September 2020

National final report on the stress tests of nuclear power plants

FANC

federal agency for nuclear control

Executive Summary

As a consequence of the accident that occurred on 11 March 2011 at the Japanese Fukushima-Daiichi nuclear power plant, a wide-scale targeted safety reassessment program was set up among the member states of the European Union operating nuclear power plants.

This "stress tests" program is designed to re-evaluate the safety margins of the European nuclear power plants when faced with extreme natural events (earthquake, flooding and extreme weather conditions) and their potential consequences (loss of electrical power and loss of ultimate heat sink), and to take relevant action wherever needed. The approach is meant to be essentially deterministic, focusing on preventive as well as mitigative measures (severe accident management).

The licensee of the Belgian nuclear power plants performed stress tests in its facilities in 2011 to evaluate the response of the facilities when facing the different extreme scenarios, and indicated, where appropriate, the improvements that could be implemented to reinforce safety. The Belgian stress-tests action plan (BEST) synthetizes all actions undertaken by the licensee as a result of the stress tests program.

The present report presents the conclusion of the implementation of the stress-tests action plan in the nuclear power plants of Doel and Tihange from 2011 to 2020.

The stress-tests performed in the nuclear power plants in 2011 identified several improvements requiring additional feasibility studies and significant on-site work, mainly for the protection against earthquakes, flooding or the enhancement of the severe accident management. For most of these issues, the licensee implemented already from 2012 on quick-wins improvements to temporarily enhance the site protection, until more definitive measures were being installed.

Since 2011, the sites of Doel and Tihange have witnessed several main achievements : reinforcement of structures, systems and components to face severe earthquakes, construction of protections against flooding, additional mobile means, such as mobile pumps and mobile diesels.

- Both sites are now adequately protected against natural hazards, such as flooding and earthquakes.
- Both sites are also now adequately protected against complete station black-out combined with the loss of the ultimate heat sink.
- Both sites have adequately enhanced their strategy to manage severe accidents.

All planned improvement measures have now been implemented. The licensee ENGIE Electrabel finalized the stress-tests action plan by mid-2020.

The Belgian regulatory body (FANC and Bel V) confirms the closure of the stress-tests action plan.

For the sake of transparency, the Federal Agency for Nuclear Control published an annual report on the progress of the stress test action plan from 2014 to 2019. This final report provides the overview of the actions undertaken by the licensee to enhance the protection of the Belgian nuclear power plants following the Belgian stress tests, and their follow-up by the regulatory body.

This final report is an update of the previous progress reports.

1. Introduction

As a consequence of the accident that occurred on 11 March 2011 at the Japanese Fukushima-Daiichi nuclear power plant, a wide-scale targeted safety reassessment program was set up among the member states of the European Union operating nuclear power plants.

This "stress tests" program is designed to re-evaluate the safety margins of the European nuclear power plants when faced with extreme natural events (earthquake, flooding and extreme weather conditions) and their potential consequences (loss of electrical power and loss of ultimate heat sink), and to take relevant action wherever needed. The approach is meant to be essentially deterministic, focusing on preventive as well as mitigative measures (severe accident management).

Belgium has seven pressurized water reactors operating on two different sites:

- Four reactors on the Doel site, close to Antwerp (Flanders), located on the Scheldt river:
    - Doel 1/2: twin units of 1312 MWth each, commissioned in 1975,
    - Doel 3: single unit of 3064 MWth, commissioned in 1982,
    - Doel 4: single unit of 3000 MWth, commissioned in 1985.
- Three reactors on the Tihange site, close to Liège (Wallonia), located on the Meuse river:
    - Tihange 1: single unit of 2873 MWth, commissioned in 1975,
    - Tihange 2: single unit of 3054 MWth, commissioned in 1983,
    - Tihange 3: single unit of 2988 MWth, commissioned in 1985.

The scope of the Belgian NPP stress tests covers all seven reactor units, including the associated spent fuel pools, the dedicated spent fuel storage and the waste management facilities at both sites:

- SCG building at Doel (dry cask spent fuel storage facility),
- DE building at Tihange (wet spent fuel storage facility),
- WAB building at Doel (Water and Waste treatment building).[1]

[1] The Water and Waste treatment building (WAB) at Doel, which includes equipment for the processing, storage and handling of liquid effluents and solid radioactive waste, is featured in this report, even though it was originally part of the stress test for the non-NPP Belgian nuclear facilities. But since ENGIE Electrabel, which is the operator and license holder of the WAB, has integrated the action plan for the WAB into his global action plan for nuclear power plants, the regulatory body has similarly chosen to include the WAB building in this report.

