BELGIAN STRESS TESTS

FANC
federal agency for nuclear control

National progress report on the stress tests of nuclear power plants

March 2017

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 summarizes the progress made on the stress-tests action plan in the nuclear power plants of Doel and Tihange since 2011.

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.

By the end of 2016, both sites are still enhancing their protection against the potential consequences of these events, i.e. loss of electrical power or loss of the ultimate heat sink, and their severe accident management. The strategy for the complete station black-out and for the loss of the ultimate heat sink is well-defined on both sites. The works are finalized in Doel, with the provisions of mobile pumps and diesels such as the realization of several modifications to protect the site in case of complete station black-out. At Tihange, most related actions are now almost finalized.

The biggest actions to be finalized in the framework of the stress-test action plan are the deployment of the Complete Station Black-Out strategy in Tihange, the construction of a new emergency response facility in Tihange (backup to current site operation center) and the construction of filtered venting systems on all reactor buildings at Doel and Tihange.

In summary, by the end of 2016, the licensee ENGIE Electrabel finalized more than 85% of the stress-tests action plan. Considering that most open actions are already ongoing, the licensee considers the project BEST to be implemented for 94%. Most remaining actions should be finalized in 2017.

The Belgian Safety Authorities consider the licensee progress made since 2011 as satisfactory but notes for some actions considerable delays in the implementation of the stress tests action plan.

These delays are mainly due to technical difficulties or procurement problems encountered by the licensee together with an underestimation of the time required by the Safety Authorities to perform the review and assessment of the feasibility and preliminary studies, to be validated before implementing the action.

These findings made in 2015 remain valid in 2016.

For the sake of transparency, the Federal Agency for Nuclear Control publishes an annual report on the progress of the stress test action plan. This report provides an 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. It focuses on the progress of the actions since 2011, with particular attention to the actions taken in 2015.

This progress report is an update of the previous 2013, 2014 and 2015 progress reports which were published in early 2014, 2015 and 2016.

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 433 MWe each, commissioned in 1975,
  - Doel 3: single unit of 1 006 MWe, commissioned in 1982,
  - Doel 4: single unit of 1 039 MWe, commissioned in 1985.
- Three reactors on the Tihange site, close to Liège (Wallonia), located on the Meuse river:
  - Tihange 1: single unit of 962 MWe, commissioned in 1975,
  - Tihange 2: single unit of 1 008 MWe, commissioned in 1983,
  - Tihange 3: single unit of 1 054 MWe, 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 here.

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. Until full implementation, this action plan is updated regularly.

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.

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, and is still liable to modifications. 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, and partly for the actions planned for Doel 3 and Tihange 2.

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 so that it no longer included those actions that had become unnecessary in the light of the shut-down and decommissioning plans. However, on December 18th 2014, the Belgian government decided to no longer oppose a 10-year life extension for these two reactors. A specific licensee LTO action plan was issued for the Long Term Operation (LTO) of Doel 1 and Doel 2 and approved by the regulatory body in 2015. This LTO action plan incorporates all remaining stress test actions for Doel 1 and Doel 2 (see § 4.2 of the LTO action plan).

Similarly, some actions for Doel 3 and Tihange 2 which were temporarily put on hold as a result of the prolonged shutdown in 2014-2015, were resumed after the regulatory body decided that these 2 reactors could resume power operation in 2015.

The target dates mentioned in the action plan must be considered “indicative”, given the fact that some actions might face time constraints due to interactions with other projects (LTO Tihange 1, Periodic Safety Review, etc.) and depend on internal or external resources for their on-site supply and implementation.

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 current national action plan (updated in February 2017) is the result of the various inputs described above.

3. Status of the stress test actions

For the purpose of readability, this report does not list the status of all actions. In the followings paragraphs, only the major actions are highlighted. The present 2016 Progress Report is primarily an update of the precedent Progress Reports of 2013, 2014 and 2015.

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 Safety Authorities in 2016. This detailed study is now currently under assessment. According to the licensee, the refined study confirm the rough results obtained in 2011 both for Doel and Tihange. 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**.

The assessment by the Safety authorities of all those justifications or reinforcements is now finalized but the compliance of these modifications will be evaluated by the Safety authorities after agreement has been reached on the assumptions, results and conclusions of the new PSHA study.

