Treatment of generic anomalies affecting the safety of French NPP
An example : non-compliance of K1-qualified electrical connections

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Abstract :

It is the French utility's (EDF) national organisation which governs the process for resolving anomalies which could potentially affect the nuclear power plant (NPP) population.
Its purpose is to apply strict management to maintain and restore compliance of all its nuclear power plants to the existing safety standards.
The process can be broken into four stages :

- emergence (detection of a probable generic deviation),
- characterization of the anomaly (its extent, root causes and potential consequences on safety),
- strategy, which purposes are, depending on safety issues, to determine the right lasting technical solution, identify deadlines needed to implement it to all the power plant units in the anomaly area and if necessary, define any temporary remedial measures,
- in-the-field completion of the strategy, for which the nuclear plant site operators are responsible.

The Nuclear Safety Authority (ASN) and the Institute for Radioprotection and Nuclear Safety (IRSN) are notified at several stages of the process.
Exchanges between EDF's experts and the IRSN, intervening directly on behalf of the ASN for technical assessment, begin at an early stage of the process, typically from the anomaly characterisation stage. These exchanges proceed on the basis of documents produced by EDF. They naturally form an integral part of the above-mentioned process and, through a continuous, transparent and detailed technical and scientific dialogue, impart the IRSN's concerns to the French utility and enhance the assessments of the IRSN intended for the ASN.

The generic compliance deviation of the K1-qualified electrical connections has been chosen to illustrate the process in this paper. This non-compliance is shortly to be notified to the Incident Reporting System.

1 INTRODUCTION

By “generic anomaly” we refer to any non-compliance to specification, unintended functionality or unforeseen fault which could potentially affect the nuclear power plant (NPP) population.
As soon as a non-compliance is detected locally at a nuclear power plant site, an analysis has to be made to identify the root causes and the actual and potential consequences. Suitable solutions must be defined and implemented within appropriate delays considering safety issues, on the one hand to restore the plant to conformity and on the other hand to avoid repetition of the anomaly. The operator of the site in question is responsible for these actions. It must inform the regional Nuclear Safety and Radioprotection Division (DSNR) of the Nuclear Safety Authority (ASN), the Institute for Radioprotection and Nuclear Safety (IRSN), and also Electricité de France’s (EDF) management (through its nuclear generating division, the DPN), which will gives technical support to the site.
When it is suspected that the anomaly may extend more generally (emergence phase) to several nuclear power plants, the EDF DPN takes over from the local site operator to :

- confirm the generic nature and identify all the potential causes and consequences (anomaly characterization phase),
- determine the appropriate and lasting technical solution, identify which resources, conditions and deadlines are needed to implement it to all the power plant units affected by the anomaly and, if necessary, define temporary remedial measures to restore the safety of the plants to an acceptable level (strategy phase).

Implementation of the decided measures (completion phase) remains within the scope of the nuclear plant site local operators and will not be discussed in the following.
IRSN intervenes directly on behalf of the ASN for the safety assessment, examining the case documentation produced by EDF.

This process for a generic anomaly is illustrated by the following example concerning a compliance deviation of K1-qualified electrical connections.

2 COMPLIANCE DEVIATION OF K1-QUALIFIED ELECTRICAL CONNECTIONS

It should be recalled that certain items of safety-related equipment located in the reactor building must be able to operate under accidental conditions. They are subject to qualification requirements aimed at ensuring their capability to perform their intended safety functions under harsh environment conditions (temperature, pressure, humidity, radiation level…). These items are classified as category "K1-qualified" equipment. In particular, there must be no interruption to their electricity supply even when water or steam are present.
The generic anomaly in question is related to this latter requirement.

