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Regulatory Use of PSA in Belgium – Status, Lessons Learned and Perspectives

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Abstract

The paper focuses on areas in the field of probabilistic safety analysis (PSA) in which AVN – as a Belgian nuclear regulatory organisation – has established its experience

Contents

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1. Introduction

For almost 20 years now, AVN is promoting the use of probabilistic safety analysis as a complementary approach to deterministic safety analysis [1].

In the eighties, first activities in this field involved the participation in EC JRC research projects, such as the common cause failure benchmark exercise (BE) and the accident sequence BE. R&D was conducted to develop and to adapt useable computer codes for the generation and the analysis of fault trees of moderate size. During the nineties, powerful PSA codes have become available which allowed developing full scale PSAs.

This paper describes the regulatory use of PSA in Belgium: what was aimed in the periodic safety reviews (PSR), what are the PSA applications to-date, what are current R&D topics, and what are the perspectives for risk-informed approaches.

2. The PSA as Part of the Periodic Safety Reviews

The Belgian nuclear power plants (NPPs), as most other NPPs, have been designed on a deterministic basis. Since many years, a program is underway to have plant specific PSA models developed for all Belgian NPPs in the framework of their periodic safety reviews. The objective was mainly to confirm the robustness of the deterministic design, to identify design weaknesses (if any), and to address these weaknesses if necessary.

This program is now well advanced. It has been finalised for the Doel 3 and Tihange 2 NPPs, and is now being finalised for Doel 4 and Tihange 3 (the level 1 PSAs of which were established on basis of the former ones). For Doel 1/2 and for Tihange 1, a PSA model already exists for some years, but an agreed list of additional enhancements of the level 1 PSA is currently being implemented, whereas the level 2 PSA review findings are still being discussed.

In the general conclusions of the AVN evaluation report of the first completed PSA studies, it is acknowledged that the objectives of this program have been met. Several safety improvements have been implemented, exclusively or mainly on the basis of PSA findings. In other cases, PSA findings have given a decisive push to safety arguments that were not necessarily new but that had so far not been able to prevail in the design or the operation. New risk insights can indicate still further opportunities for safety improvement.

One of the main technical conclusions particularly concerns the PSA results for low power and shutdown states. Whereas little explicit attention has been paid to the safety analysis for these operational modes in the deterministic approach, the results of the PSA analyses have indicated the need to improve safety in low power and shutdown states. Besides a discussion of typical measures taken to improve safety based on PSA results, a discussion will also be held on how to develop further the deterministic approach for low power and shutdown states. In view of the latter, a specific subject has been defined within the upcoming periodic safety reviews of the NPPs.

The AVN evaluation report of the PSA of Doel 3 and Tihange 2 also identifies 27 recommendations on various PSA issues that should be considered for further improvement, such as some methodological aspects, scope, data, additional initiating events, modelling issues, and above all a deeper analysis of the PSA results. It also addresses some problems with maintaining the PSA documentation consistently – an issue that was revealed to be a major challenge, in particular during the implementation of additional

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improvements after the first round of regulatory review. Furthermore, it describes the on-line review process that was applied, and it needed to discuss some PSA project management aspects, especially regarding the very long calendar time that the project took to finalise, and the roles and levels of involvement of the three main stakeholders: the architect/engineer (author), the utility (owner) and the regulatory organisation (reviewer).

The perspectives that are drawn up in this evaluation report are not limited to a punctual use of PSA as a periodic design (re)evaluation tool, but also look forward to host other PSA applications and risk-informed methods.

An update of all PSAs is foreseen in the framework of the coming PSRs.

3. Comparison of PSA Models

In the framework of the cooperation between French and Belgian regulatory organisations, a PSA comparison exercise has been carried out for several years. This comparison deals with two PSA level 1 studies for internal events, performed for both power and shutdown states: the French PSA of the 900 MWe-series PWR, and the Belgian PSA of the Tihange 1 PWR, which both concern PWRs with a similar Framatome design. The main goal of this comparison exercise is to increase confidence in the PSA models and to identify opportunities for model improvement and for PSA harmonization [2].