Both sites are operated by the same licensee, ENGIE Electrabel, a company of the ENGIE energy and services Group.

For all matters related to nuclear safety, the licensee's activities are under the control of the Belgian regulatory body[2], which consists of:

- the Federal Agency for Nuclear Control (FANC),
- and Bel V, its technical subsidiary.

Similar stress tests have been performed in Belgium for the non-NPP nuclear facilities. The results of these tests are presented in other reports from the regulatory body, available on the FANC website.

In accordance with the European methodology, the stress tests of the nuclear power plants were performed in three phases:

1. The licensee performs stress tests in its facilities and submits a final report to the Belgian regulatory body (in the present case, one final report per site). In these reports, the licensee describes the reaction of the facilities when facing the different extreme scenarios, and indicates, where appropriate, the improvements that could be implemented to reinforce safety. The licensee completed this phase on 31 October 2011.
2. The regulatory body reviews the licensee's final reports and evaluates the approach and the results. Based on these data, the regulatory body writes its own national report and communicates it to the European Commission. This phase was completed by the regulatory body on 30 December 2011.
3. The report of all national regulatory bodies participating in the stress tests program is subject to an international peer review. The national reports are reviewed by other regulatory bodies representing 27 European independent national Authorities responsible for the nuclear safety in their country. This phase was completed by ENSREG on 26 April 2012. A follow-up meeting was organized in April 2015 to present the developments of the stress test action plans. The final synthesis by ENSREG on the follow-up of the stress tests performed on European nuclear power plants is available on the ENSREG website.

The resulting national action plan synthetizes all actions undertaken by the licensee as a result of the stress tests program.

All these reports are available on the FANC website.

Upon demand of the Belgian Federal Government, terrorist attacks (aircraft crash) and other man-made events (cyber-attack, toxic and explosive gases, blast waves) were also included as possible triggering events in the stress tests program for the nuclear power plants, even though the assessment of these man-made events does not fall under the scope of the European stress tests programs. For security reasons, the progress on specific actions related to man-made events is not included in this report.

[2] Additional information about the Belgian regulatory body and nuclear facilities is available in the 2017 report for the Convention on Nuclear Safety, which was published on the FANC website (http://www.fanc.fgov.be).

2. Development of the national stress test action plan

The national action plan was drafted and updated progressively in accordance with the stress tests program. The national action plan was indeed amended several times to take into account the requirements and recommendations resulting from the on-going stress tests and from consultation with several interested parties on a national and international level.

Over time some actions specific to a particular reactor have been amended or put (temporarily) on hold waiting for a decision to be taken on the future operation of the reactors. This was the case for the actions planned for the Doel 1 and Doel 2 units. In 2012-2013, the Belgian government decided to cease the operation of the Doel 1 and Doel 2 units in 2015. As a consequence, the Stress Test action plan was amended at that time for these two reactors. As the Belgian government decided to allow a 10-year life extension for these two reactors in 2014, the LTO action plan incorporated the stress test actions for Doel 1 and Doel 2.

a) Licensee's initial action plan

A self-assessment led the licensee to identify a set of safety improvements, which were presented in the licensee's final reports released in October 2011. The proposed actions pursued the following main objectives:

- Topic 1 (extreme natural events):
  - enhanced protection against external hazards (earthquake, flooding, extreme weather conditions).
- Topic 2 (loss of electrical power and loss of ultimate heat sink):
  - enhanced power supply,
  - enhanced water supply,
  - enhanced operation management (procedures),
  - enhanced emergency management (on-site),
  - non-conventional means (NCM).
- Topic 3 (severe accident management) :
  - enhanced protection against severe accidents (SAM).

Overall, the indicative deadlines proposed by the licensee for the implementation of the actions were in line with the importance of the issues. They also took into account the complexity of the actions, the dependence on internal or external resources for supply and implementation, and the potential interactions with other projects (especially the "LTO" project for the oldest units).

b) Regulatory body review

The regulatory body reviewed the licensee's final reports and approved the proposals made by the licensee, but also identified some opportunities for additional improvement, for which it expected relevant actions. These were detailed in the national report, released in December 2011.

Furthermore the regulatory body asked the licensee to complete a few specific actions earlier than planned, because of their importance for the improvement process. The licensee's action plan was updated accordingly.