At Tihange 1, the licensee classified the **Electrical Auxiliary Building** (BAE) as having a medium probability to withstand a RLE without damage. As no cliff edge effect is expected after a RLE, this medium probability is considered acceptable in the context of the stress tests. Nevertheless, the licensee committed to evaluating the feasibility of raising the BAE to a high probability of resistance. This feasibility study showed that the improvements were impossible. The licensee is now investigating an approach to further reduce the associated risk.

Doel WAB

Concerning **earthquakes**, the licensee proposed to develop procedures in order to detect possible leaks in the WAB after earthquakes and to isolate them. This action has been officially closed by ENGIE Electrabel and the regulatory body. The regulatory body also requested an upgrade of the four SSC graded at a low probability to resist a RLE to a high probability. The upgrades of the four SSC has been realized by the licensee. The compliance of these modifications will be evaluated by the Safety authorities after agreement has been reached on the assumptions, results and conclusions of the new PSHA study.

Synthesis

Similarly to 2015, the main progress made in 2016 for the protection against earthquakes consists of the revaluation of the PSHA study for both sites. These studies have been finalized in 2015 by the ORB and delivered in 2016 for approbation to the Belgian Safety Authorities. This detailed study is now currently under assessment. The review of the detailed studies is now ongoing but takes longer than expected due to the complexity of the basic assumptions and calculations.

All other related actions have now been carried out at Tihange and Doel by the licensee. During 2017, the safety authorities plan to finish its assessment of the enhancement of the protection against earthquakes in Belgian Nuclear power plants.

The compliance of the present seismic designs and of all these modifications will be evaluated by the Safety authorities after finalization of its assessment of the assumptions, results and conclusions of the new PSHA study.

