Recent PSA developments and use of PSA applications in Belgium

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Abstract: As Technical Support Organization (TSO) of the Belgian Federal Agency for Nuclear Control (FANC), Bel V has continuously stimulated the development and use of PSA as a complementary approach to deterministic safety analysis. This paper summarizes (1) the status of PSA for the Belgian nuclear power plants (NPPs), (2) the current use of these PSAs, and (3) the main perspectives for the coming years.

Keywords: PSA update, Regulatory review, TSO.

1. INTRODUCTION

Belgium has 7 NPPs of the Pressurized Water Reactor (PWR) type (Westinghouse and Framatome designs PWR) on its territory (grouped at two sites). The Tihange site is composed of 3 units (Tihange 1, Tihange 2 and Tihange 3) and the Doel site of 4 units (Doel 1-2 (twin units), Doel 3 and Doel 4). For these units, the Licensee (ENGIE Electrabel) and its architect engineer (Tractebel ENGIE) have developed and maintain:

- 6 Level 1 Internal Events PSA models (as the twin unit Doel 1-2 is being treated by one single model),
- 6 Level 1 Internal Hazards PSA models (Internal Fire and Internal Flooding),
- 4 Level 2 Internal Events PSA models (for two of the 7 units, another unit has been considered as representative and Doel 1-2 is being treated by one single model),
- 2 Level 2 Internal Hazards (Internal Fire and Internal Flooding) PSA models (Doel 1-2 and Doel 3).

In 2020, Issue O ("Probabilistic Safety Analysis") of the Western European Nuclear Regulators Association (WENRA) report "Safety Reference Levels for Existing Reactors" of 2014 [1], has been transposed into the Belgian nuclear safety regulation without substantive change compared to the WENRA text related to this particular issue.

The main additional requirements for PSA added to the regulations were:

- to include the probabilistic safety assessment of fuel damage in the Spent Fuel Pools (SFP) (in addition to the already performed PSA studies related to the reactor);
- to consider the relevant External Hazards (for both SFP and reactor PSA studies).

Following this regulatory evolution, Internal Events/Hazards and Seismic SFP Level 1 PSA models have been developed by the Licensee for each Belgian NPP unit. The Licensee also developed External Flooding SFP Level 1 PSA models for the Tihange units.

PSA is increasingly used by the Licensee in the framework of their PSA-based applications programme (e.g. precursor analysis, Risk Increase Factor follow-up, etc.). Additional to those common applications over the past years, specific Post-Operational Phases (POP) SFP PSA models for the Tihange 2 and Doel 3 units (permanently shutdown in, respectively, 2022 and 2023) were recently developed by the Licensee. These aim to complement both the deterministic approach and engineering judgment used to

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define the required configuration of the remaining nuclear island during the POP, within the development and definition of the Nuclear Safety Requirements Document to be applied during the POP.

Furthermore, in 2023, the Belgian government and the Licensee have reached an agreement to keep the country's two most recent nuclear reactors, Tihange 3 and Doel 4, in operation for 10 years beyond their planned closure date in 2025. The Licensee has now to develop the preparatory safety studies (including PSA) as well as a complete action plan with modifications aiming at further increasing the safety level towards the level of these most recent nuclear reactors.

2. STATUS OF PSA DEVELOPMENT IN BELGIUM

2.1. Influence of WENRA Reference Levels

Following the Fukushima-Daiichi accident, WENRA was tasked with reviewing the reference levels for existing reactors.
The Belgian Federal Agency for Nuclear Control (FANC) launched a regulatory project in 2015 to integrate the new WENRA safety reference levels into the Belgian regulation. The existing Royal Decree (RD) on the safety of nuclear installations (30/11/2011) has been amended accordingly. It should be noted that the Belgian transposition of the reference levels introduces some additional requirements, mainly having an impact in the case of lifetime extension of the units.
On the operator side, a compliance analysis with the new WENRA reference levels was carried out. This resulted in the creation of a study plan and a concrete action plan necessary to meet the regulatory requirements.