2.1 How was the anomaly detected (emergence phase)

On 23 September 2003, while the 1300 Mwe Penly unit 2 was running at full power, an insulation fault was observed on an electrical circuit located within the reactor building connecting two K1-qualified containment isolation air-operated valves of the nuclear sampling system (NSS). This fault was caused by inadvertent spraying of 2 splice boxes (see attached photo) from a minor leak in a nearby circuit. Plant safety was not endangered.
When Penly 2 was shut down for the 10-year inspection in February 2004, inspection of the splice box electrical connections revealed cuts in the cable insulation and exposed bare copper wires (the cables connect 125 V solenoid power supply wires and 48 V limit switch wires). The plant operator carried out a visual inspection of all the K1 solenoid and moto-operated valve splice boxes of the Penly unit 2. These inspections revealed that the same type of fault was present on about 50 of the 122 cases on the unit.

According to the operator's safety analysis, the actuators fitted with this type of box could no longer be guaranteed as qualified for accidental conditions. The splice box provides cable termination to a multi-pin socket connector to the pre-cabled valve actuator. Cables connected to containment penetrations enter the splice box via a cable gland and are joined by heat-shrink sheathing technique inside the splice box. Since the box is not designed to be watertight, the internal connection must maintain the insulation continuity and ensure that the connections are waterproof to guarantee K1 qualification. With the faults observed, if the atmosphere in the reactor building were to become degraded, equipment using this type of connection would no longer be capable of fulfiling its mission. Accordingly, the Penly site informed the regional DSNR and the IRSN of an "event with significant implications for safety" (notification 2nd March 2004). An information meeting involving representatives from the DSNR, ASN, IRSN and the Penly operator took place on site on the 16th March.

2.2 How was the anomaly characterized (characterization phase)

2.2.1 Its generic nature

The ASN and the IRSN had been informed by the DPN on the 15th March of the actions to be taken in the characterisation phase. They were formally notified on 22nd March of an "event of a generic nature with significant implications for safety" rated at level 1 on the INES scale. This was subsequently upgraded to level 2 on the 9th April.
The preliminary results of an inspection conducted mid-march on a few NPP units confirmed the generic nature of the compliance deviation at a national level. It showed similar defects on the electrical penetrations of the containement and the splices boxes of these NPP. The defects were found on the K1-qualified solenoid valves, motor operated valves, power-assisted safety valves, with a few exceptions (the 6.6 kV power supplies use different

connection technologies). Depending on the series, about 90 to 150 actuators per NPP could be affected by this non-compliance.

From mid-March 2004, considering that safety of the park could seriously be compromised, IRSN set out to draw up a list of actuators that it considered indispensable to inspect and restore to compliance if necessary. IRSN emphasised the importance of the "feed and bleed" function in reducing core meltdown sequences (increased probability of core meltdown resulting from the unavailability of the "feed and bleed" function estimated at some 10^{-5} per year and unit).

2.2.2 Its root causes

According to EDF, the deviation originated from the installation operations. When the cable sheathing that protects the electric wires was stripped for connection, the stripping pliers were badly used. The heat-shrinkable sheathing could also present poor adhesion that could cast doubts on the tightness of the assembly. These operations either dated from the construction of the NPP units or were carried during equipment modifications. EDF has recognised that unprofessional work had been carried out and that its works control system had failed. These are latent faults. Furthermore they are not detected by periodic tests carried out on the equipment, since these tests only address equipment functions under normal conditions.

2.2.3 Its potential consequences for safety

The EDF’s analysis of safety issues considered that the containment safety function is preserved. Despite the fact that the isolation valves located inside the containment could be affected by the anomaly, the availability of the redundant isolating valves outside of the containment is guaranteed. This is because, in the event of an accident in the reactor building, the independent and simultaneous failure of the equipment items outside of the containment was discounted as they are not subjected to the degraded conditions in the containment and are not supplied by the same power train as the isolation equipment items inside the containment.

Concerning reactivity control issues, EDF considered that all required protection and safeguard orders are correctly executed. A failure in the very short term is not envisaged due to the kinetics of degraded atmosphere within the containment. Consequently, this safety function is not compromised.