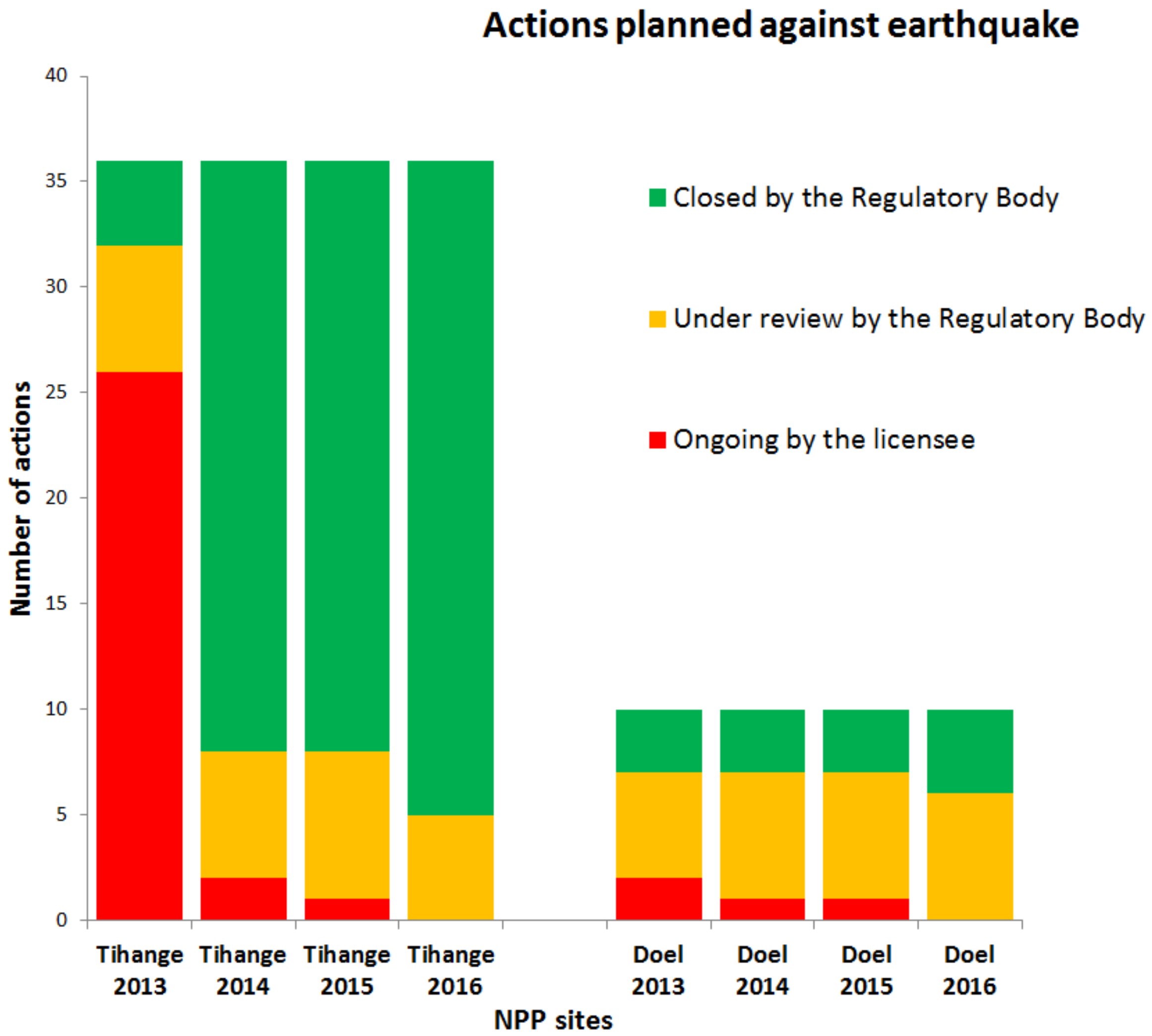

Figure 1: Evolution of the implementation of the actions concerning the protection against earthquakes between 2013 and 2016.

3.1.2. Flooding

Tihange

- During the previous Periodic Safety Review (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. In line with the licensee's schedule, the civil works have been completed by the end of February 2015 and the mechanical and electrical devices by June 2015. The commissioning and final reception were done in September 2015. This first provision against flooding is now fully operational.

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

Figure 3: 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.

Doel WAB

No specific actions had to be undertaken concerning the **flooding** hazards in the WAB building.

Synthesis

By the end of 2016, the additional protection measures against flooding at Tihange and Doel are fully operational. All the actions are now either already closed or under review by the regulatory body. The main discussions between the licensee and the safety authorities in the framework of the review address the documentation of the modifications and the new operational procedures.