Issue O ("Probabilistic Safety Analysis") of the WENRA report "Safety Reference Levels for Existing Reactors" of 2014 is transposed in article 29 (as part of chapter 3 – section IV about the nuclear safety demonstration) of the RD Safety Requirements for Nuclear Installation (SRNI) of 30/11/2011, update of 19/02/2020, without substantive change with respect to the WENRA RL 2014.
The main changes to the PSA related safety reference levels and in the RD update of 19/02/2020 are the requirements to include the assessment of the fuel in the spent fuel pools (SFP) in the PSA studies (in addition to the fuel in the core) and the more explicit requirement to consider the relevant external hazards.

2.2 Development of SFP PSA models

SFP Level 1 PSA studies were developed for the following initiators: Internal Events, Internal Fire, Internal Flooding, Seismic Events and External Flooding.
Contrary to the other initiators mentioned, the external flooding SFP PSA studies are limited to the Tihange units following the results of the screening of the External Events performed by the Licensee.

The general technical approach and methodology for developing the SFP PSAs has been based on the SFP risk assessment framework described in the Electric Power Research Institute (EPRI) report [2], with some particularities:

- the Tihange 3 and Doel 4 Internal Events models have been developed in a so-called integrated framework modeling approach, meaning that the impact of a potential accident at the reactor side on the SFP has been evaluated (and vice-versa);
- the other SFP models (other units and other initiators) have been developed as stand-alone models (meaning that the impact of a reactor accident on the SFP – and vice-versa – has not been analyzed).

2.2.1 Internal Events

For the Internal Events, a pilot project was established by the Licensee (ENGIE Electrabel) and its architect engineer (Tractebel ENGIE) for one unit, permitting regular discussions between the PSA developers and the Safety Authority. Part of the intermediate comments of Bel V could therefore already be taken into account during the development of the pilot project by the licensee and its architect engineer.
This pilot project was followed by a second phase of model development for other units and initiators.

During the (still ongoing) Bel V review, comments were made leading to the identification of potential improvements of the PSA studies, clarifications and associated study document updates as well as additional safety improvements on site included in the action plan of the licensee. The following examples are highlighted:

- Addition of operator actions in a procedure to be followed in case of a level drop in the spent fuel pools in order to anticipate (and hence facilitate/ensure) an alternative potential mean to refill the pools;
- Completion of the criteria in the on-site emergency procedure regarding the declaration and notification to the authorities of the emergency plan by explicitly mentioning the criteria associated to the risks related to the spent fuel pools;
- Modification of one of the on-site emergency plan procedures to clarify the importance of timely asking for information on also longer term (external) flooding forecasts to external stakeholders.

2.2.2 Internal Hazards

The methodology for the development of the Level 1 Internal Fire SFP PSA was based on the NUREG/CR-6850 [3], its Supplement 1 [4] and the NUREG-1921 [5], developed jointly by US-NRC and EPRI. These guidelines were followed except for specific points such as:

- No consideration of the explosion phenomenon in the scope of the Fire SFP PSA study;
- No consideration of seismically-induced fire in the scope of the Fire SFP PSA study;
- The detailed quantification of the human errors probabilities retained in the Fire SFP PSA.

For developing the Internal Level 1 Flooding SFP PSA for each Belgian unit, the EPRI guideline 1019194 [6] and the EPRI document 1021086 [7] (pipe rupture frequencies) were followed.

The evaluation by Bel V of the different Fire and Flooding Level 1 SFP PSA projects is still ongoing at the time of writing this paper. Nevertheless, Bel V can already mention the following important recommendation in relation to the Internal Hazards SFP PSA studies:

- Request for additional walkdowns to confirm some fire and flooding scenarios, and a reminder of the need to install additional fire detection in a specific room.

2.2.3 External Hazards

All External Hazards, besides Seismic Events and, for the Tihange site, External Flooding, have been screened-out of PSA studies.

Seismic Level 1 SFP PSA models have also been developed, by the Licensee, based on the EPRI documents [8] and [9].

