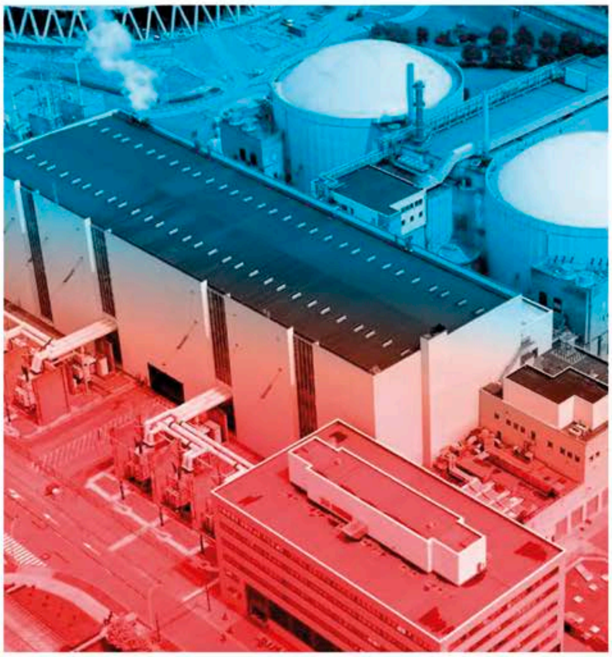
ENGIE Electrabel

LONG-TERM OPERATION
OF NUCLEAR POWER PLANTS
DOEL 1 AND 2 (BELGIUM)

European investment Projects

Version 1 – 13 may 2016

NOTIFICATION
TO EURATOM IN
THE FRAMEWORK
OF ARTICLE 41
EURATOM TREATY



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1 Preface

In 2003, the Belgian government voted the Nuclear Phase Out Law, stipulating that:

- All seven Belgian nuclear reactors had to be shut down after 40 years of industrial operation
- No new commercial nuclear reactors could be built in Belgium

Hereafter, it became clear that nuclear power plants (NPP) could play an important role in securing the supply of electrical power, the adherence to the Kyoto protocols and the economic stability of the country. In 2008, the Belgian government made its intention clear to make it legally possible again to operate the three oldest plants (Doel 1 and 2 and Tihange 1) after 2015 up to 2025.

This statement was the starting point for the framework of the Long-Term Operation (LTO) programme, in particular the Study phase.

The strategic note published by the Federal Agency for Nuclear Control (FANC), in September 2009 [REF 1], was the impetus for Electrabel NV's LTO programme. In its strategic note for Doel 1, Doel 2 and Tihange 1, the FANC laid down the conditions to be met by the plants in the event of ‘a possible political decision for the further operation of these nuclear power plants’, as well as a step-by-step plan for such an extensive programme. At the end of 2011, Electrabel NV submitted the initial version of this report to the FANC. After some technical clarifications, FANC presented its final evaluation to the Scientific Counsel on 25 June 2012, where a positive advise was obtained.

Nevertheless, on 4 July 2012 the Belgian government only agreed to the LTO of the Tihange 1 NPP. For the Doel 1 and 2 NPPs the production lifetime was limited to 40 years (15 February 2015 for Doel 1 and 1 December 2015 for Doel 2). Consequently, Electrabel NV immediately started preparing the final shutdown of the two Doel units.

On 18 December 2014, the Belgian government decided to reconsider the shutdown of the Doel 1 and 2 NPPs, and extend operations for an additional 10 years, in order to secure Belgium's supply of electricity. Previously, the FANC had published a strategic note in September 2014 [REF 2] stating that it will only give its approval for the LTO of Doel 1 and 2 when Electrabel NV presents an Integrated Action Plan and provides the necessary guarantees for the foreseen investments.

In line with the FANC's strategic note, Electrabel NV developed an Integrated Action Plan [REF 3] that focuses on the continuous improvement of nuclear safety. The Belgian Nuclear Safety Authorities have thoroughly analyzed and approved this action plan.

Since then, the LTO of both Doel units has been made possible by the law of 28 June 2015, amendment to the law of 2003.

Belgium has taken this decision in the framework of its right, according to article 194 (2), paragraph 2 of the Treaty on the Functioning of the European Union, to determine the conditions for exploiting its energy resources, its choice between different energy sources and the general structure of its energy supply, and taking into account:

- The task of the European Atomic Energy Community, laid down in article 1 of the Euratom Treaty, to contribute to the raising of the standard of living in the Member States and to the development of relations with the other countries by creating the conditions necessary for the speedy establishment and growth of nuclear industries.
- Article 2 (c) of the Euratom Treaty according to which the Community shall facilitate investment and ensure, particularly by encouraging ventures on the part of undertakings, the establishment of the basic installations necessary for the development of nuclear energy in the Community.

This decision permits to maintain a net capacity of 433 MW (data 2014) for each of the Doel 1 and Doel 2 NPPs for the coming 10 years, and thus contributes to securing the electricity supply.

Ensuring the security of supply in Belgium is a primary responsibility of the Belgian State, which was confronted with several studies by official authorities voicing concern with respect to the adequacy of the electricity production capacity in Belgium, such as