On 15 March 2012, the licensee submitted a detailed stress tests action plan, including the additional requirements of the regulatory body mentioned in the national stress tests report. This plan identified a total of 350 individual actions.

c) International peer review

The subsequent international peer review of the national stress tests reports, supervised by ENSREG, provided further improvements, not only on a national level but also on the European level. One of the objectives of the peer review was to share relevant findings and to benefit from the best practices and insights found in other countries, in order to further improve safety. ENSREG issued a number of suggestions in a peer review report and a peer review country report released in April 2012, followed by a compilation of recommendations and suggestions released in July 2012.

Analysis of these documents led to addition of several actions to the licensee's action plan. Most of the recommendations based on practices in other countries were already being implemented in the Belgian units or were already featured in the action plan.

After the integration of the additional actions resulting from the ENSREG peer review, the FANC formally approved the consolidated version of the licensee's action plan on 25 June 2012.

d) Current national action plan

The content of the national action plan updated in March 2020 is the result of the various inputs described above.

3. Stress test NAcP

For the purpose of readability, this report does not list the status of all actions but focuses only on the major actions and achievements during the year. This Final NAcP Report is therefore primarily an update of the previous annual Progress Reports.

3.1. Enhancement of the protection against external hazards

The stress tests of the Belgian nuclear power plants comprised an extensive reassessment of the protection of the nuclear reactors against seismic and external-flooding hazards as well as extreme meteorological conditions. In its final stress test report, ENSREG recommends that the return frequencies of the dimensioning hazards be decreased to 10E-4 per annum. The nuclear reactor protections need to be improved in order to resist a flood or a seismic hazard with a return period of 10,000-year.

An analysis of the stress test results revealed that several actions were necessary to enhance the protection against external hazards.

3.1.1. Earthquake

Both sites

In order to assess the **adequacy of the Design Basis Earthquake** (DBE), the Royal Observatory of Belgium (ROB) performed a preliminary seismic risk assessment in 2011, using a Probabilistic Seismic Hazard Assessment approach (PSHA).

For the Doel NPP, the obtained results still (or nearly for Doel 1 and Doel 2) conformed with the values used in the design basis.

For the Tihange NPP, this preliminary assessment resulted in the finding of a greater peak ground acceleration (“PGA”) than was presumed when designing the facilities. Nevertheless, the safety margin assessment performed during the stress tests has demonstrated that the equipment is more robust than required by the **design basis earthquake**.

Due to the stringent timeframe of the European stress tests, the preliminary PSHA study of the ROB had to be conducted in a short period of time with conservative assumptions. As suggested by the Royal Observatory of Belgium, the regulatory body requested the licensee **to carry out a more elaborate study** with due consideration of:

(1) other elements such as the use of a more recent ground-motion prediction equation or such as a cumulative absolute velocity (“CAV”) filtering,
(2) external reviews by international experts and
(3) results from other international studies.

The reevaluation of the seismic hazard has been finalized in 2015 by the ORB and delivered for approval to the Belgian Regulatory body in 2016. This detailed analysis confirms the rough results obtained in 2011 both for Doel and Tihange so that the licensee concludes that the two sites are adequately protected against seismic hazards and that additional measures are not necessary.

The **safety margin assessment** for the Doel and Tihange units was performed on the basis of a review level earthquake (“RLE”) as high as 1.7 time the peak ground acceleration (PGA) of the current design basis earthquake. It showed that the Systems, Structures and Components (“SSC”) required for achieving and maintaining a safe shutdown state are robust enough, except for a few mechanical and electrical elements that have a low or moderate probability to resist a RLE. More information on the definition of the probability levels can be found in the Belgian Stress Tests - National Report for the Nuclear power Plants on [the FANC website](). Further justifications or improvements of these SSC through easy-to-implement modifications were realized in 2011 and 2012.

The stress tests have highlighted that 28 Structures, Systems and Components (SSC) of Doel and Tihange had a low probability of resisting an earthquake exceeding the “Review Level Earthquake” (RLE). 22 SSCs were identified at Tihange 1, 3 at Tihange 2, 1 at Doel 1/2, 1 at Doel 3 and 1 at Doel 4. Following the stress tests, the licensee has committed to either confirming that the current margins are sufficient by means of more precise calculations, or raising these SSCs to a high probability of resisting an RLE by means of corrective actions. The licensee completed most modifications in 2013; the final modifications in Doel and Tihange were completed in 2014.

Synthesis

All actions related to the protection against earthquakes were carried out at Tihange and Doel by the licensee by the end of 2015. During 2018, the regulatory body finalized its review and assessment of most remaining actions concerning the protection against earthquakes in Belgian Nuclear power plants.