A similar cooperation between French, Belgian and South-African regulatory organisations has been set up more recently. This comparison is based on the updated French 900 MWe PSA (2003), the Tihange 1 PSA and the Koeberg PSA. It focuses on internal events for power states, and constitutes an extension of the initial French-Belgian comparison, yielding additional or confirming previous insights.

The lessons learnt from these PSA comparisons are to be used during the above-mentioned update of the Belgian PSA models.

4. Probabilistic Precursor Analysis

Since several years AVN runs a precursor analysis program. It applies the guidelines for PSA-based event analysis (PSAEA) that were developed in the framework of an international project involving the regulatory bodies of six countries [3,5,8]. Today, the PSAEA process has become an integrated part of the overall AVN process of follow-up of operating experience. It includes the following phases: screening and selection of events, analysis of the selected events, internal review by PSA specialists, by engineers involved in experience feedback and by plant inspectors. The revised analyses are subsequently presented to the utility for comment, further consideration and – where applicable – for follow-up of identified safety issues for improvement. As such the main objectives, i.e. the determination of the quantitative importance of well-selected operational events per year and the possible subsequent identification of safety issues for improvement, are achieved.

In order to ensure a close contact with other experiences and developments in this field, AVN has taken the initiative to organise an annual meeting on probabilistic precursor analysis in the nuclear industry. The interaction with a wide audience of other practitioners and stakeholders has not only advanced the understanding of many technical issues, but it has also contributed to the evolution of a broader view on the process itself of precursor analysis by a nuclear regulatory organisation.

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As the results of this PSAEA process for the years up to 2001 have already been presented at previous conferences and seminars [4,6,7,8], the opportunity is taken to present the results obtained in 2002 and 2003.

4.1 Precursor Analyses Performed in 2002

In 2002, a total of 52 new operational events were screened. Four of them were selected to be analysed in detail.

The first event is the internal flooding of AFWS equipment. This case demonstrated a particular plant vulnerability that existed since plant construction: the loss of AFWS equipment by lack of protection against post-accidental conditions after a feedwater line break (FLB) or a steam line break (SLB). When considered over the entire duration of 43 years, this long-lasting event can be considered as an important precursor.

Subsequently, AVN analysed the inadvertent progressive dilution of the primary circuit during plant start-up. This initiating event turned out to have low safety significance (no precursor).

The third event was the unavailability of the automatic start of the AFWS during plant start-up. The modelling of this condition event involved CCF as well as modelling operator recovery. This event is not a precursor.

Finally, the unavailability of the alternative raw water make up for the auxiliary feedwater system to all safety trains (CCF) which was a long lasting event that could not be entirely quantified.

4.2 Precursor Analyses Performed in 2003

Out of the 47 events from the incident record database that were subject to screening in 2003, four events have been selected for further analysis:

Excessive torque on external and internal screw bolts of check valves, discovered before start-up. The event involved two independent errors, and would have been a very important precursor if it had remained undetected. The main risks are induced LOCA initiators (including LBLOCAs) due to flange bolt failure(s). The modelling included a CCF that consists of an excessive torque applied on the internal bolts of a heterogeneous set of valves.

Spurious safety injection during plant start-up due to secondary pressure transmitter misalignment, and with partial inhibition of safety systems. The initiating event of "spurious SI" is a precursor. Modelling includes the unavailability of the pressure transmitters (elaborating the SI-signal), and the introduction of a new basic event to model the non-recovery of the undue inhibitions (but only credited for accidents that do not require a fast safety injection).

Safety injection in hot shutdown as a result of a test of the pressuriser discharge valves. The initiating event is a small LOCA. Since the LOCA-model of the PSA is a non-isolable leak, the probability of operator non-recovery is introduced. The unavailability of all protection trains ensuring closure of the pressuriser discharge valves has been modelled as a CCF. The event can be classified as a precursor.