On the other hand, the analysis demonstrated that, following accidents that lead to degraded atmosphere conditions (third and fourth category postulated initiated events), the cooling safety function could be seriously compromised.

2.2.4 Basis of the strategy to be defined : safety analysis

Considering the large number of equipment items possibly affected by the anomaly, a more detailed analysis was deemed necessary in order to define the basis of the strategy. The objective for EDF was to establish which equipment was strictly needed to control and limit the consequences of incidents and accidents that could lead to degradation of the conditions inside the containment.

The analysis entailed defining a set of realistic assumptions in view of the problem posed, with the hypothesis that the operability of the isolation equipment located outside the containment remains unaffected by the anomaly. The following main assumptions were made :

- independent and simultaneous failure of several equipment items other than those affected by the deviation is ruled out ; in this approach, the rule of accumulating a single aggravating factor as prescribed by the safety report accident studies is not applied,
- the protection and safeguard orders are correctly executed, a failure in the immediate term of an accident is not envisaged : consequently, the position demanded of the actuators is considered as achieved,
- following the accident, spurious switching of actuators out of their safety position is ruled out,
- the Emergency FeedWater system (EFWS) is considered fully available, principally in order to extend the capacity of primary system cooling by the steam generators, in the case that the valves located on the Residual Heat Removal System (RHRS) conditioning lines proved to be unavailable.

Using these assumptions, EDF defined the priority functions for post-accident operation that would be likely to be significantly affected if the equipment that contributes to their accomplishment failed because of the anomaly. In this context, the resources for post-accident operation require the availability of functions that allow the nuclear plant to be returned and maintained in a safe shutdown state, namely boration, depressurization and cooling.

The related equipment items that play a part in providing these functions are as follows :

- the Chemical and Volume Control System (CVCS) letdown line which must be reopened, following an automatic isolation signal generated by a very high

pressurizer level or a high CVCS let-down line temperature, to allow for boration or blow-down by mass defect ; the boration function can also be carried out by the Safety Injection System (SIS) or by CVCS injection at the primary pump seals as cooling progresses, the latter being guaranteed by different designs depending on the reactor series,

- the pressurizer auxiliary spray line is needed if normal spraying becomes unavailable or ineffective (in case of shut down of the primary pumps or load valve closure unavailability) ; as the pressurizer can fill up to the spray nozzle flooding level, the letdown line must be available for this depressurisation method,
- the CVCS load line, resulting from the previous considerations,
- the RHRS connection lines to the primary circuit (RCP) are needed to protect the latter from overpressure at low temperature,
- the RHRS exchanger cooling lines by the component cooling water system (CCWS) to control the coolant temperature,
- the SIS accumulators isolation valves to avoid injecting nitrogen into the primary system (primarily in the steam generator tubes which could reduce their cooling capability),
- electrical control of the pressurizer power-assisted safety valves, which is needed if all other depressurisation means are unavailable in order to ensure the "feed and bleed" function, the last available method of cooling the core.

Thus EDF was able to draw up a list of about 30 K1-qualified actuators per NPP unit that are essential to mitigate incidents and accidents that could lead to degradation of the conditions inside of the containment.

The results of this characterization phase were transmitted to the ASN and the IRSN on the 8th April. At that time, investigations concerning the K1-qualified instrumentation connectors were still in progress and therefore this package was not taken into account in the strategy.

2.3 Strategy for resolving the deviation (strategy phase)

2.3.1 Its development by EDF's power plant management

On the 8th April, EDF informed the safety authority of its initial strategy for dealing with the deviation. This strategy was established taking into account the safety-related issues and industrial constraints (personnel resources, spare parts, dosimetry, deadlines and implementation complexity). The strategy was revised in May 2004 to include the K1 instrumentation, due to a few defects noted mean-time. Therefore, the instrumentation which monitor the thermo-hydraulic conditions in the containment and verify the progress of an accident (Post Accidental Monitoring System) was added to the aforesaid list.