- The study by the CREG entitled "*Etude relative à la sous-capacité de production d'électricité en Belgique*" (study with respect to the lack of capacity of electricity production in Belgium), 27 September 2007, réf. (F) 070927-CDC-715. [REF 4]
- The report of the GEMIX group, an international expert group charged by a Royal Decree of 28 November 2008 to study the ideal energy mix for Belgium in the medium and long term, which concluded that the shutdown of the three oldest nuclear power plants in 2015 would lead to a deficit in energy and in capacity, for which it was not guaranteed that imports could fill the growing deficit and which pointed out that Belgium had become more and more dependent on structural electricity import. The report recommended a.o. to postpone the shutdown of Doel 1 and Doel 2 with 10 years. [REF 5]
- The report of the International Energy Agency of 9 March 2011 on the Belgian energy policy stating that "*Since 2000, demand has been greater than generation, so imports have risen. At present, there is a gap in generating capacity of 1000 MW, with imports amounting to more than 13% of demand for electricity in 2008 (some 10 TWh out of total 77.6 TWh) meeting that gap. Furthermore, 50% of present capacity is more than 30 years old (almost all coal-fired baseload capacity) and will have to be replaced by 2020. The decommissioning of nuclear power plants between 2015 and 2025 will likely further exacerbate the serious risk of capacity shortage. The lack of domestic generating capacity could result in power cuts and blackouts during periods of peak demand*". [REF 6]
- The report of June 2012 on the means of electric power production 2012-2017 of the General Directorate Energy of the federal public administration Economy, SME, Middle Classes and Energy pointing out that, taking into account the import capacity and in the hypothesis that new flexible power plants cannot be taken into service before 2017, none of the examined scenario's of shutdown of nuclear power plants permitted to meet the criteria of security and continuity of electric supply. [REF 7]

The decision to allow the operation of Doel 1 and Doel 2 for the ten coming years was also coherent with the capacity provisions of the ENTSO-E study of 30 June 2015 "*Scenario Outlook & Adequacy Forecast 2015*" representing the more and more perilous situation of the Belgian production park and its structural lack of capacity without recourse to imports that may become scarce.

In order to permit the long-term operation of Doel 1 and Doel 2, Electrabel NV committed to executing the works and making the required investments that allow to continue safe operations under the control of the FANC, which verifies compliance with the Belgian legislation (which is in accordance with Belgium's international obligations).

The long-term operation of Doel 1 and Doel 2 contributes to the limitation of greenhouse gas (GHG) emissions. As confirmed by the Intergovernmental Panel on Climate Change (IPCC), the international body for assessing the science related to climate change set up in 1988 by the World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) to provide policymakers with regular assessments of the scientific basis of climate change and options for adaptation and mitigation, nuclear energy is a mature low-GHG emission source of baseload power and could make an increasing contribution to low-carbon energy supply.[1]

In 2014, Europe decided to reduce its GHG emissions: at least 40% below the 1990 levels by 2030.This will enable the EU to take cost-effective steps towards its long-term objective of reducing emissions by 80-95% by 2050.

In 2015, Belgium also signed the COP21 objectives in Paris, aiming to keep the planet temperature increase well below 2°C compared to pre-industrial levels. This requires a 40-70% reduction of the global GHG emissions by 2050 compared to 2010.

In this regard, it is worth mentioning that the Belgian nuclear power fleet avoids CO_2 emissions equivalent to the emissions of half of Belgium's entire transport activities.

Furthermore, the nuclear sector contributes to the development of Belgium's economic activities representing approximately 20,000 jobs. Belgium can be considered as a forerunner in the nuclear sector through its research center SCK•CEN, that is currently involved in the MYRRHA-project. This is a multi-purpose hybrid research reactor for high-tech applications with an investment of approximately 1,100 M€ included in the list of Belgian projects for the European Commission's new investment plan.

Due to its low cost, the Belgian nuclear power fleet also contributes to a large extent to an affordable electricity price for the end customer.

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[1] IPCC, 2014 : Summary for Policymakers. In: *Climate Change 2014: Mitigation of Climate Change. Contribution of Warking Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer,O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S.. Brunner, P. Eickermeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 20.

2 Description of the Investment Project

2.1 Notifying organization

Electrabel NV

Boulevard Simon Bolivárlaan 34

BE-1000 Brussel

2.2 Name of the investment project

Long-term operation of the Doel 1 and 2 NPPs (Belgium).

In the rest of the document this will be referred to as 'the LTO-D12 programme'.

2.3 Industrial activities

Regarding the Annex II of The Euratom treaty, the LTO-D12 programme falls within item 11: Nuclear reactors of all types for all purposes.

2.4 Replacement of industrial equipment

The LTO-D12 programme envisions the replacement of some equipment at the Doel 1 and 2 NPPs, as well as the design upgrade of the installations as agreed with the Belgian Nuclear Safety Authorities.

2.5 Euratom references

This report is the first document supplied to Euratom with respect to the LTO-D12 programme. No notification according to article 37 of the Euratom Treaty was required since the long-term operation of the Doel 1 and 2 NPPs does not entail a difference in risk of radiological emissions compared to the previous operation of these units.

2.6 Contact information

2.6.1 Operation of the installation

Electrabel NV is operator of the Doel 1 and 2 NPP.

Electrabel NV

BE0403.170.701 – RPM Bruxelles

Boulevard Simon Bolivárlaan 34

BE-1000 Brussel

2.6.2 Project preparation

Electrabel NV is in the process of preparing the LTO-D12 programme.

Electrabel NV

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Boulevard Simon Bolivárlaan 34

BE-1000 Brussel

2.6.3 Project supervision and execution

Electrabel NV is in charge of the LTO-D12 programme's supervision and execution.

Electrabel NV

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Boulevard Simon Bolivárlaan 34

BE-1000 Brussel

2.6.4 Equipment suppliers

The LTO-D12 programme consists of several stand-alone projects to be implemented by 2019. These projects include several supplies and/or field works.

As the tendering process for these stand-alone projects is still ongoing or has not yet been started, only potential suppliers can be listed: main suppliers which could be involved in the LTO-D12 programme are [redacted]

2.7 Methods of financing

The investment programme will be financed by Electrabel NV, using own resources. The 2014 annual account of Electrabel NV is publicly available on the website of the Central Balance Sheet office:
https://cri.nbb.be/bc9/web/catalog;jsessionid=9FAB77413771B070499452C587E5DC3A?execution=e1s1

2.8 Geographical location

The Doel NPP is located in the Port of Antwerp, on the River Scheldt, approximately 6 kilometres from the border between Belgium and the Netherlands. The site covers a surface area of 80 hectares.

Figure 1: Doel Nuclear Power Plant.