A case of degradation of the heat exchange capacity of the LU-coolers on the emergency diesels as a consequence of pollution was studied. The specific challenge for modelling this condition event lies in the gradual nature of the pollution. Specific attention is therefore given to the CCF modelling. The traditional approach with the MGL-method is used. However, the drawback of this approach in this

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specific event is that the gradual aspect of the pollution would then be lost. Therefore, an alternative approach consisting in increasing the failure rate to run, based on actual data, of the affected systems is applied and compared with the MGL-approach. The results for both calculations are more or less comparable.

5. Research and Development

5.1 Enhancing the Use of PSA

In order to facilitate the understanding and the possible use of PSA by non-PSA specialists (for instance to help focus plant inspections on safety significant issues), some investigations are undertaken to determine how to elaborate comprehensive representations of PSA results and appropriate methods to use them. Some existing examples in other countries were visited that have been proven to be successful in using risk insights or running PSA applications by non-PSA specialists. These examples are expected to help in directing AVN's short-term R&D efforts in this field. It has also been concluded that there are established and very convincing benefits for both regulatory organisations and utilities in the use of a complementary probabilistic approach to nuclear safety.

Moreover, the process of risk ranking of components, (sub)systems and other groups of basic events will be explored.

5.2 Participation in SARNet

Amongst other organisations, AVN will participate in the SARNet project (Severe Accident Research), one of the European Networks of Excellence proposed in the 6th Framework program of the EC. The objective of one of the SARNet work packages is to compare, to improve and to harmonise the methodologies used for developing level 2 PSA within European countries and to share effort and to develop advanced tools, as far as they are required. In a first period, the AVN activities will mainly be focused on the comparison of level 2 PSA approaches and on the identification of improvement needs. This effort is made to compare the approaches encountered by the different partners in elaborating, quantifying and reviewing both existing as well as ongoing level 2 PSAs to be able to identify the points related to methods or knowledge that appear to be the most critical and for which improvements are judged necessary.

The identification of methodological subjects is important since it could be used to define new projects within the "Level 2 PSA methodology and advanced tools" domain, in the second stage of the SARNet project. Note that presently, two such topics have already been identified: assessment of uncertainties and dynamic reliability. The entire work package should start in 2004 and is scheduled to last for about 18 months

6. PSA of a Research Reactor

AVN is also reviewing the PSA of the Belgian research reactor BR2, which has very different characteristics from e.g. the PWR design of the Belgian NPPs mentioned above.

The initial PSA level 1 (1994) is being extended in a way and to a level of detail that is more coherent with the PSA studies of the Belgian NPPs. In particular, fault trees of front-line systems and support

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systems have been developed into a level of detail that is comparable with the PSA models of the NPPs. The main concern is to model functional dependencies correctly, so as to catch potential weaknesses in support systems design, in particular for electrical systems.

This second stage of the BR2 PSA is currently being finalised. AVN expects that this improved model will lead to more reliable risk estimates and will help to identify or prioritise potential safety improvements.

7. Perspectives

Some considerations are already being made on the scope of the PSA update to be planned for the periodic safety reviews to come. For AVN, the objective of any of the PSA updates is to verify again the robustness of the plant in its current state,

- taking into account all changes to systems, procedures, and considering an extended operating experience;
- taking into account more refined working hypotheses were necessary (correcting errors, filling gaps, more balanced modelling);
- reconsidering the PSA methodologies to be applied in view of the current state-of-the-art;
- to provide the basis for – existing or anticipated – PSA applications;
- possibly extending the scope of the PSA (e.g. beyond internal events only, or applying the same level 2 approach to all plants).

Moreover, significant improvements in maintainable PSA documentation and ready-to-use computer models are expected.

As an outlook towards future applications of risk-informed approaches in safety evaluation activities, new PSA applications might include risk-informed regulatory inspections as well as risk-informing the Technical Specifications and risk-informing the licensing of changes to the design basis.

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