PRECURSOR INCIDENT PROGRAM AT EDF

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Abstract

The precursor program was started by EDF in 1994, after an investigation of the US NRC's Accident Sequence Precursor Program. Since then, reported operational events identified as Safety Outstanding Events have been analyzed whenever possible using probabilistic methods based on PSAs. Analysis provides an estimate of the remaining protection against core damage at the time the incident occurred. Measuring the incidents' severity enables to detect incidents important regarding safety. Moreover, the most efficient feedback actions can be derived from the main accident sequences identified through the analysis.Therefore, incident probabilistic analysis provides a way to assess priorities in terms of treatment and resource allocation, and so, to implement countermeasures preventing further occurrence and development of the most significant incidents. As some incidents cannot be analyzed using this method, probabilistic analysis can only be one among the methods used to assess the nuclear power plants' safety level. Nevertheless, it provides an interesting complement to classical methods of deterministic studies.

1. Introduction

Up to now, the standard incident analysis has mainly consisted in studying the origins and the actual consequences of incidents. Indeed, cause identification allows to take measures to prevent the same incident from occurring again. However, this approach does not lead to assess the risk induced by the incident (potential consequences).
By considering how and to which extent the installation could have been further degraded, the incident probabilistic analysis complements the standard cause analysis. By detecting the most significant incidents, it enables to set priorities in terms of treatment.

The incident probabilistic analysis consists in imagining, starting from the observed plant situation, degradation scenarios that could lead to unacceptable consequences (usually core damage).
Probabilistic quantification of these scenarios provides an estimate of the remaining protection against core damage during the event. The conditional probability of core damage, knowing that the incident did occur, is called Potential Risk Index (PRI).

The incident probabilistic analysis method is essentially based on the French PSAs.
Incidents showing a Potential Risk Index above 10^{-6} are called « precursor incidents » (precursor to potential severe core damage accidents).

The precursor incident program started at an experimental stage in 1994. The 1994 and 1995 incident probabilistic analyses led to settle the selection process and analysis methods. In 1996, the Nuclear Power Plant Operations Division (EPN) and EDF's executive management confirmed the benefit of the program and decided to carry it on.

2. The objectives of the incident probabilistic analysis

The assessment of the first two years of the program allowed EDF to identify four objectives for the program:

2.1 - Exploiting quantitative results

The Potential Risk Index, measuring the incident severity, is doubly interesting:

- it enables to detect precursor incidents and make sure that relevant feed-back actions are proposed,
- it also enables to assess priorities in terms of treatment (in-depth analysis, emergency of feed-back actions, etc.) as well as in terms of resource allocation (use available resources first for incidents with important safety impacts).

Thus, severity evaluation can contribute to point out incidents initially passed unnoticed, but also to confirm or weaken other incidents' supposed significance.

2.2 - Qualitative analysis

Determination of the main sequences leading to core damage enables to accurately identify the nature of risks linked with the incident. The most relevant feed-back actions can thus be derived from the analysis, in terms of:

- design of plants (proposing or justifying changes - or absence of modification),
- operation of plants, concerning documents (incidental and accidental procedures...) and organization (especially planning of activities).

2.3 - Enriching safety culture

Spreading probabilistic analyses and the main results of the program should make operators aware of the most important defense lines, as well as of the hazardous operational situations or transients.
More generally, it should support the habit of plant people not only to investigate causes but also to assess consequences of events and situations.

2.4 - Improving data and models used for the existing French PSAs

The comparison of sequences based on observed incidents to what is theoretically expected by the existing PSAs leads to validate or improve these PSAs.

3. Selection process and probabilistic analysis methods

3.1 Selection process

The selection process enables the identification of Safety Outstanding Events *(«incidents marquants pour la sûreté»)* among the reportable Safety Significant Events *(«ISS: Incidents Significatifs pour la Sûreté»)* and some of the Safety Related Events *(«EIS: Evénements Intéressant la Sûreté»)* occurring on EDF nuclear power plants.
The selection criteria are based on the potential consequences of the incident, considering the risks of core damage or important radioactive releases. 9 deterministic criteria are used and a probabilistic analysis of the related incidents is made whenever possible. Another criterion, based on expert opinion, opens the way to examine any incident of a kind which has not been previously analyzed.

3.2 Analysis method

Two different methods are used, and combined if necessary, depending on the kind of incident to analyze:

- If the incident is of the «initiator» type (of sequences which can lead to core damage), the analysis consists in estimating the available defense lines from a probabilistic point of view,

- If the incident is a degradation of in-depth defense (situation where some plant systems are degraded), the analysis consists in evaluating the consequences if an initiator had occurred (when it did not).

Event tree branch probabilities are modified to reflect the incident: failure probability of systems observed failed during the incident are set to 1. The other branches which have not been affected by the event are weighted by their usual probability of occurrence.

To assess the overall risk, all the factors that are likely to have an appreciable aggravating effect on consequences are identified. For example, a real equipment failure may have no effect given the state of the plant at the time it occurred, but could have had a detrimental effect if the plant had been in another state. Therefore, the result has to take into account a sensitivity analysis carried on the initial state of the plant. Parameters that can be modified in accordance with the actual situation are, for instance, failure and common cause failure rates, probabilities of occurrence of human error, type of reactor, repair rate of an equipment item, etc.