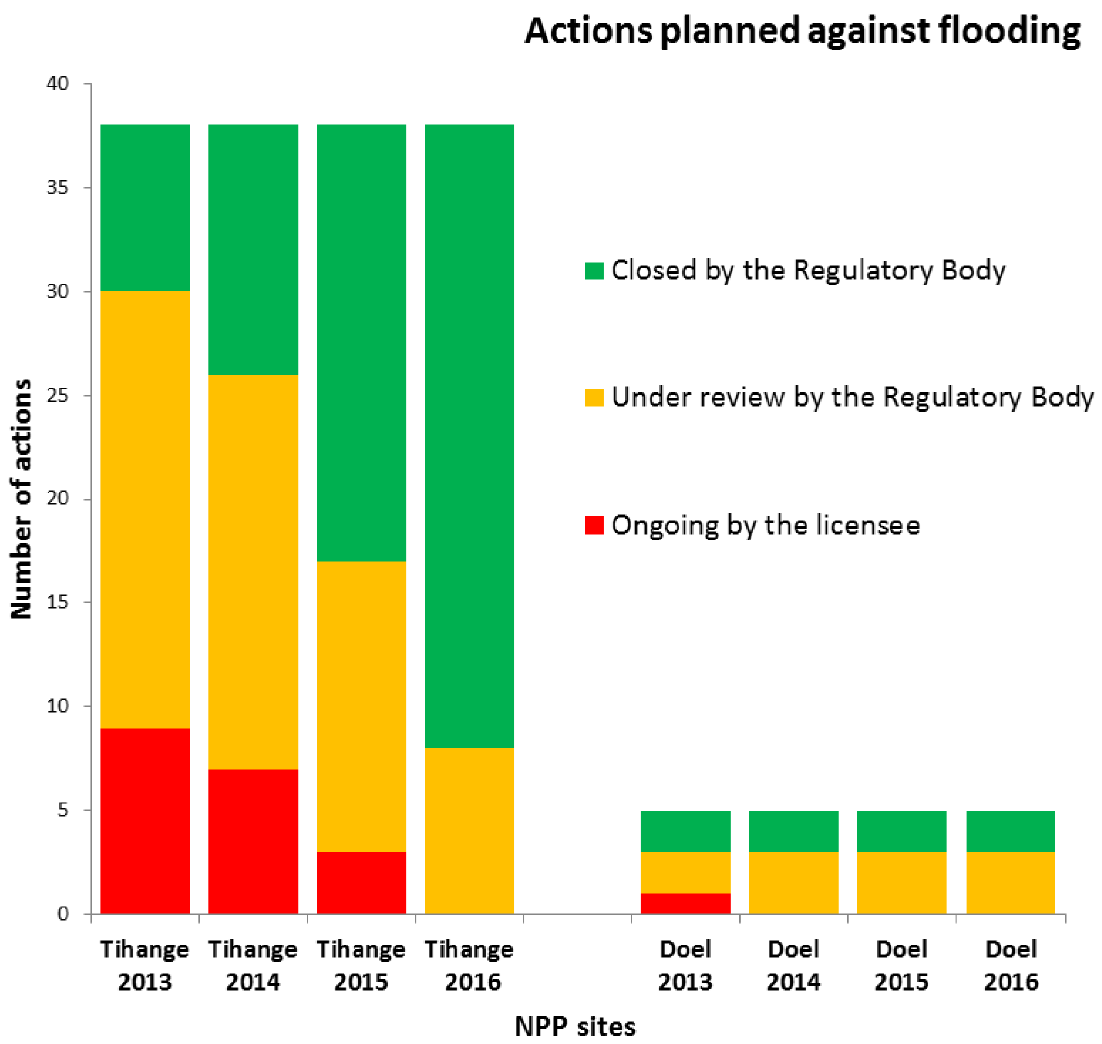

Figure 4 :: Evolution of the resolution of the actions concerning the protection against flooding between 2013 and 2016.

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. Important delays occured due to the administrative complexity for obtaining the necessary environmental permits for the deviation and the construction of a new sewer and the modifications of the discharge points of the Tihange site in the Meuse river.

Figure 5 : Deviation of the underground municipal sewers

- 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 this action in 2014.

- 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.

- Finally, the regulatory body has requested to evaluate the possibility of water entering into the WAB building and to define its potential impact on the safety functions. This action was finalized by the licensee in 2013.

By the end of 2016, both sites are protected against most extreme weather conditions (tornadoes, heavy snowfalls, heavy rainfalls and lightning hazards) according to the licensee. One last action is ongoing in Tihange consisting in carrying out an impact evaluation of the upgraded sewage capacity for the site. However most actions are still under review by the safety authorities. Indeed the main discussions between the licensee and the safety authorities in the framework of the review address the documentation of the modifications and the new operational procedures, so that the Belgian safety authorities plan to finalize the assessment on this topic by 2017.