Figure 2: Location of the Doel (BE) and Borssele (NL) Nuclear Power Plants.

2.9 Brief description and general plans

Electrabel NV emphasizes its ambition to continue the safe operation of the Doel 1 and 2 NPPs.

2.9.1 Integrated action plan

In line with the FANC's strategic note [REF 1], Electrabel NV developed an Integrated Action Plan that focuses on the continuous improvement of nuclear safety. It is an 'integrated' plan as it combines various other action plans:

- The Doel 1 and 2 LTO action plan (version 2.0) that was approved in 2012 [REF 8] containing four chapters: (1) Preconditions, (2) Ageing Management, (3) Design re-evaluation and (4) Management of competences, knowledge and behavior.
- The evaluation of the BEST action plan from the viewpoint of LTO instead of final shutdown. [REF 9]
- The actions resulting from the Periodic Safety Review (PSR) from the viewpoint of LTO instead of final shutdown. [REF 10]
- The actions resulting from the experience that was gathered between 2012 and 2015, including the ultrasonic inspection of the reactor pressure vessels in the Doel 3 and Tihange 2 NPPs.
- The evaluation of all foreseen, planned and/or realized actions since stopping the LTO-programme in 2012.

With this Integrated Action Plan Electrabel NV confirms to continue its continuous improvement efforts and actions.

According to most of the Performance Indicators of the World Association of Nuclear Operators (WANO), the Doel 1 and 2 NPPs still belong to the top 25 percent NPPs in the world.

Electrabel NV is also fully compliant with the Belgian legislation and regulations on nuclear safety, which in turn correctly reflect international standards, such as the Council Directive 1996/29/EURATOM, laying down basic safety standards for protection against the dangers arising from exposure to ionizing radiation (EURATOM Basic Safety Standards), transposed into the Belgian legislation in 2001 (through modifications of the Royal Decree of 25/04/97 and the Law of 15/04/94). The amendment to the latter Directive by Council Directive 2013/59/Euratom of 5 December 2013, which shall be transposed into Belgian legislation in the future, has been analyzed but did not reveal any relevant gaps. Nevertheless, the transposition into Belgian law remains to be awaited to determine if any final actions are required.

Belgian legislation is also compliant with Directive 2009/71/Euratom establishing a Community framework for the nuclear sefaty of nuclear installations transposed into Belgian legislation by the Royal Decree of 30 november 2001. It is to be expected that Belgium will transpose the Council Directive 2014/87/Euratom amending Directive 2009/71/Euratom into Belgian legislation and that Electrabel NV will comply with such rules when they come into effect, implying that the nuclear safety objective for nuclear installations of article 8 a 1 of Council Directive 2014/87/Euratom will be used as a reference for the timely implementation of reasonably practicable safety improvements to existing nuclear installations, including in the framework of the periodic safety reviews.

The general approach that was followed in order to define the design upgrade is based on a risk reduction approach. Starting from a safety concern that warrants evaluation, it is determined how this concern affects risk, defined in terms of core or spent fuel damage and/or likelihood of significant radioactive release. The sequence leading to the release, forming the risk chain, is determined qualitatively and the significance of the concern depends on the way that it contributes to the considered risk. The concern can have an impact on one or more elements of the risk chain, and identifying this allows to work directly on affected elements. This is illustrated in Figure 3 below for concerns related to sequences leading to core damage.

Figure 3 also illustrates that the scope of solutions is much larger when looking at the complete sequence that ultimately leads to core damage, instead of trying to define a solution starting from the concern.

This risk-informed perspective is used to allow a rational but quantitative prioritization of concerns.

Risk reduction is not solely based on a risk informed-perspective, but also based on qualitative expert judgment and or deterministic significance.

In some cases, some investments are decided, even if they don’t reduce the core damage risk. The investment in a Containment Filtered Venting System (CFVS) is a typical example. The CFVS has no impact on the core damage frequency, but can reduce significantly the release of radioactivity in the atmosphere and thus the impact of an accident to the population and the environment.

The risk reduction approach is both qualitative and quantitative and calls upon expert judgment in different phases of the process.

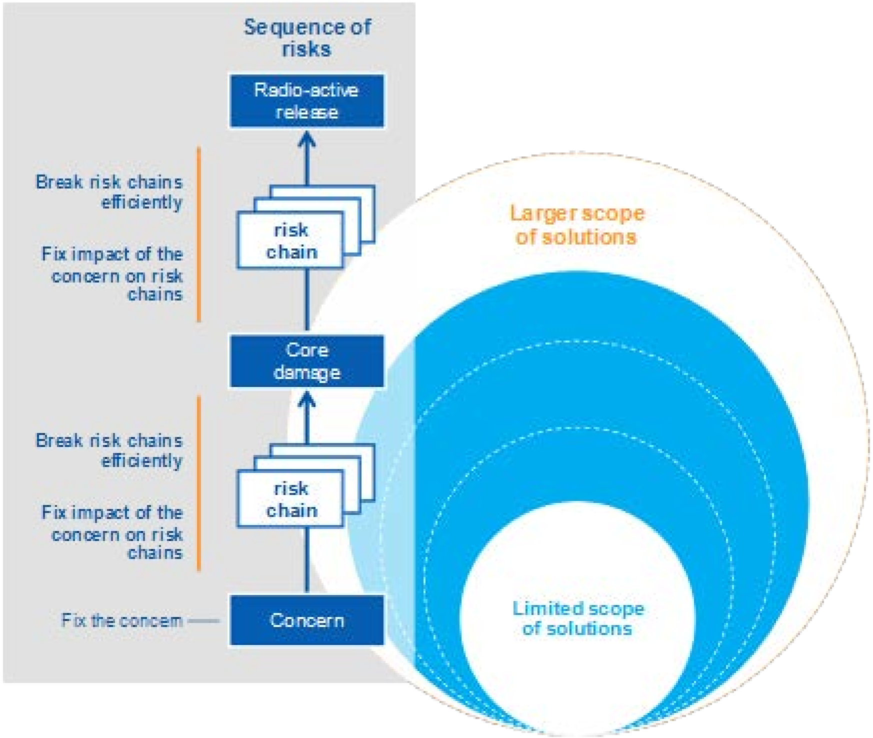

Figure 3: Concerns, solutions and their impact on risk.