3.1.2. Flooding

Tihange

- During the 2002-2005 Periodic Safety Reviews (PSR) in Tihange, a probabilistic methodology was used to determine the flood level of the Meuse as a function of return frequency. One of the conclusions reached shortly before the Fukushima event was that the Tihange site was protected by its design against a Reference Flood with a statistical return frequency between 1.0E-2 and 1.0E-3 per annum. Nevertheless, so as to comply with the new international standards, it was decided in 2011 to use a more conservative flood corresponding to a 10,000-year return period as the new design basis for the Tihange site. It turned out that the Tihange site could not be considered fully protected against this new Reference Flood. As discussed in the previous Progress Reports, several actions were proposed to enhance the protection against flooding by means of the following additional provisions:

    i. A peripheral protection of the site,
    ii. The mobilization of non-conventional means on site.

  The **peripheral protection** of the site consists in a wall, together with isolation devices of water intakes and solutions for discharging cooling and sewer water into the Meuse river. As requested by the regulatory body, a safety margin for the wall height to adequately cover uncertainties associated with the new design basis flood was considered. The construction of this peripheral protection began in October 2013 and was completed in 2015 so that the first provision against flooding is fully operational since 2015.

Figure 1 : Peripheral protection of the site of Tihange against beyond-design flooding realized in 2015

Figure 2: Peripheral protection of the site of Tihange against beyond-design flooding realized in 2015

The second flooding provision aims to protect the site either in case of a flood beyond-design, or in case of a failure of the peripheral protection in protecting the site against a flood below or equal to its design value. This second level of protections consists of **non-conventional means** that can be deployed during the flooding alert period. These non-conventional means are kept at least 1 m above the level corresponding to the design flood and consist of:

- Additional diesel generators located in new specific buildings,
- Fixed pipes (with a few exceptions of flexible elements),

- Pumps for make-up of water from water tables to the primary circuit, the steam generators and the spent fuel pools.

This second level of protection was finalized by the licensee in 2013 and is considered fully operational since 2014.

- At Tihange, the robustness of the **emergency preparedness strategy** and organization had to be improved. The flooding alert system is based on a direct communication between the SETHY (the regional authority in charge of the protection against flooding) and the NPP. As a conclusion of the stress test analysis, the regulatory body recommended to further improve the robustness and the efficiency of this communication. A convention was signed in 2013 between the licensee and the SETHY to define a collaborative environment, including access to more flow measurements and water levels over the Meuse and an increase of the available instrumentation during a flooding period.
  Moreover, means for on-site transport of personnel and equipment while the site is flooded (amphibious vehicles) are available since June 2012 at Tihange. In 2013, the licensee finalized the implementation of the associated procedures and the organization of the training of its staff.

- At Tihange, the internal hazards potentially induced by the flooding were examined, as requested by the regulatory body. The possibility of internal fires and internal explosions was considered. The licensee proposed protective actions, which were judged acceptable by the regulatory body and were then implemented.

Doel

The Doel site was already well protected against flooding; it is only under a few specific circumstances that water can intrude into the site. As a preventive measure, sandbags are available to protect the critical entrances. In the framework of the Belgian stress tests, these sandbags were planned to be replaced by permanent volumetric protections. These barriers (cofferdams, etc.) against flooding were installed at Doel in 2013.

In addition, to enhance the protection of the Doel site against flooding, some actions were carried out on the embankment. To prevent any possible weakening, the licensee reinforced the embankment with concrete tiles in 2013. The licensee also modified the internal procedures to perform embankment inspections more regularly.

Synthesis

The additional protection measures against flooding at Doel and Tihange are fully operational respectively since 2013 and 2015.

3.1.3. Extreme weather conditions

In addition to the earthquake and flooding hazards, the resistance of the sites against extreme weather conditions was evaluated in the framework of the stress tests. Additional hazards like tornadoes, heavy raining, lightning, snowfall, etc. have also been taken into consideration. The stress tests have resulted in a list of actions to enhance the protection of the site.

- The regulatory body recommended reassessing the capacity of the **drainage systems** (five separate networks at Doel, separate networks per unit at Tihange), using a detailed hydrodynamic model in order to cover both short-duration heavy rains and long-lasting rains.

  At Doel, the licensee finalized its revaluation of the impact of heavy rains in 2014 and concluded that the site is satisfactorily protected against the potential impact of heavy rains.