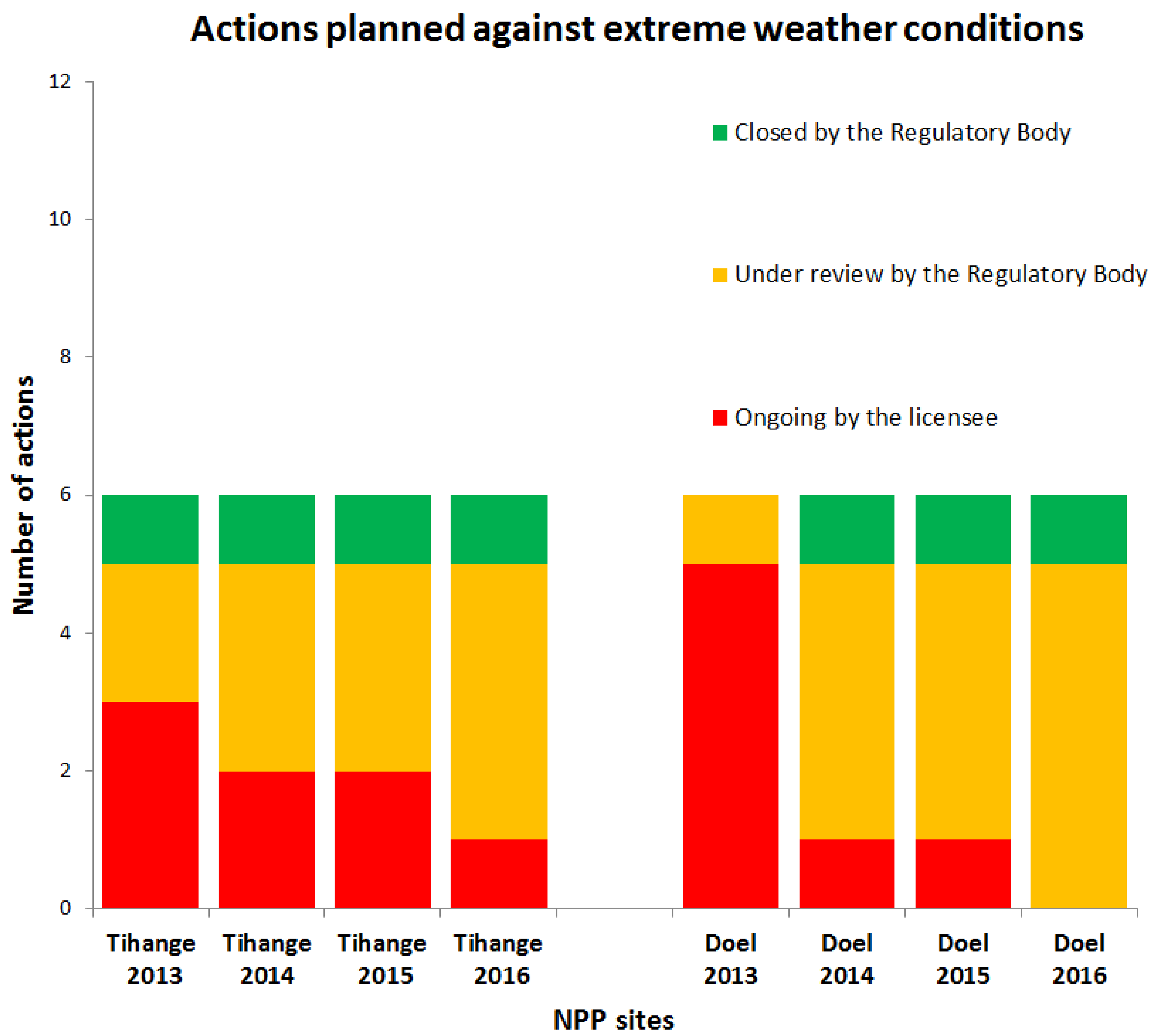

Figure 6 : Evolution of the resolution of the actions concerning the protection against extreme weather conditions between 2013 and 2016.

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 is ongoing. The proposed 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... The finalization of the modifications suffers important delays compared to the initial schedule and is planned for 2017.

Indeed since 2012-2013, the licensee ENGIE Electrabel had to regularly update the planning of the CSBO project for several reasons : first of all most actions related to the CSBO project were delayed in 2013-2014 by the licensee in order to primarily focus the attention on the flooding protection at Tihange. Nevertheless, priority actions have already been executed in function of plant outages. Second, the CSBO project and the related operation management appeared to be more complex issues than initially expected. In consequence, the licensee had to focus

his work in 2014-2015 on the revaluation and the development of a new site global strategy against CSBO.
The new site global strategy has been presented to the Belgian regulatory body in early 2015. The design review of the CSBO improvements followed soon after. 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.

By the end of 2015, several actions related to the CSBO topic in Tihange were redefined and their planning adapted for new target dates in 2016 and 2017. By the end of 2016, the CSBO action plan is planned to be finalized in March 2017 in accordance to the revised action planning of the project. Most of these actions are indeed finalized or under finalization by the licensee by the end of 2016.

Some CSBO actions specific to Tihange 1 unit have been included in the action plan of the Long Term Operation of this reactor and are no more considered in the stress test action plan. This is specifically the case for the actions that will enhance the autonomy of the EAS auxiliary feedwater reservoir and will add an auxiliary feedwater pump.

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 (purchased or hired) are now operational and are stored in this building. As a consequence of the uncertain future operability of the nuclear reactors of Doel 1, Doel 2 and Doel 3 in 2014-2015, the regulatory body authorized the licensee to delay the purchase of some of the mobile pumps and mobile generators and to replace them by hired equipment.
In the framework of the CSBO strategy, a fuel tanker truck is available since 2013 for the on-site transport of diesel fuel as required in the stress test action plan.

A new fire truck, multifunctional and designed to play in case of CSBO the role of a mobile pump, is also available since 2014 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 now available, this part of 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.

In the framework of the CSBO and the LUHS (see definition in § 3.2.2), the regulatory body has requested several actions (additional summary screen on the Digital Control System, additional control procedures, evaluation of the electric grid of the WAB, etc.). Most of these actions (5 out of 6) were finalized by the licensee in 2014. The last one has been finalized in 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 is almost finalized in Tihange 1.

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 will be enlarged so as to keep a radiological shielding above spent fuel after PL piping break. These modifications should be finalized by end2017.

Figure 7: Alternative water supply installed in the Tihange 1 spent fuel pool in 2016.

3.2.4. Synthesis

The following figure summarizes the evolution of the implementation of the actions planned in Doel and Tihange to protect the nuclear power plants in case of a loss of power supply and a loss of water supply, from 2013 to the end of 2016. The inclusion of a beyond-design scenario for LUHS and CSBO involves a lot of actions in the stress tests action plan, as this topic includes one third of the total number of actions.