For the External Flooding PSA, the Licensee and its Architect Engineer developed a methodology based on the overall approach to analyse External Events in Level 1 PSA presented in the IAEA Specific Safety Guide SSG-3 [10], with, among others, the following assumptions/limitations:

- No inclusion of Level 2 PSA;
- The methodology was developed for a 'stand-alone' Tihange 3 unit (the models for Tihange 1 and 2 being developed as a "generalization & adaptation of the Tihange 3 External Flooding PSA Model");
- Offsite power is assumed to be non-recoverable for the duration of the mission times used in the study.

The evaluation of those models by Bel V is still ongoing at the time of writing this paper. Nevertheless, Bel V can already list the following important recommendations in relation to the seismic SFP PSA studies:

- Evaluate the conservatisms taken for evaluating the fragilities of the buildings;
- Extend the number of human actions subject to a detailed analysis;
- Evaluate the conservatisms in the hazard curves taken as input of the studies;
- Clarification of the procedure on actions to take in case of a level drop in the spent fuel pools by identifying the preferential way to refill the pools in case of an earthquake (taking into account the seismic capacities of the makeup means);
- Extend the analyses to SIFF (Seismically Induced Fire and Flooding).

For both Seismic and External Flooding PSA studies, the following important requirement is already identified:

- Extend the studies to the reactor part for the units subject to Long-Term Operation (LTO) (Doel 4 and Tihange 3).

2.3 Post-Operational Phases (POP) SFP PSA models

Post-Operational Phases (POP) SFP PSA models have been developed for the Tihange 2 and Doel 3 units (units definitively shutdown in, respectively, 2022 and 2023) [11]. These aim to complement both the deterministic approach and engineering judgment used to define the required configuration of the remaining nuclear island during the POP, within the development and definition of the Nuclear Safety Requirements Document to be applied during the POP.
Those models are based on the SFP PSA models previously developed, as explained in section 2.2. Initiating Events (IEs) considered to be applicable to the post-operational phase have been screened from the list of IEs considered in the Internal Events SFP PSA model. Hazards or External Events have not been included in this specific complementary evaluation.

2.4 PSR updates

Finally, for the Tihange 2 and Doel 3 units and conform to the Belgian Regulations, the licensee was required to carry out a Periodic Safety Review (Safety Factor 6 as defined in [12]) to demonstrate and improve safety during the Decommissioning and Dismantling Phases. The Tihange 2 and Doel 3 Internal Events SFP PSA models discussed in 2.3 have therefore been updated to reflect the actual configuration of those units.

3. CURRENT USE OF PSA FOR BELGIAN NPPs

3.1 Regulatory PSA applications in Belgium

The initial use of PSA involves the systematic re-evaluation of the design of nuclear installations. Indeed, the main objective of the PSA study, within the framework of Periodic Safety Reviews (PSRs), was to confirm the robustness of the deterministic design, to identify any design or operational weaknesses, and to address them if necessary, for instance by evaluating the importance of possible improvements to systems and procedures.

The development of PSA in Belgium has also provided specific insights and led to several plant modifications. In some cases, the results and insights obtained at various stages of the PSA projects have directly led to a number of safety improvements in the design of systems, structures, and components (SSC) and in operating practices. In other cases, PSA findings have given a decisive push to safety arguments that were not necessarily new but which had not yet prevailed in re-evaluations of design or operational practices.

Proposals for modifications have emerged in two different ways:

- On the initiative of the licensee or its architect/engineer.
  Numerous opportunities for improvement were identified, decided upon, and already implemented at an early stage of PSA development ("early feedback") by the licensee. These proactive modifications to the plant and to operating procedures were then directly incorporated into the PSA model. However, this practice also poses a challenge for the quality assurance of PSA models and documentation, as it may occur that some design or procedural modifications are not ultimately implemented as initially proposed, leading to discrepancies between "as built" and "as modeled" that need to be resolved subsequently.
- On the initiative of Bel V based on its regulatory review.
  The established PSA results were explicitly used to address unresolved issues regarding operating practices (for instance, safety improvement during mid-loop operation).