2.9.2 Expert and SALTO Missions

In the framework of the LTO-D12 programme, the FANC has asked the IAEA to organize an IAEA Expert Mission and a full SALTO (Safety Aspects of Long-Term Operation) Mission.

The IAEA Expert Mission was concluded between 1 and 9 February 2016. During the Mission's final meeting, the IAEA team members stipulated that the equipment is in good condition and that Electrabel NV has made significant progress since the beginning of the LTO programme. The current approach and the preparatory work of Electrabel NV are in line with the IAEA safety standards and international best practices.

The experts also identified some opportunities for improvement. The majority of these improvements are linked to the temporary interruption of the LTO programme between July 2012 and 2015. For instance, the experts suggested to better tune the organizational structure to the implementation of the ageing management during the full term of the LTO.

In order to identify opportunities for improvement, the FANC expects the operator to implement the lessons learned of the SALTO Mission in the Ageing Management Programmes of Doel 1 and 2.

The FANC will closely monitor the operator's implementation of the SALTO's opportunities for improvement. The SALTO Mission is planned from 14 to 23 February 2017. During the full SALTO Mission, the experts will look into aspects such as human resources and knowledge management, management of the ageing of mechanical and electrical components, civil engineering, internal organization and change management).

2.9.3 Description of the LTO programme

Prioritized actions: safe from day one after restart

In conformity with the FANC's strategic note, the Integrated Action Plan describes two types of actions:

- **Prioritized actions** need to be carried out before restarting the NPPs. The prioritized actions are necessary in order to ensure the proper functioning of the safety systems, structures and components (SSC) as of day one of the extended operation. Other actions ensure the continuous improvement of safety.
- **Non-prioritized actions** need to be executed within three, exceptionally five, years after restart of the NPPs, with a focus on the outages in 2018 and 2019. During these outages, both NPPs will be in cold shutdown, leading to several months of unavailability. Some actions will be executed during the planned maintenance overhauls in 2016 and 2017, as long as the conditions allow it. The results and experience of the LTO programme for the Tihange 1 NPP will be integrated into the LTO-D12 programme. In conformity with the operating licence Electrabel NV will provide the FANC a new status report after each operating cycle.

The Belgian Nuclear Safety Authorities have thoroughly analyzed and approved the list of prioritized actions that have been described in the 'LTO Syntheserapport'.

As mentioned in the 'LTO Syntheserapport' the project portfolio of the Integrated Action Plan is built around five main themes, including thirteen packages.

Project portfolio	Domain
Review of the 2012 LTO programme	LTO Ageing Mechanics
	LTO Ageing EI&C
	LTO Ageing Engineering
	LTO Design
	LTO Preconditions and Management of competences, knowledge and behavior
BEST re-evaluation	Re-evaluation of the BEST actions
PSR	Periodic Safety Review
Additional inspections regarding LTO	
Other projects	Modifications to the installations
	Projects Doel NPP

	Projects Electrabel Corporate
	Non-conformity reports
	Delta 2012-2015 as a result of operating the plant from a shutdown perspective instead of an LTO perspective

Most of the projects are executed on existing systems and in existing buildings.

The LTO-D12 programme only plans the construction of three new buildings on site (see Figure 4):

- Two buildings for the Containment Filtered Venting Systems (CFVS) of the Doel 1 and 2 NPPs.
- One building housing the new Fire Extinguisher Pump Station.

[redacted]

Figure 4: Location of the new installations at the Doel 1 and 2 NPPs.

Investing in safety

Electrabel NV will continue its investments in human resources. As indicated in the 'LTO Syntheserapport', the LTO of the Doel 1 and 2 NPPs implies the hiring of approximately 140 new employees for the Doel NPP organization and an additional 60 people specifically for the LTO organization.

The significant investments in employees, technical installations, methodologies and continuous improvement provide the best possible guarantee to ensure a high level of nuclear safety, reliability and availability of the Doel NPPs.

2.9.4 BEST and PSR Programmes

These two programmes are described in attachments 6.1 and 6.2.

2.10 Costs of the LTO-D12 programme

The prospected costs of the LTO-D12 programme can be subdivided into the following items (see Figure 5).