The CSBO strategy was finally well defined on both sites in 2015. By the end of 2016, the deployment of the strategy is almost fully completed in Doel. The only remaining action consists in the finalization of the procedures for alignment and commissioning of alternative power supplies.

In Tihange, the implementation on site of the CSBO strategy is still ongoing. Most actions have been launched and regrouped in a major project that should be completed in the first quarter of 2017 in accordance to the revised stress tests action plan (version of January 2017).

By the end of 2016 (2015), some 25% (40%) of the actions still have to be finalized by the licensee while 35%(33%) of the actions are still under a questions/answers processes between the regulatory body and the licensee.

The protection of the site of Tihange against the loss of water and power supplies is now one of the main issues to be addressed by the licensee by 2017.

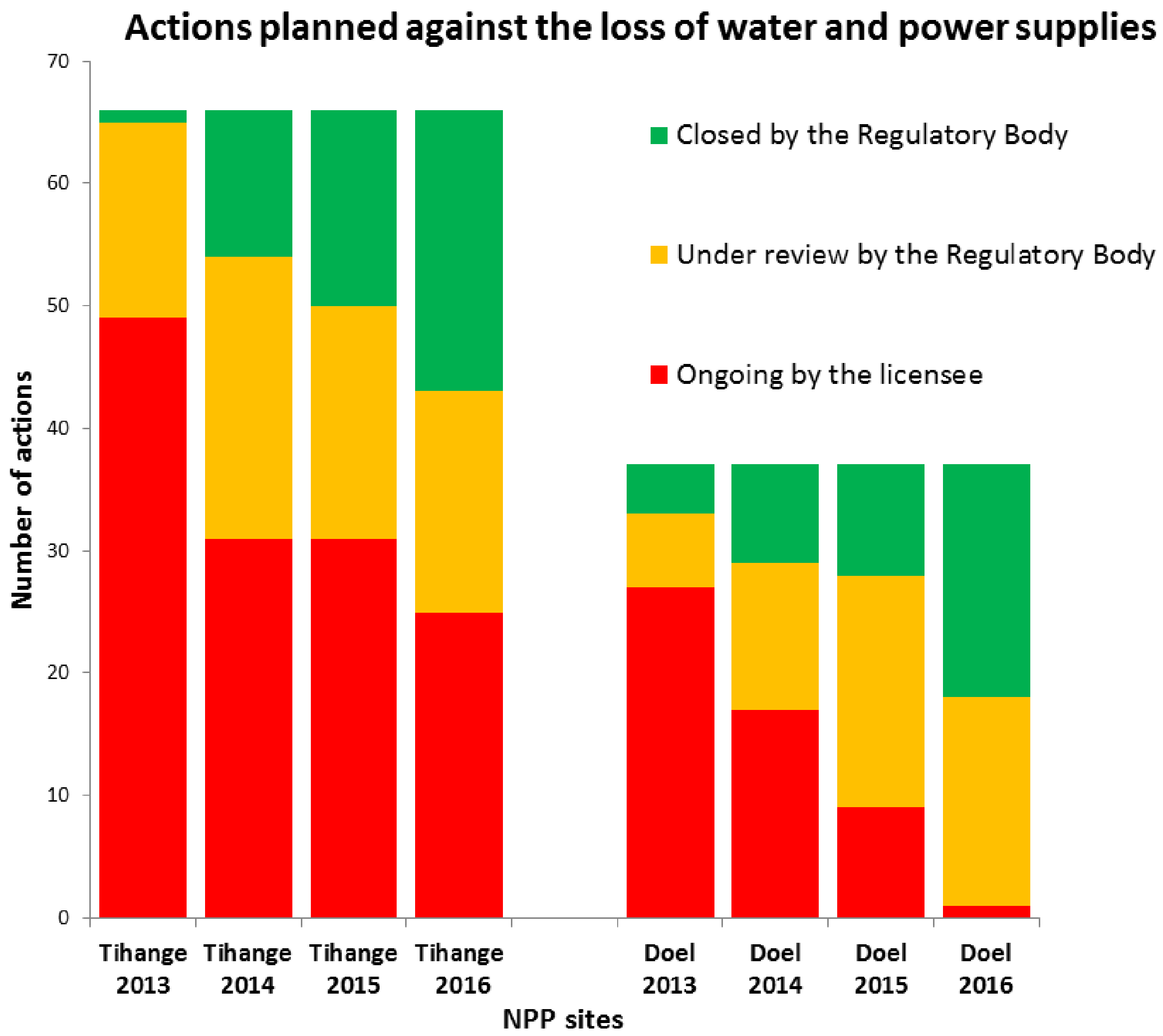

Figure 8 : Evolution of the resolution of the actions concerning the enhancement of power and water supply at Doel and Tihange between 2013 and 2016.

