability on a long-term range

- Salty environment should be taken into consideration in the design, especially in the case of electric systems.

- Scaling kinetic of cooling-tower packings should be analyzed to define cleaning periodicity. The scale characteristics should be analyzed to define an efficient cleaning process. CWS suction grids are recommended to prevent scale penetration inside pumps and to avoid tripping due to important fouling

4.8 Man-induced events

- The potential impacts of industrial activity in the vicinity of the site (for instance blasting operations) should be known, by elaborating, for example, appropriate safety assessments.

4.9 Solar magnetic disturbances

- Solar magnetic disturbances may induce voltage potentials in the earth's crust which in turn cause geomagnetically induced currents (GIC) to flow in transmission lines. This can affect the power systems in different manners: power transformers excessive heating, spurious actuation of protective relays or voltage drops. These events can thus be precursors to loss of offsite power or station blackout sequences.

- Warning systems and procedures should be implemented to respond to a strong solar magnetic disturbance event (for instance by close monitoring of the electrical power system or rescheduling electrical equipment planned maintenance).

5 CROSS CUTTING RECOMMENDATIONS

The lessons learned issued in the previous chapter are specific to every category of external event. However, a number of cross cutting recommendations have been extracted from the analysis. It must be noted though that the applicability of these recommendations to a particular site must be based upon further specific analysis.

1) Re-assess the robustness of the plant design to ensure it can cope with all types of external hazards.

Design is the base of the "defense-in-depth" concept to protect NPP against the external hazards effects. The maximal effects of each type of external hazards should be re-evaluated considering recent trends and protections have to be designed and sized in consequence. Moreover, appropriate safety margins should be taken.

"Passive" protection should be favored to "active" protections because they are less susceptible to failure.

2) Consider all combination of phenomena that can lead to an external hazard.

Combination of several "minor" phenomena can lead to an "important" external hazard. For example, the combination of a big storm with a high tide led to the external flooding of a power plant in 1999.

Therefore, even minor phenomena should be characterized and all possible combinations of these phenomena should be considered.

3) Anticipate the external hazard situations to ensure the NPP preparation.

Anticipation is essential to ensure NPP safety in case of an external hazard, notably concerning the extreme weather conditions.

The measures to ensure NPP safety in case of an external hazard should be pre-established for each type of hazards or combination of hazards. (For example, in case of storm the operators should carry out some preventing actions like the closure of all external openings in the NPP, a particular monitoring of the heat-sink, the check of demineralized water quantity and fuel quantity available on NPP site, the operating emergency team has to reach the NPP site, etc.).

In particular, procedures for managing the combination of an external hazard and its probable consequences (i.e. flooding and loss of offsite power) should be developed.

4) Implement a systematic communication to the plant personnel in case of expected extreme environmental conditions (high/low temperatures, wind, river/sea level…).

The management of NPPs should make provisions in order to convey the weather forecasts and warnings to the plant staff early enough to take the anticipated actions recommended in the preceding paragraph.

5) Train regularly operators and emergency teams to cope with all types of external

hazards, including rare phenomena.

Linked to the previous recommendation, training should enable operators and emergency teams to be familiar with the procedures, organization and equipment necessary to cope with each type of external hazard. Furthermore, training can reveal problems that can be corrected.

In addition, drills, with scenarios inspired by real events, should be periodically organized to check the ability of operators and emergency teams to manage events involving external hazards.

6) Analyze periodically foreign Operating Experience Feedback (OEF) on external hazards to find out potential safety vulnerabilities.

OEF from member countries of IAEA is collected in the IRS database. Several other organizations (suppliers owners groups, WANO, INPO, etc.) are also valuable sources of international operational experience A lot of information about external hazards events can be found in these databases, including the lessons learned and corrective actions.

Information should be used to evaluate the potential impacts of similar events on NPP safety and to create scenarios for drills.

7) Inspect regularly the protections against external hazards.

Periodic inspections should ensure that protections against external hazards are in compliance with the requirements defined during the design stage. These periodic inspections should be carried out by the licensee (“internal” check) and by safety authorities (“external” control).