The quantitative processing is usually manual. Nevertheless, it might be necessary to use computerized tools, for instance when the degradation of a defense line involves a great number of scenarios.

4. Difficulties

Difficulties related to probabilistic analysis are twofold:

4.1 Difficulties related to quantification

The conversion of a real incident into a set of probabilities involves some major difficulties:

- Failure of **human actions** are assessed using the human reliability models developed in the French PSAs. However, these models usually have to be adapted in order to take into account the specific behavior of the operators during the incident under study.
- Other difficulties are related to **component degradation** (assessing the probability that the component become unavailable under certain conditions) or **common cause failures** (whenever a redundant equipment item fails, the probability to loose the other one has to be revised).

A methodological framework has been developed to address these problems.

4.2 Methodological limits

This type of analysis is subject to limitations inherent to the PSA itself. Indeed, hypotheses and uncertainties related to data and models used in the PSA are transferred to the probabilistic analysis. Moreover, some events meeting the Safety Outstanding Event criteria are impractical to analyze. For instance:

- loss of containment isolation, since the analysis is limited to scenarios leading to core damage,
- incidents that would require to take into account internal hazards (fire, flooding, etc.), for which no PSA has been developed yet,
- operation outside the operating range, for which no direct consequence can be identified,
- some events characterized by an important number of individually insignificant failures.

5. Quantitative analysis results

The Potential Risk Index should be considered as a means to rank and compare incidents rather than as an absolute measure of the incidents' severity.

5.1 1995 to 1997 results (see main reports [1] to [3])

1994 can be considered as an experimental year regarding the precursor incident program; results are therefore presented from 1995 to 1997 only. Results do not take into account the N4 plant series brought into commissioning in 1997.

Table I presents the distribution of the number of analyzed incidents ranked by Potential Risk Index intervals from 1995 to 1997.

TABLE I

Number of precursor incidents by PRI intervals:	1995	1996	1997
10^{-1} to 1			
10^{-2} to 10^{-1}			
10^{-3} to 10^{-2}	**1**		
10^{-4} to 10^{-3}	2	**5**	
10^{-5} to 10^{-4}	3	3	**7**
10^{-6} to 10^{-5}	27	25	22
Number of precursor incidents (PRI > 10^{-6})	**33**	**33**	**29**
Number of SOE with PRI < 10^{-6}	18	16	21
Number of SOE impractical to analyze	22	17	18
Total number of Safety Outstanding Events (SOE)	73	66	68
Total number of reported Safety Significant Events	377	437	421

Even if the total number of reported Safety Significant Events increased notably in 1996 and 1997, as compared to 1995, the number of Safety Outstanding Events and precursor incidents has remained stable during this period. It is interesting to point out that the seriousness of the most important incidents has decreased from one year to another. From this point of view, safety has been improved for the last three years.

Figure 1 shows the distribution of precursor incidents for the past three years.

Table II hereafter shows the most significant incidents (ranked by descending PRI) for the past three years.

5.2 Using the probabilistic analysis results to assess the plant operation safety level

Because of the limitations of the method (only incidents potentially leading to core damage can be analyzed), the probabilistic analysis of incidents cannot be the only representation of the French nuclear infrastructure's safety level.
However, it provides information concerning the evolution of the safety level from one year to another. For instance, an increase in the number of reported incidents (as observed from 1995 to 1996) can be more than mitigated by the relative stability of the number of precursors and a decreasing severity of the top incidents.