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 will introduce procedures describing the actions to take in case of a total loss of heat sinks and in case of a total loss of internal or external power supplies. Many of these procedures have been finalized at Doel in 2014, except for the spent fuel pools. Some of them are still under development in Tihange.
  However, as these actions are directly linked to the CSBO project, described in section 3.2., they will be finalized in Tihange during the first quarter of 2017.

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 planned then to move the COS to a new building to be constructed but new considerations led the licensee to propose a new strategy for the COS in 2016.
  The current proposition 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 will be parked, enabling the crisis management center to be moved in case of risk of radiological or toxic releases during the accident.
  However the difficulties encountered in recent years have had an important impact on the construction schedule of the new COS backup building. This new facility will be available by 2019, whereas the mobile COS backup will be available by early 2017.
  In this context, several actions have been undertaken as quick-wins in the present 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:

- The feasibility study for installing a **filtered vent system** on the containments of each unit was started in 2012 and has been finalized in 2013. Filtered vent systems will be installed on all reactors in operation.
  The basic design has been carried out in 2014 and the realization phase of the filtered venting systems is ongoing since 2015 on each units, except Doel 1 and 2 (The installation of filtered vent systems at Doel 1 and Doel 2 is included in the LTO-project and is scheduled in 2018-2019). Each filter venting systems should be made available between April and December 2017.

Figure 9 : Design and construction of the CFVS

- In parallel, the assessment of the residual risk of hydrogen production and accumulation in spent fuel buildings have been carried out in 2013. After evaluation the licensee considers that it is not necessary to protect the Spent Fuel Pool buildings of the NPP's against explosion risks due to the accumulation of hydrogen by installing passive autocatalytic hydrogen recombiners. By the end of 2016, discussions are still ongoing between the safety authorities and the licensee on the rationale behind this position.

- Concerning the estimation of the radiological release in case of a multiple-event, the Belgian emergency plan model developed by SCK•CEN has been upgraded in the framework of the stress-tests. Although the action felt far behind the schedule in 2014 and 2015, the action has been finalized in early 2016.

3.3.4. Synthesis

More than 120 actions have to be realized by the licensee in the framework of the Severe Accident Management. By the end of 2016, some 11% of these actions are still ongoing by the licensee.

Regarding this specific area, some difficult issues, with considerable delays were finally resolved in 2016. The licensee took a step towards the finalization and closure of these actions (updated emergency plan model…). The new site operation center in Tihange suffers now important delays compared to the initial planning.

Otherwise, the other big design project in the SAM area that is the filtered venting systems is announced as always in accordance with the initial schedule of end 2017.