In its review, Bel V always encourages the licensee to explore PSA results for identifying safety improvements and evaluating safety insights. Following the development of the SFP PSA models, an action plan has been established, taking into account improvements following the PSA evaluations (see §2.2.1).

The decision-making policy established by the licensee requires using PSA as a supplementary tool for risk management, meaning that its decision-making process is not solely based on PSA insights.

The use of PSA to assess the adequacy of plant modifications and changes in operational practices being legally binding (see Issue O 3.4 of [1], which has been transposed in the Belgian regulation), in principle any change in the plant's design, operational procedures, or technical specifications must be assessed using PSA. In practice, this only concerns modifications that can be modelled by the licensee using existing PSA models. The Regulator does not allow any risk increase unless it is compensated by a significant safety improvement (e.g., in post-accidental management). Alternatives to the proposed modification, which do not lead to a risk increase, should nonetheless first be sought by the licensee.

Real events at Belgian NPPs must also be assessed using PSA (PSA Event Analysis or precursor analysis). PSA outputs are also used to identify important post-accidental situations to be highlighted during on-site operator training. Significance measures analysis performed on the existing PSA allowed creating an input providing the list of most critical components to be included in the Safety Analysis Report (SAR) (see also Issue O 4.3 of [1], which has been transposed in the Belgian regulation), thus providing information to non-PSA practitioners and enabling risk-informed inspections and plant operation.

3.2. PSA Policy and PSA Applications by the Licensee

While PSA is a consolidated element of the periodic safety review and an important element in the Belgian regulation, a tangible use of PSA in safety management by the licensee has also emerged. The Belgian licensee ENGIE Electrabel, being the actual owner and end-user of the PSA models, has taken up an active ownership over the PSA developments and PSA applications. This is reflected in the publication of a PSA Policy.

Following the publication of the licensee’s PSA policy, a “PSA standing committee” was established. This committee actively involves PSA team members from the architect-engineer Tractebel ENGIE as

well as dedicated staff from the licensee (at headquarters and both NPP sites). This group has gradually worked to concretize the PSA policy, first by identifying all potential PSA applications, next by performing a prioritization exercise, and now implementing the selected applications while keeping models up-to-date across the different processes. Bel V holds a (at least) yearly meeting with this PSA Standing Committee to discuss globally the current PSA applications and future PSA perspectives.

4. PERSPECTIVES

For PSA, the upcoming challenges will be related to the development of reactor PSA for external hazards for the two units (Tihange 3 and Doel 4) subject to a 10 years life-time extension and to the development of plant-specific Level 2 PSA models (Internal Events/Hazards and External Events) for those two units.

The remaining units (Tihange 1, Doel 1 and Doel 2) will have to be permanently shut down by 2025. It is at the moment still not decided to what extent POP models (as presented in §2.3) will also be developed to complement the definition of the required configuration of the remaining nuclear island during the POP. The PSA models of those units will also be the object of the Safety Factor 6 assessment ([12]) of the upcoming PSR.

5. CONCLUSIONS

Spent Fuel Pool PSA Level 1 models for all Belgian NPPs have been established and updated for Internal Events, Internal Hazards and External Events in the framework of the transposition of the WENRA Reference Levels of 2014 into the Belgian regulation. SFP PSA Level 1 models have also been used to complement the definition of the required configuration of the remaining nuclear island during the Post-Operational Phases for the units that went in permanent shutdown in 2022 and 2023.

The licensee ENGIE Electrabel keeps an active ownership over the PSA and its applications and defines its own policy and strategy in terms of PSA activities.

Upcoming challenging perspectives, in relation to the decision to keep the country's two most recent nuclear reactors - Tihange 3 and Doel 4 - in operation for 10 years beyond their planned closure date in 2025, will be the development of reactor Seismic Level 1 and 2 PSA models and the development of plant-specific Internal Events/Hazards and External Hazards Level 2 PSA models.

Bel V, as Belgian TSO, will continue by its regulatory review to encourage the Licensee to explore the PSA results for identifying safety improvements and to evaluate safety insights.

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