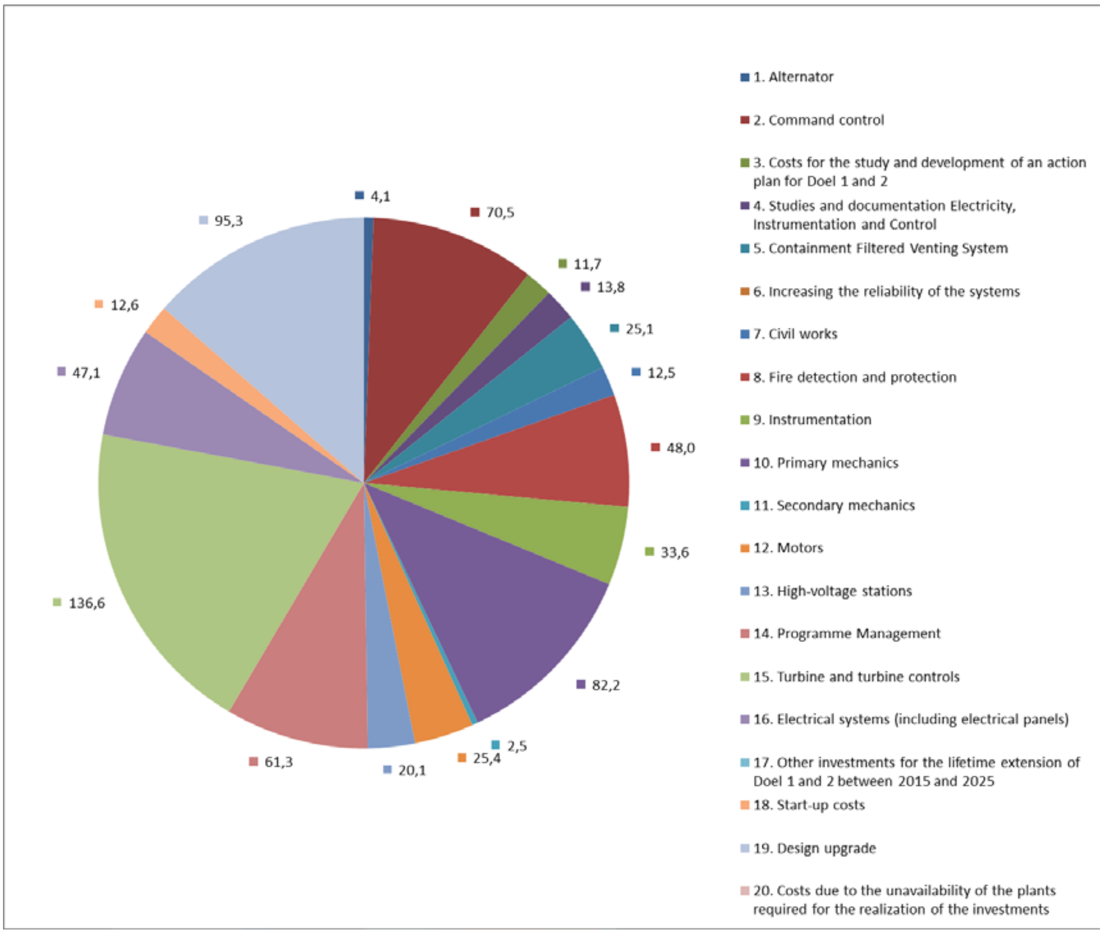

Figure 5: Costs of the initial installation per equipment category (in millions of euros).

Figure 6 represents the time-scale of the various investments.

			REA 2015 + Preliminary Spread 2016-2020 in MEUR					
		Total/rubrique en MEUR	Rea 2015	2016	2017	2018	2019	2020
1.	Alternator	4,1		1	1	1	1	0
2.	Command control	70,5	1,1	11	11	21	25	2
3.	Costs for the study and development of an action plan for Doel 1 and 2	11,7	11,7					
4.	Studies and documentation Electricity, Instrumentation and Control	13,8	3,8	0	0	4	5	0
5.	Containment Filtered Venting System	25,1	0,0	4	4	7	9	1
6.	Increasing the reliability of the systems							
7.	Civil works	12,5	0,0	2	2	4	4	0
8.	Fire detection and protection	48,0	0,8	7	8	14	17	1
9.	Instrumentation	33,6	0,0	5	6	10	12	1
10.	Primary mechanics	82,2	10,0	8	9	24	29	2
11.	Secondary mechanics	2,5	0,1	0	0	1	1	0
12.	Motors	25,4		4	4	8	9	1
13.	High-voltage stations	20,1	8,6	1	1	4	5	0
14.	Programme Management	61,3	2,0	13	13	15	15	3
15.	Turbine and turbine controls	136,6	6,6	19	20	40	48	3
16.	Electrical systems (including electrical panels)	47,1	1,2	7	7	14	17	1
17.	Other investments for the lifetime extension of Doel 1 and 2 between 2015 and 2025							
18.	Start-up costs	12,6	12,6					
19.	Design upgrade	95,3	0,5	15	16	28	34	2
20.	Costs due to the unavailability of the plants required for the realization of the investments							
	LTO-D12 - Investment envelope	**702,2**	59,1	98	103	196	231	16

Figure 6: Time-scale of the various expenditures.

The main investments include:

- Item 2 - Command control: the investments in command control include the replacement of the GNS teleperm, the SIP and the SIN
- Item 8 - Fire detection and protection: a new seismic fire pump station building needs to be constructed on site
- Item 9 - Instrumentation: the replacement of some radiation monitoring systems, pneumatic systems and several instrumentation devices is foreseen
- Item 10: Primary mechanics: primary inspections and repairs regarding a.o. the reactor pressure vessels, reactor pressure vessel heads, internals, split pins, small bore piping, baffle bolts, etc.
- Item 14: Programme management: coordination of the various aspects of the LTO-D12 programme including the various studies that need to be executed
- Item 16: Electrical systems: replacement and retrofit of several electrical devices and systems such as the pressurizer heaters, voltage panels, cables and connectors, etc.
- Item 19: Design upgrade: LTO of the Doel 1 and 2 NPPs requires several design upgrades, including the extension of the instrument air, adaptation of the condensate and feedwater system valves, new RW replenish, replacement of the main steam supply system valves, deduplication of the RJ injection system.

2.11 Timing and status of the Integrated Action Plan

Electrabel NV has provided the FANC with a time-scale for the LTO-D12 programme. The time-scale has been approved by the Belgian Nuclear Safety Authorities and is monitored closely. Any modifications to the original time-scale need to be reported and justified to the Belgian Nuclear Safety Authorities. Before each operating cycle of the Doel 1 and 2 NPPs, Electrabel NV will report the status of the LTO-D12 programme to the FANC. Based on these status reports, the FANC will decide whether or not the unit can resume operation. The LTO status report of December 2015 is available on the FANC website [REF 11].

There are two main time windows in the implementation of the LTO-D12 programme:

- The first time window (prioritized actions) runs until the restart of the Doel 1 and 2 NPPs (T_0). Both plants were restarted in December 2015.
- The second time window (non-prioritized actions) extends to three, exceptionally five, years after the restart date. This time window consists of implementation works during the maintenance overhauls of 2016, 2017, 2018 and 2019.