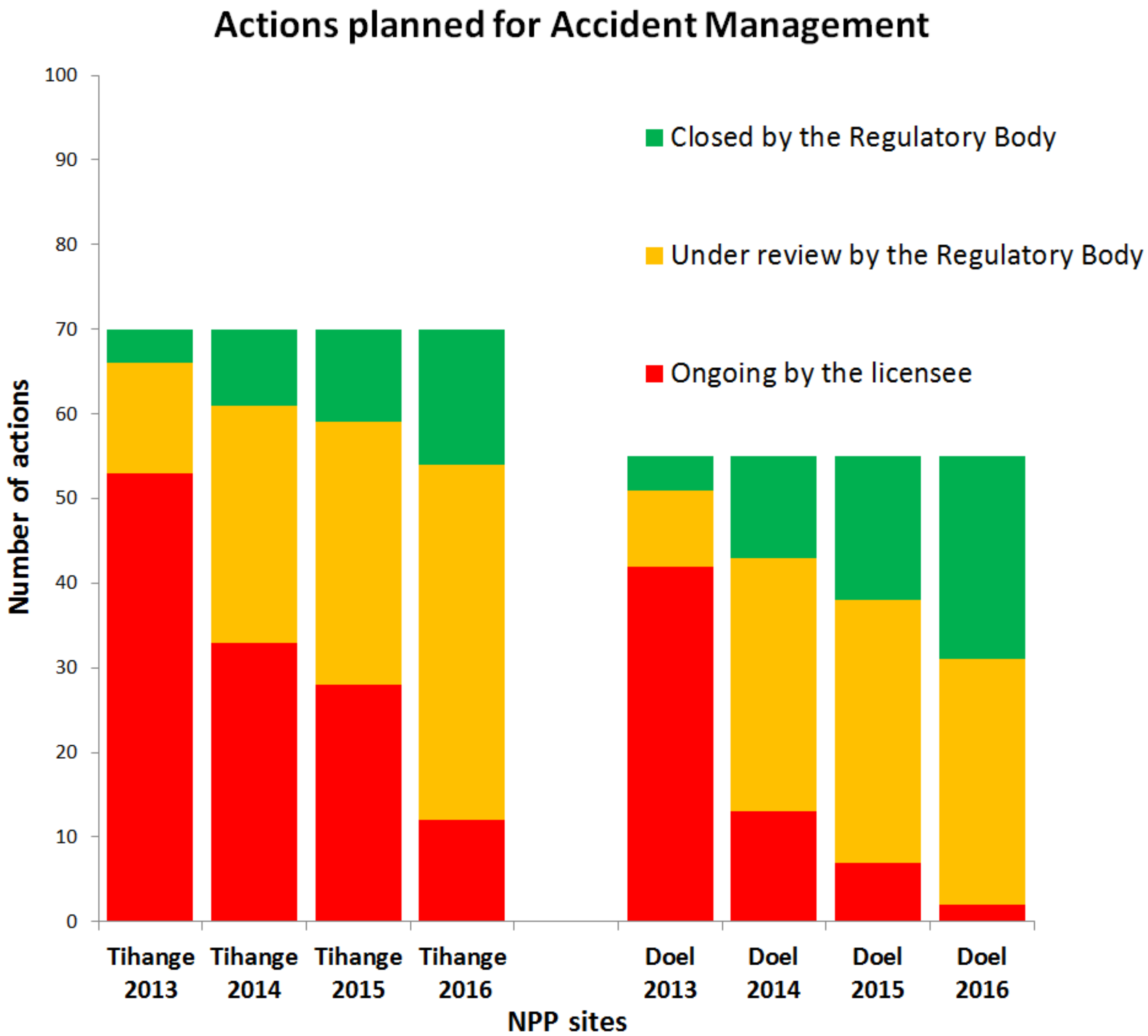

Figure 10 : Evolution of the resolution of the actions concerning the severe accident management at Doel and Tihange between 2013 and 2016.

4. Conclusions on the progress made in 2016

This report presents the status at the end of 2016 of the action plan defined by ENGIE Electrabel following the stress tests on the Belgian nuclear power plants.

In 2016, the main achievements and progresses to note are:

- The protection against the external hazards (flooding, earthquakes, extreme events…) is now mostly developed on both sites.
- The strategy for the complete station black-out and the loss of the ultimate heat sink is now well-defined on both sites. The induced actions are ongoing at Tihange and finalized at Doel. At Tihange, most actions are now finalized or under finalization, so that the CSBO and LUHS strategy should be made operational in the beginning of 2017.
- A reviewed strategy for the emergency response center in Tihange (COS) has been proposed and discussed with the safety authorities; successive strategy changes induced important delays for the implementation of the emergency response strategy.
- The filtered venting systems are now under construction and should be finalized in the end of 2017.

The findings made in 2015 remain valid in 2016. The regulatory body considers that the progress made in 2015 and 2016 is satisfactory but notes considerable delays in the implementation of the stress tests action plan. The last remaining actions are now beyond the time schedule of the original action plan by an average of more than one year. These delays have been duly justified by ENGIE Electrabel for technical or procurement difficulties but they are also partly due to changes in the action plan due to the review of the feasibility and preliminary studies by the regulatory body. On both sides the workload of the stress tests project has probably been underestimated when setting the deadlines.

Nevertheless by the end of 2015, more than 320 out of 365 actions are completed by the licensee ENGIE Electrabel (86%). Since most of the remaining actions are already partly done, ENGIE Electrabel considers the stress tests project around 94% completed (compared to 80% and 90% by the end of 2014 and 2015).
Currently the regulatory body have confirmed the closure of more than 150 actions out of 320 finalized by the licensee, this is some 41% of the total number of actions (35% in 2015).

The regulatory body will continue to carefully follow the progress of the stress test actions implemented by the licensee in the future years.

The next update/follow-up of this report, describing the status of the action plan at the end of 2017, will be presented by FANC at the beginning of 2018.