  At Tihange, the licensee performed in 2016 major improvements in order to avoid a flooding internal to the site by sewer overflow. These improvements mainly consist of deviating the underground municipal sewers that were crossing beneath the site of Tihange. The deviation and the construction of a new sewer and the modifications of the discharge points of the Tihange site in the Meuse river consist in the main improvements. A complementary assessment of the capacity of the drainage systems of Tihange, considering the impact of rainfall of 1.0E-3 return frequency, is still ongoing.

- The licensee had to enhance the protection against **heavy rains** for the WAB building. Indeed, the regulatory body has requested to limit the accumulation of water on the WAB roofs either by periodic inspections or by periodic maintenance of the necessary overflows. The licensee also had to evaluate the impact of rainfall of 1.0E-3 return frequency on the sewer system network. These two actions were realized by the licensee in 2014.

- The robustness of the second-level system of Tihange 1 and Doel 1/2 against a beyond-design **tornado** had to be confirmed by the licensee, given the fact that high intensity tornadoes have been observed in the past years in neighboring countries. The licensee ENGIE Electrabel finalized their evaluation in 2014. Following new questioning, a little modification of the installations for protecting the aquifer well in Tihange against tornados is now planned in early 2019.

- At Doel, the assessment of the protection against **lightning** has been finalized in 2015. Based on this analysis, some modifications of the existing installation on the roofs and the infrastructure have been carried out in 2016 in order to enhance the protection against lightning, such as drilling additional grounding points.
  The Tihange site was already satisfactorily protected against lightning.

- In 2012-2013, the licensee improved its intervention procedures in case of **heavy snowfall** to remove snow layers of more than 30 cm from “non-bunkered” buildings.

Synthesis

By the end of 2018, both sites were adequately protected against extreme weather conditions (tornadoes, heavy snowfalls, heavy rainfalls and lightning hazards).

3.2. Enhancement of the power and the water supply

a) Initial situation on both sites

Tihange NPP

Considering the numerous and redundant power supply sources and heat sinks available, every reactor unit in Tihange has a high level of robustness in this respect. Indeed, every unit disposes of:

- three external power supply sources;
- two independent ultimate heat sinks (river water and alluvial groundwater);
- at least two levels of technically and geographically independent internal sources of power supply (in total, 16 diesel generators and a turbine-driven alternator), with a fuel autonomy of several weeks;
- a turbine-driven safety feedwater pump for each unit;
- and various cooling water capacities.

Furthermore, mobile devices (power generators, flexible hoses, pumps, valves, etc. - some of which are preinstalled) can also ensure power supply of the essential equipment and water supply of the steam generators and the primary system. Their capacity and deployment time have been designed according to the dynamics of the situations that were assessed.

Doel NPP

The Doel 1/2 units can use three independent heat sinks, which are all capable of independently keeping the units cooled:

- the Scheldt river;
- the atmospheric forced draught cooling towers;
- the heat exchangers cooled by the ambient air.

Likewise, the Doel 3 and Doel 4 units can use independent heat sinks which are all capable of independently keeping the units cooled:

- the atmospheric forced draught cooling towers, with supply from the Scheldt river and from cooling ponds;
- 3 cooling ponds of 30 000 m^3 each.

In every unit there are 2 internal electrical power supply levels. These 2 levels function independently from one another and are physically separated. For the power supply of the safety equipment, there are 19 diesel generators with – in total – a few weeks fuel supply. Moreover, most diesel generators are air-cooled, thus making them independent from an external heat sink.

Finally, every unit disposes of a pump, powered by a steam turbine, in order to be able to continue supplying cooling water to the steam generators. This cooling water is available in various tanks and in the cooling ponds.

As a conclusion, both at the Doel and Tihange NPP, the cooling of reactor core and of the spent fuel pools are secured with a high degree of certainty even in very unlikely cases such as the loss of power supply sources or heat sinks. As a result, the risk of significant activity release should these extreme scenarios occur is negligible. In conclusion, the NPP has emergency equipment and sufficient autonomy to manage this kind of hazards for a long time. This time period is sufficient to restore off-site power supply or to bring in off-site resources.

b) Planned improvements

Nonetheless, some measures were considered to still enhance the robustness of the facilities. In this framework several actions have been undertaken for the enhancement of the power and the water supply in the Belgian NPPs.

3.2.1. Power and Water Supply

CSBO consists in a loss of off-site power supply and first-level and second-level internal power supplies. Compared to the design basis scenario of Station Black-out, this scenario adds the loss of the second-level internal power supplies. As this scenario is a beyond design basis scenario for all Belgian units, the licensee has proposed a set of additional measures to avoid cliff edge effects.