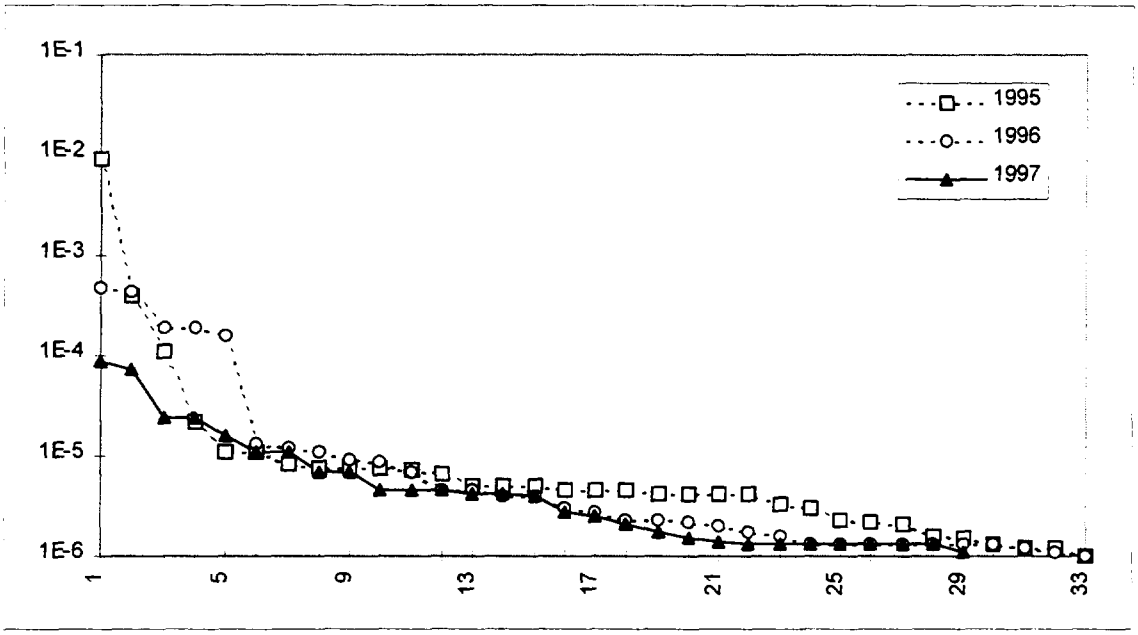

Figure 1: *Precursor incidents ranked by decreasing Potential Risk Index (1995 - 1996 - 1997)*

TABLE II

1995	
$9.3\ 10^{-3}$	Leakage on the Residual Heat Removal System
$3.9\ 10^{-4}$	Loss of main power supply - Control rod jamming during reactor trip
$1.1\ 10^{-4}$	Water level dropping under the flange seal surface
1996	
$4.8\ 10^{-4}$	Control rod jamming during reactor trip
$4.4\ 10^{-4}$	SCRAM contractor unreliable
$1.9\ 10^{-4}$	Main power transformer explosion, followed by a fire
$1.9\ 10^{-4}$	Safety Injection System and Containment Spray System unavailable
$1.6\ 10^{-4}$	Component Cooling and Essential Service Water Systems unavailable
1997	
	None > 10^{-4}

In this way, it must be considered as complementary to classical methods of deterministic analysis.

5.3 Using the probabilistic analysis results to set priorities

Incident probabilistic analysis makes it possible to identify the most significant incidents regarding safety, among some 8000 Safety Related Events and 400 Safety Significant Events reported yearly by the French nuclear power plant operators. Actions can therefore be undertaken as a priority towards a few 30 precursor incidents.

6. Lessons learnt from the program

6.1 Qualitative analysis results

The following points are just examples of lessons that can be learnt from the examination of precursor incidents.

A posterori justifications
Backfitting actions such as automatic water makeup in the state when residual heat removal system is connected, primary system open, or alarm indicating a low level when primary level is at the vessel mating surface, have proved to lower the Potential Risk Index of many incidents.
The analysis of a water seepage in electrical rooms (1995) shows the benefit of using state-oriented approach in case of plurality of unavailabilities.

Choice of the appropriate reactor state
After an explosion affecting the main power transformer and considering the unavailability of main power supply would last several weeks, the reactor was brought to cold shutdown. Probabilistic analysis then pointed out that it would have been more appropriate to bring the reactor to intermediate shutdown, RHR valved in, a state where seal water injection is not required any more and where steam pressure allows operation of the turbine-driven auxiliary feedwater pump and of the emergency supplied distribution system.
Generally speaking, in case of simultaneous unavailabilities, probabilistic analysis can help to choose the most appropriate reactor state for safe operation.

Repetitive incidents
Some incidents which occur many times a year have proved to be precursors. Probabilistic analysis has contributed to point out the problem and speed up the introduction of solutions. As a consequence, incidents such as uncontrolled drainings of reactor coolant system or depressurization while at water-solid cold shutdown, which were quite frequent in 1994 and 1995, have been rare since 1996.
Incidents involving control rod jamming due to the wear of drive mechanism bolts happened several times in 1995-1996 (mainly during tests) on 1300 MW PWRs. The associated Potential Risk Index proved to be around 10^{-6}. EDF took the decision to replace control rod drive mechanisms on all the 1300 MW plant series.

6.2 Improving the operational feedback

The program has also become a whole part of the operating feedback process as a method which enables qualitative analysis of potential consequences.
The analysis method is now stabilized. The use of qualitative results to define and implement the most relevant feedback actions has to be further developed in the future.

Thus, probabilistic analysis is used not only to back up standard deterministic analysis, but also to point out problems which were not identified and make concrete feedback actions emerge.

7. Conclusions and prospects

The precursor incident program results are now widely used.
Together with more classical methods, incident probabilistic analysis provides an original enlightening to assess the plant operation safety level. In all respects, quantitative results achieved on the 1995-1997 period show that safety has been improved.

The program has also become a whole part of the operating feedback process as a method which enables:

- to focus feedback actions towards the most significant incidents (around 30 precursor incidents instead of some 400 reported Safety Significant Incidents),
- to help to define the most efficient corrective actions through the study of the main sequences leading to core damage.

Analyses are now being distributed to plant operators. Corresponding members, nominated for each plant, are commissioned to understand and spread the probabilistic analyses on their plant, so that lessons learnt from the program can be directly used to improve safety culture.

As the benefit of the program has been confirmed, it was decided to carry it on for next years.

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