This strategy is based on :

- the potential and random nature of the anomaly,
- the availability of the EFWS system,
- the probability of an initiating situation,
- the definition of a limited equipment package, designated the “priority batch”, needed to reach and maintain a safe shutdown state when initiating accidental situations arise.

Accordingly, EDF decided to proceed with inspections and to restore to compliance during scheduled shutdowns as follows :

- treatment of the “priority batch” equipment, during simple refuelling outages (short shutdowns), with full reworking to be carried out during the subsequent scheduled shutdown,
- all K1 equipment potentially challenged by the anomaly is to be treated during partial or 10-year outages.

Assuming this strategy, which does not foresee any shutdown of any NPP units solely for the anomaly, the “priority batch” will be made compliant before mid 2005 and the whole of the "K1 connector" problem by mid 2008. EDF considers that these are suitable timescales for managing the risk over the period in question.

The strategy was addressed by safety bodies in two technical meetings on the 22th April and the 5th May. Following the IRSN’s questions, discussions focused on whether a defect, such as loss of insulation or short-circuit, affecting K1 items in the containment not included in the “priority batch” but nevertheless connected to the switchboards and I&C supply units that supply equipment of the “priority batch”, could lead to the loss of the latter. This would be the case in the event of inappropriate selectivity of the electrical protection devices. As a result, a few items were added to the list.
Accordingly, IRSN did not raise any major objection to the scope of the “priority batch” and the implementation of EDF’s strategy.

2.3.2 Extending the problem

During the various exchanges between the IRSN and EDF, several issues were raised, some of which are still outstanding.
Primarily it needs to be established :

- whether other equipment items, in particular those located outside the containment which perform safety functions (that meet the qualification requirements for K3 classification), can present similar connecting anomalies,

- whether different causes can lead to similar effects. In this respect, it should be pointed out that, following a request from the IRSN, EDF plans to undertake an inspection programme of a sample of damages (nicked) cables so as to differentiate defects caused by inappropriate use of the cable sheathing stripping pliers from those likely to be provoked by ageing or wear-out mechanisms, this given the standard mounting procedure (particularly heating up the heat-shrinkable sheathing to high temperature). This programme will be sent to the ASN at the end of 2004.

3 CONCLUSION

It is the French utility's (EDF) national organisation which governs the process for resolving generic anomalies. Its purpose is to apply strict management to maintain and restore compliance of all its NPP to the existing safety standards.
The process for treating a generic anomaly can be broken down into four stages :

- emergence of the deviation,
- characterization of the non-compliance,
- strategy for resolving,
- carrying out the actions in the field,

the last being the local plant operators responsability.
The information of ASN and IRSN is formalized at several stages of the process :

- following the emergence phase, when characterization is effectively set up, with a presentation of the planned deadline for its achievement and the measures adopted at that stage,
- when the characterization is completed so that safety consequences of the generic deviation and the targeted treatment deadlines can be presented,
- when the strategy is defined, with justified schedules for restoring compliance.

During or at the end of characterization, this information could also results in the notification of significant safety-related events of a generic nature.
Technical exchanges between the IRSN and EDF's power plant management begin at an early stage of the process, typically at the anomaly characterisation stage. These exchanges proceed on the basis of documents produced by EDF which primarily cover the analysis of consequences for safety of the deviation, the identification of root causes and the definition of adequate solutions in order to restore compliance of the NPP units within appropriate timescales depending on safety issues and to avoid recurrence. They naturally form an integral part of the above-mentioned process and, through a continuous, transparent and detailed technical dialogue, impart the IRSN's concerns to the French utility. Regarding the case of compliance deviation for K1-qualified electrical connections presented by this paper, the effectiveness of the process, the quality and the density of the technical exchanges can be emphasised.

PENLY 2 NSS SPLICE BOX