The licensee commits to use non-conventional means:

- to refill the steam generators and the spent-fuel pools,
- to ensure make-up for the primary circuit in open configuration,
- to avoid the overpressure in the reactor building,
- to restore the electrical power supply to instrumentation and control panels, and
- to make operable the emergency compressed air circuit.

Therefore, in the action plan, an alternative power supply for non-conventional means or safety equipment has to be implemented on both sites.

Tihange

At **Tihange** the enhancement of the nuclear power plant against the consequences of a loss of off-site power supply and/or first-level and second-level internal power supplies has been **put in operation in 2017**. The protection consists in developing an emergency internal 6 kV electrical grid in order to restore the electrical power supply to control panels, instrumentation, and existing safety systems including shutdown cooling... This strategy mainly consists in the use of existing devices (ultimate safety diesels, …) and the deployment of additional equipment (fixed and mobile) to meet the CSBO extreme circumstances.

Doel

At **Doel**, the CSBO strategy is already being implemented. Several actions have been realized by the licensee such as the delivery of the requested mobile means in 2014 and 2015.

The construction of the new storage building for non-conventional means has been completed in 2014. The mobile pumps and the mobile generators are operational and are stored in this building. A fuel tanker truck is available for the on-site transport of diesel fuel and a new fire truck, multifunctional and designed to play in case of CSBO the role of a mobile pump, is also available on the site.

In addition, in order to manage the autonomy of the electrical diesel generators, the Licensee defined in 2013 which equipment and facilities can be stopped in case of external event to reduce the diesel and oil consumption of the electric diesel generators and therefore increasing their autonomy. Depending on the situation, 33 to 36 pieces of equipment can be stopped (mainly fans and pumps).

Finally, at Doel 3 and Doel 4, the licensee installed during the plant outages of 2014 and 2015 nozzles on the intake and discharge of the spray pumps (SP) and connections to the emergency cooling (LU) and to the emergency feedwater (EF) systems. In case of CSBO the mobile pumps will be used in order to achieve alternative water make-up of the reactor via this system. Since these equipment are available, the CSBO strategy is now fully operational.

Doel WAB

The regulatory body has formulated several requests to enhance the protection of the WAB building against the loss of power and water supply (additional summary screen on the Digital Control System, additional control procedures, evaluation of the electric grid of the WAB, etc.). All actions were finalized by the end of 2015.

3.2.2. Loss of primary and alternate ultimate heat sink (LUHS)

"Loss of primary ultimate heat sink" has been studied in the original design basis of all the Belgian units when one unit is affected by this accident. "Loss of primary and alternate ultimate heat sink" is a beyond design basis accident. To avoid cliff edge effects, several measures have been proposed by the licensee. Some of them are similar to the CSBO measures like the use of non-conventional means to refill the steam generators and the spent fuel pools, to ensure make-up for the primary circuit in open configuration or to avoid the overpressure in the reactor building.

- In the framework of the LUHS scenario, Tihange 2 and Tihange 3 units carried out alignment tests of the emergency deep water intakes from the Meuse river and to justify the availability of the emergency intakes. The related actions have been finalized in 2013 by the licensee.
- In addition the licensee justified that the water capacity of the second level of protection is sufficient when all the units of the site are affected by the loss of primary UHS. This justification has been presented by the licensee in 2013 for both sites and has been analyzed and confirmed by the regulatory body in 2014.

3.2.3. Spent Fuel Pools

At Doel, alternative water supply for the spent fuel pools (PL) using supplementary nozzles, connections and mobile pumps has been made operational by the licensee in 2014-2015. A similar improvement has been realized in Tihange 1 in 2017.

On both sites, improvements of level measurements in the spent fuel pools are implemented by the licensee. These modifications aiming at enhancing the monitoring of the spent fuel pools have been realized in 2016.

The licensee also worked on the enhancement of the prevention of a loss of water inventory of the spent fuel pools. Siphon breakers have been enlarged so as to keep a radiological shielding above spent fuel after PL piping break both in Doel and Tihange.

3.2.4. Synthesis

The protection of the site of Tihange against the loss of water and power supplies is fully completed in Doel and Tihange since 2017.

3.3. Severe Accident Management (SAM)

3.3.1. Enhancement of the operation management (procedures)

As a result of the Fukushima accident, the licensee reassessed its organization so that it could face situations that are far beyond the design basis, which could affect several units simultaneously and could lead to the unavailability of some parts of the emergency management infrastructure or affect the access conditions and the environment.