The Doel 1 and 2 NPPs are twin power plants with several shared safety systems. For this reason, a shared cold shutdown is necessary whenever significant interventions have to be carried out. During such cold shutdown, the installations are put into a state in which long-term unavailability of the systems is allowed. In specific terms and with regard to carrying out complex long-term operations, two long-term cold shutdowns are foreseen for the Doel 1 and 2 NPPs: one in the summer of 2018 and one in the summer of 2019.

2.11.1 LTO Ageing Mechanics

For LTO Ageing Mechanics, a list of 79 prioritized actions has been defined. This exhaustive list guarantees a proper management of the effects of ageing on the SSC in this particular domain. The actions that have been taken by Electrabel NV, and in the meantime have been reviewed by Bel V, are subdivided into the following categories: Inspections, Ageing Analysis (Time Limited Ageing Analysis) and Improvement Actions.

Inspections	Priority	Non-priority
Inspection of all components of the reactors: reactor vessel heads, baffle bolts, split pins, Instrumentation penetrations (BMI) at the bottom of the reactor of Doel 1, Enhanced VT1	Completed	-
Inspection of FW baffle boxes, small bore piping, bolts for presence of 17-4PH material and other small components	Completed	-
Ultrasonic thickness measurements and boroscopic inspections of components	Completed	-
Inspection of mechanical structures (baseline inspection)	Completed	-
Inspection of fire-resistant barriers (doors, penetrations, fire dampers)	Completed	-

Note: following these inspections, seven additional prioritized actions were identified and have now also been completed.

Ageing analyses (TLAA)	Priority	Non-priority
Number of areas of the pressure control vessels	Completed	-
Regenerative heat exchanger of the CV circuit (Chemical and Volumetric control system)	Completed	-
Nozzles and baffle boxes in the feed-water lines to the steam generators	Completed	-

Improvement actions	Priority	Non-priority
Optimization of the maintenance programmes of mechanically active components (RCM or Reliability Centred Maintenance)	Completed	-
Visual inspection of structures for the systems in RGB (Reactor Building), TUR (Ancillary Space) and GNH (Nuclear Auxiliary) buildings	Completed	-
Expansion of inspection programme of pressurised bi-metallic welds and of penetrations	Completed	-

2.11.2 LTO Ageing EI&C

After the 2012-2015 period, there was a balance of 165 actions for LTO Ageing EI&C, of which 81 were prioritized actions. The actions that have been taken by Electrabel NV, and in the meantime have been reviewed by Bel V, are subdivided into the following categories: Inspections, Changes and Replacements, Rating and Documentation and Maintenance 1EA 1EB 1EC.

Inspections	Priority	Non-priority
Inspection of the electrical power boards and circuit breakers (AC and DC)	Completed	-
Inspection of the cabinets containing control and management circuits in the relays rooms (including the remaining dampers on which the cabinets are mounted)	Completed	-
Inspection of a representative sample of smaller electric cabinets, which do not contain any active components	Completed	-
Inspection of other components required to demonstrate that they meet the qualifying requirements	Completed	-

Changes and replacements	Priority	Non-priority
Rated 380 V motors of pumps, valves and fans and 6 kV motors of pumps (replacement and/or upgrade)	Completed	-
Accessories (positioning, boosters, membranes, etc.) of pneumatic and hydraulic actuators	Completed	-
Transmitters	Completed	-
6 kV back-up fuses and fire detection system (already carried out in the period 2012-2015)	Completed	-
Reactor Protection System (CPR)	-	2018-2019
Process Controls (Teleperm, SIP)	-	2018-2019
Nuclear Instrumentation System (SIN)	-	2018-2019
Turning and push buttons, alarm signals and management system in the control room (CR)	-	2018-2019

Electric power supplies and switches	-	2018-2019
Scram breakers	-	2018-2019
Non-safety related 380 V-boards and switches (replacement or retrofit)	-	2018-2019

Rating, documentation and maintenance 1EA, 1EB and 1EC	Priority	Non-priority
Components with formal RSQ[2]: every non-conformity has been eliminated	Completed	-
1EA and 1EB components exposed to radiation: on the basis of technical analyses and/or rate testing, a suitably qualified service life is demonstrated or they are replaced by a new component with a formal RSQ	Completed	-
1EB components without exposure to radiation and 1EC components: a justification is drawn up, based on technical analyses, inspections and maintenance work. After the relaunch, these components will obtain a formal RSQ on the basis of technical analyses and/or rate testing or they are replaced by a new component with a formal RSQ.	-	Before 2019

After all actions have been implemented (after the outages of 2018 and 2019 at the latest), all components will have a formal RSQ and will comply with the rules, including their documentation and maintenance programmes.

2.11.3 LTO Ageing Engineering

It was essential for this programme to extend and/or adjust the existing inspection programmes. The 2015 analysis eventually led to 12 out of a total of 77 prioritized actions being performed: Extension of the In-Service Inspection (ISI) programme for engineering structures, Inspections and resulting actions, Curative actions and Renovation works.

[2] RSQ (Rapport Synthétique de Qualification) is a report which summaries the qualification requirements.

Extension of ISI programme for engineering structures	Priority	Non-priority
Inspection procedures are adapted (they are also used at the next scheduled inspections in 2016)	Completed	-
Maintenance plans completed	Completed	-
Existing ISI inspection programme upgraded, with an inspection interval for each group of engineering structures	Completed	-
New inspection of various structures similar to the one performed in preparation of the LTO report in 2011	Completed	-

The results of all inspections, including those from the period between 2012 and 2015, show that all buildings are in good condition. Maintaining the inspection programmes will continue to ensure their good condition in the future.