The inspection process should verify the integrity of protections but also the “organizational systems” related to these protections: the maintenance process, the ability of operators to use safety equipment, the sufficiency of emergency procedures…

8) Maintain the systems and devices necessary to cope with external hazards.

Maintenance ensures availability of protections against external hazards. A particular attention should be paid to systems and equipment that have not been used for a long time.

Maintenance process should take into account the ageing phenomenon to ensure availability of protections on a long time range.

9) Monitor equipment and rooms necessary to ensure NPP safety.

Monitoring should enable problem detection on safety-related equipment and rooms., especially in the case of the integrity of flood barriers.

Monitoring can be enhanced by emphasizing during the shift briefings of operating personnel the specific procedures for patrols and the particular features of plant operation under abnormal weather conditions.

Monitoring action can be carried out in different ways: periodic inspection by an operator, video surveillance, monitoring of several running parameters in the control room.

6 CONCLUSIONS

The result of trend analyses of the different groups of external events reported to each of the databases (IRS, SAPIDE and VERA) has been presented.

Based on the analysis of external events reported to the IRS database, the main external phenomenon affecting nuclear plant operation is extreme weather conditions. The next frequent groups are the water intake fouling (mostly of biological origin) and lightning.

The conclusions are slightly different at the national level: in France, the fouling events are the most frequent (36%), followed by extreme heat sink conditions (17%). The combination of those two types of events clearly emphasizes the high exposure of the heat sink to external factors, and the need to ensure its protection in order to avoid common cause failures with potential very significant consequences.

It was observed that the external hazards, in general, had no severe actual impacts on nuclear safety based on the events reported to the IRS database. Safety significance according to the International Nuclear Event Scale (INES) was reported in nine cases, which is less than 14 % of all external reports. Most events were below the scale with no safety significance. Two IRS reports reported on the events of levels 1 - 3. However, some reports indicated that the intensity of a phenomenon was much stronger than could have been foreseen from the history so far (like the tsunami originated from the earthquake in the Indian Ocean in 2004).

Based on the observations of this study, external phenomena mostly affected the systems and equipment of heat sink or power supply. Extreme strong wind conditions and lightning strikes in all reported cases affected electrical equipment and grid disturbances. Cold air temperature, external phenomena related to biological reasons, debris and soil related generally impacted on heat sink systems and equipment. One frequent group of consequences was the spurious actuation of safety systems due to the freezing of instrumentation impulse lines or due to lightning strikes.

In some cases, multi-units or even multi-plants consequences of external hazards were not considered as a design basis for plant safety. The consequences of external phenomena to infrastructure and communication means may also cause unforeseen problems in an accident management in the nuclear plant during extreme external conditions.

One observation in the current study was that when a recurred event reached the threshold of reporting, the corrective actions implemented afterwards the last recurrence, were mostly effective and comprehensive enough to prevent the recurrence. Furthermore, some event reports indicated that if the existing operational experience, domestic or foreign, would have been taken into account, and preventive actions taken in a timely manner, an event might have been prevented. It is therefore very important, on one hand, to report an event upon the first occurrence even though the safety significance seems to be low (which could mean that the reporting criteria may need to be changed) and on the other hand, to consider this event in the operating experience feedback process.

Finally, when this study is read in the perspective of Fukushima, some of the events could be considered as precursors of this accident, such as events caused by flooding affecting several units, combination of high tide and strong wind or a tsunami. Some interesting insights can be raised also from events concerning failures of EDG in case of LOOP. However, as it was not the objective of this study – which was started before the Fukushima accident – to raise and analyze those precursors, it could be valuable to complement the Fukushima lessons learned by such a precursors study.

7 REFERENCES

[1] IAEA Safety Guide NS-G-1.5 "External Events Excluding Earthquakes in the Design of Nuclear Power Plants", 2003.

[2] European Clearinghouse Topical Study SPNR/CLEAR/12 01 002 Rev. 01 "External Hazards Related Events at NPPs", 2012.

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Abstract

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