The Belgian stress tests have highlighted that the operation management could be improved on the nuclear sites. In this respect, several procedures have been modified in order to enhance the operator response:

- At Tihange and Doel, the "earthquake procedures" have been modified in 2013 by the licensee to speed up the detection and mitigation of induced flooding on the site.

- The actions resulting from the periodic safety review concerning the flooding hazards at Tihange are described in section 3.1. The procedures for the beyond-design protection and those related to the peripheral wall are now operational.

- On both sites, the licensee introduced procedures describing the actions to take in case of a total loss of heat sink and in case of a total loss of internal or external power supplies.

3.3.2. Enhancement of the emergency management (PIU)

So far, the licensee's organization in emergency situations has been designed to overcome events affecting a single unit of the NPP and to manage design basis external events. This organization is periodically tested and improved through exercises.

As a result of the Belgian stress tests, the licensee reassessed this organization in order to be able to face far beyond design situations that could affect simultaneously several units.

In this respect, several actions have been decided in the framework of the stress tests:

- A study on modifying and strengthening the emergency management organization has been launched to include "multi-unit" events at Doel and Tihange. The licensee has finalized the implementation of the new organization of the emergency plan and of the adapted logistics in 2013. The description of the new organization of the emergency plan has already been analyzed and questioned by the regulatory body. In 2014, the licensee has implemented the modifications and thus strongly adapted the emergency management organization as requested by the regulatory body which has closed this action.
- In addition, several additional actions have been or are carried out by the licensee in order to enhance the emergency management. These actions include the harmonization of site training programs, the construction of on-site resistant storage for mobile means (see (§3.2.1), the setting-up of fallback bases, the improvement and diversification of communication means, additional means for managing work on a contaminated site, and so on. Most of these additional actions were finalized on schedule in 2013 and in 2014 by the licensee.
- At **Tihange**, the **site operation center** "COS" was planned to be moved to an underground room in the new entrance building. However, this building has appeared to not be conveniently located to resist to a beyond-design flood and to not be ideally protected against earthquakes. The licensee developed a new strategy for the COS in 2016 that consists in the construction of

an annex to the current COS to serve as a backup center for crisis management. In this annex, a mobile COS backup is parked, enabling the crisis management center to be moved in case of risk of radiological or toxic releases during the accident.

Difficulties encountered in recent years had an important impact on the construction schedule of this **COS backup building** that was finally available by mid-2020, while **the mobile COS backup** was already available in 2017.

Figure 3 - New annex to site emergency center

Several actions were undertaken as quick-wins in the COS and other emergency rooms to improve their capacities (additional communication means, additional radiation protection equipment, an additional power generator - available since 2014).

3.3.3. Enhancement of the protection against severe accidents (SAM)

The scenarios involving severe accidents have been reassessed from a “defense-in-depth” perspective during the Belgian stress tests. Some actions that could further reduce the risk of potential releases into the environment resulting from an extreme situation were identified in the action plan. The main issue on this topic is the installation of a filtered containment vent system for each nuclear reactor:

Figure 4 : **Filtered containment venting systems of Tihange 3**

Filtered containment venting systems have been installed on each unit and made operational by the end of 2017 (except for Doel 1 and 2, where the FCVS project is integrated in the LTO action plan and must be made operational by 2018-2019).

This action was one of the main issues of the BEST action plan and was carried out in accordance with the planning agreed between the licensee and the regulatory body.

Concerning the estimation of the radiological release in case of a multiple-event, the Belgian emergency plan model has been upgraded in the framework of the stress-tests to tackle multiple-event model in early 2018.

3.3.4. Synthesis

More than 120 improvements were implemented in the framework of the Severe Accident Management. After construction of an annex for the site emergency center in Tihange, both sites have been adequately upgraded to face and manage severe accidents.

4. Conclusions on the NAcP

The National Action Plan for the two Belgian NPPs, initiated in 2011, contained 365 actions aiming at improving the protection of the sites against external hazards (mainly earthquakes and floodings) and the consequences of such events, like the loss of the ultimate heat sinks, a complete station black-out, or a combination of them.

By the end of 2017, almost all actions were already finalized by the licensee (98%). Only a few actions still needed attention during the last three years. After the construction of the annex to the site emergency center in Tihange in 2018-2020, both sites are now adequately protected against external hazards and their potential consequences (CSBO or LUHS). In parallel, with the improvements brought to the severe accident management, both sites are adequately upgraded to face severe accidents.