Inspections and resulting actions	Priority	Non-priority
Actions according to reinforced programme and/or following the first (baseline) inspections (timing depends on the accessibility and consistent with the type of engineering structure)	-	As of 2016
Installing and/or repairing of measuring points and instruments	-	As of 2016

Curative actions	Priority	Non-priority
Analysis to determine degradation status and the necessary curative action (core drilling in concrete walls, inspections and measurements for chimneys, etc.)	-	As of 2016
Arrangements with specialised laboratories	-	As of 2016

Renovation works	Priority	Non-priority
Concrete renovation works at the water intake	-	2016-2017
Chimneys at Nuclear Auxiliary Building: address corrosion and repair paintwork	-	2017-2018
GNH outer walls: facade renovation	-	2017-2018

A strict roadmap has been drawn up for the implementation:

1. Carry out the correct and complete inspections.
2. Determine where and what additional analyses are needed to correctly map any instances of damage or ageing.
3. Determine and implement correct renovation.

It is also ensured that the repairs and renovations are carried out by certified companies using certified repair techniques and certified products.

2.11.4 LTO Design

The Agreed Design Upgrade (ADU) consists of 31 design improvements (actions) coming out of the LTO project. In addition, there are 7 design improvements (actions) coming out of the BEST project (see 2.2 Re-assessment of the BEST project).

The 31 LTO Design actions are part of the PSR concept, which is aimed at getting the actions implemented as quickly as possible over the next three to (maximum) five years. An overview of the key actions and their timing:

Design actions	Priority	Non-priority
Focused improvement of the control room's (CR) airtightness	-	2016 - 2017
New, submersible pumps to fill the RW cooling towers to refill with water from the river Scheldt	-	2017 - 2019
New, seismic FE pump station with larger FE pumps and a larger FE tank (preparations have started)	-	2017 - 2019
CFVS (preparations have started)	-	2018 - 2019
Automatic refilling of the steam generators in the Emergency Systems Building (GNS)	-	2018 - 2019
In the GNS: 2 EI pumps per unit instead of one	-	2018 - 2019

De-duplicate the valves on the intake of the SC system from the RC system	-	2018 - 2019
Improved automatic fire extinguishing in turbine hall (MAZ)	-	2018 - 2019
Improved fire barriers and automatic fire extinguishing in GNH	-	2018 - 2019
Improved fire barriers and automatic fire extinguishing in RGB	-	2018 - 2019

To be able to carry out certain LTO Design actions, the Teleperm system in the GNS first needs to be replaced. This replacement is scheduled for 2018-2019.

2.11.5 LTO Preconditions and Management of Competences, Knowledge and Behavior

All actions relating to the area of Preconditions have now been carried out. The improvement actions planned in 2012 relating to Management of Competences, Knowledge and Behavior have mostly been carried out, as part of other action plans. The remaining items are carried out as part of continuous improvement and are therefore not among the prioritized actions.

Preconditions	Priority	Non-priority
The current RCM project has been finished and integrated into the existing maintenance process	Completed	-
The current RSQ project has been carried out in accordance with the requirements of 2.1.2 ' LTO Ageing Electrical and I&C '	Completed	-
The strategy regarding MOVATS testing has been carried out and there is an action plan in place (including performing a number of tests in consultation with the Physical Inspection Department) taking into account the pilot project on Tihange 1	Completed	-
The SHR process is applied to the main SSC in scope for LTO Ageing. There is a stricter and more targeted follow-up of corrective actions resulting from the SHR. The KPIs linked to the SHR process have been elaborated further.	Completed	-
The project relating to spare part preventive maintenance has been completed	Completed	-

2.11.6 BEST re-evaluation

BEST resulted in a number of improvement actions in the area of organisation, hardware, procedures, etc. Their implementation started almost immediately. As part of the LTO programme, and besides the site-specific actions, some 16 actions remained: 3 of these have been carried out and 13 actions are started according to the chart below:

Improvement actions (BEST)	Priority	Non-priority
Finishing the fixed water pipes to the pools in the GNH	Completed	-
New mobile pumps and diesel generators (currently rented equipment)	-	2016
Additional hydraulic connectors	-	2016 - 2017
Additional electrical wiring	-	2016 - 2017
Additional valves in the SP spray pipes	-	2017
Seismic strengthening of the RWSTs and adding a seismic water pipe for refilling	-	2018 - 2019

2.11.7 PSR

The amended licensing conditions (RD ANPP-0011847 – Royal Decree supplementing the license conditions of nuclear reactors Doel 1 and Doel 2 as part of long term operations – http://fanc.fgov.be/GED/00000000/4000/4003.pdf) mention the timely submission of a synthesis report on the fourth PSR as a priority action. This report was submitted on 30 November 2015.

28 actions from the action plan relating to the third PSR were eventually reactivated. The most important ones are listed below:

Improvement actions (BEST)	Priority	Non-priority
Deduplication of CC power supply coolers SC basement	-	Completed
Separation of electric polarities	-	Completed
Installation of new toxic gas measurements	-	2017
Upgrade of polar bridges Doel 1 & 2	-	2018
Deduplication of FW check valves	-	2018

2.11.8 Additional inspections regarding LTO

As the implementation of the previous LTO action plan was delayed, ageing received greater attention in the form of additional inspections. All these inspections have now been carried out. An overview.

Inspections	Priority	Non-priority
Inspection of the reactor vessels for the absence of hydrogen flakes: no indications were detected	Completed	-
Inspection of the penetration of the reactor vessel heads	Completed	-
Inspection of turbines	Completed	-
Inspection of crucial electrical boards (AC and DC)	Completed	-
Inspection of pre-selected rooms by fire experts	Completed	-
Inspection of a number of control rods (ring gauging)	Completed	-

2.11.9 Modifications to the installations

A total of 55 modifications to the installations have been re-activated, all of which relate to continuous improvement. Hence, they are not a prioritized actions. After discussion with Bel V, one prioritized action was identified:

Modifications to the installation	Priority	Non-priority
Modification of the fire detection in the primary pumps	Completed	-

2.11.10 Projects Doel NPP

The analysis ultimately led to 15 actions: 14 projects were reactivated and one JCO (Justification for Continued Operation) was extended and carried out in the meantime.