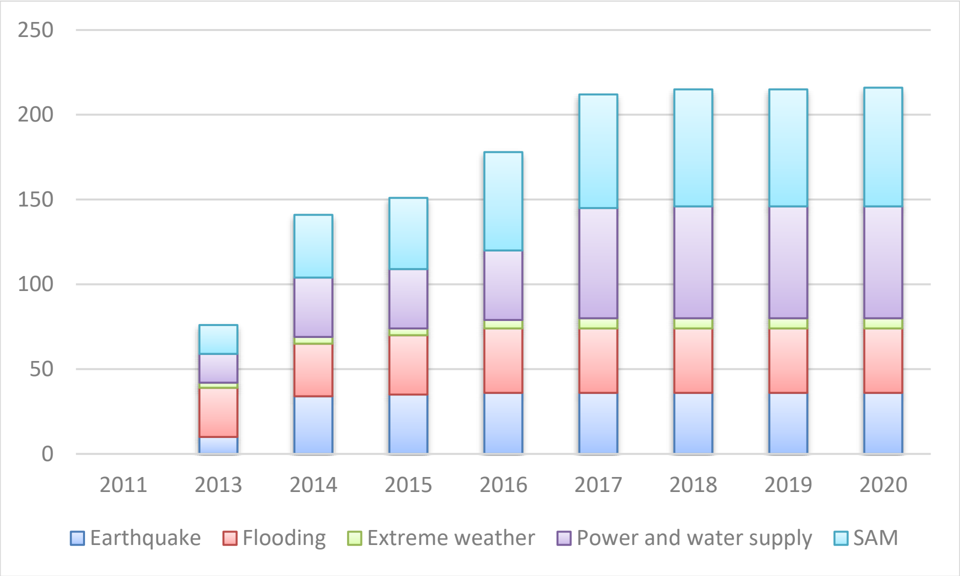

Figure 4 - Evolution of the NAcP implementation in Tihange NPP

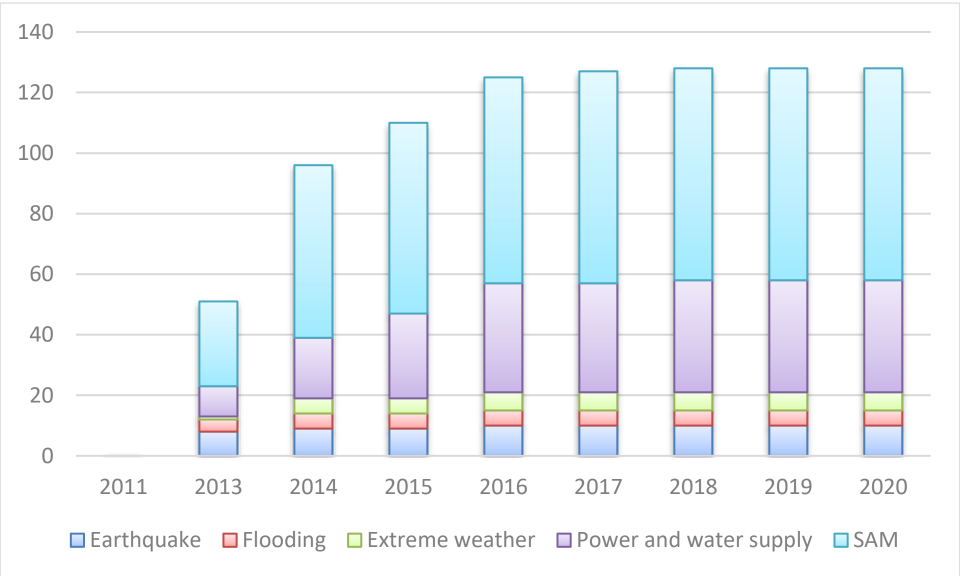

Figure 5 - Evolution of the NAcP implementation in Doel NPP

Nevertheless, in 2014 as an extended lesson from Fukushima, WENRA has increased its requirements, especially on the topics of design extension and natural hazards. The new elements of the WENRA 2014 reference levels have been integrated in the Belgian regulation in 2020. Additional evaluations are ongoing to confirm the safety demonstration of the NPPs and their compliance with this new regulation, potentially leading to additional improvements.

Concerning the chapter devoted to man-made events, which is not detailed in the current report, the ongoing status is a 100% realization of the actions. Therefore the enhancement of the protection against the man-made events is considered satisfactory.