One of the 14 projects that was reactivated is about improving the fire-extinguisher installation in the turbine hall (MAZ). This will be carried out by 2019 at the latest.

2.11.11 Other projects

As part of the WENRA regulations, a number of studies had to be carried out by the end of 2015. For the Doel 1 and 2 NPP, this was not possible, as not all of the required data were available and the average time needed to perform the studies takes more than a year. The following schedule remains in effect:

Projects at Electrabel Corporate	Priority	Non-priority
MOVATS: as part of the LTO Preconditions, it was suggested to select a number of critical valves, gather data and prepare and carry out a test campaign with greater priority. The remaining MOVATS programme is started as of 2016.	-	As of 2016
Cable routing: serves as input for FHA and Fire PSA Level 1. Status: partially implemented in the period 2012-2015 and re-included in the LTO vision.	-	2016 - 2017
Flooding PSA Level 1: completion of the first iteration of the study according to the existing methodology. Experience has shown that this first iteration is usually sufficient (initial analysis already carried out as part of LTO Design).	-	2017
FHA (Fire Hazard Analysis): compliant of the study in accordance with the IAEA methodology (initial analysis already carried out as part of LTO Design).	-	2017
Fire PSA Level 1: completion of the study of both iterations according to the existing methodology.	-	2017
Barsebäck: to remain in line with the hypotheses for rating the already installed recirculation filters, the aluminium hydroxide powder will have to be removed from the so-called powder holes.	-	2018

For the WENRA-related studies, a number of specific actions will be carried out on fire protection after walkdowns with fire experts in a number of pre-selected rooms.

2.12 Decommissioning plans

The long-term operation of a NPP is becoming common practice in the world of nuclear operators.

Operating a plant induces several radioactive waste streams. Long-term operation does not influence the nature of these waste streams and no additional waste streams are created due to the extension.

The volume of radioactive waste (RAW) that is generated during operation is proportional to the lifetime. Contrary to this increasing volume of operational RAW, the RAW masses from Decommissioning and Dismantling (D&D) of a plant with an extended operational life are steady.

D&D RAW results from the dismantling and conditioning of contaminated and/or activated equipment, installations, systems and buildings. The major components in D&D RAW are concrete and steel. Hence, operating a NPP longer will not significantly increase the D&D RAW volumes as the main nuclear buildings, such as the RGB, and the main nuclear circuits will not be enlarged. This is typicaly the case for the LTO-D12 programme.

The dismantling and management of irradiated fuel are financed by the provisions constituted in Synatom S.A. in accordance with the law of 11 April 2003 ‘Provisions for the dismantling of nuclear power plants and the management of fissile materials irradiated in these plants’.

2.13 Official state authority

Belgium is a federal state composed of three regions: the Flemish, Walloon and Brussels Capital Region.

The federal state authority is responsible for the nuclear energy policy, nuclear safety and radiological protection of the public, the workers and the environment.

The nuclear phase-out law of January 31, 2003 as modified on June 28, 2015 is an economic policy to allow the Doel 1 and 2 NPPs to continue their production of electricity for a new period of ten years. This law is not an authorization and does not govern safety aspects.

The federal state is authorized for granting the operating license regarding safety and radiological aspects including with regard to the environment. The federal operating licence for a NPP is granted by Royal Decree, after approval of the application file by the FANC and countersigned by the Minister of Home Affairs. The federal operating license is granted for an unlimited period of time but imposes periodic safety reviews (PSR) every ten years. LTO is evaluated in the framework of the fourth PSR.

The regional authorities are responsible for non-radiological aspects of environmental protection as well as for urbanism. Hence, the regions are authorized for granting the operating license regarding non-radiological aspects on the environment and construction permits.

For the Doel 1 and 2 NPPs, Electrabel NV is holder of:

- The federal operating license of unlimited duration delivered by the Royal Decree of 25 January 1974.
  With regard to the Long Term Operation, Electrabel NV has transmitted a technical report as well as a screening note on the environment to the FANC. The FANC has confirmed in its decision of 30 September 2015:
  - That the actions proposed by Electrabel NV in its action plan to implement the LTO-D12 programme are not considered as important modifications to the installation by virtue of Article 12 of the Royal Decree laying down the General Regulation for the protection of the public, workers and the environment against the hazards of ionizing radiation and that no application for modification to the authorization has to be filed by Electrabel NV.
  - With regard to the radiological aspects on the environment that no environmental impact assessment is required as the LTO-D12 programme does not create a negative radiological impact on the environment, nor does it lead to significant evolution in the existing radiological environmental impact.

  The federal operating license has been modified by the Royal Decree of 27 September 2015 to impose additional operating conditions to Electrabel NV with regard to the LTO Project.
- The regional operating license, which is valid until 30 March 2031 and was delivered by the Permanent Deputation of East-Flanders on 31 March 2011. No important modifications have been notified to the regional authorities with regard to the LTO-D12 programme.

In the framework of the LTO-D12 programme, an application for a building permit will be introduced for the construction of the new buildings as mentioned in item 2.9.

2.14 Research and development programmes

In general we can say that Electrabel NV is involved in several R&D programmes. Electrabel NV is involved in the OECD (Organisation for Economic Co-operation and Development) and European Union programmes in order to improve the management of severe accidents, following the evolution in the thermo-hydraulic studies and PSA (Probabilistic Safety Assessment) studies. In order to improve the accident procedures Electrabel NV is co-operating with the WOG (Westinghouse Owners Group). Electrabel NV is also a member of different FROG (Framatome Owners Group) working groups related to ageing, materials, chemistry, diesels, outage optimization, accident procedures, PSA and steam generators.

Electrabel NV, together with ENGIE Lab Laborelec, also participates in specific EPRI (Electrical Power Research Institute) R&D programmes for material research and chemistry. Electrabel NV can also use the WANO and INPO databases.

Special tasks, mainly in the specialised radiological area are contracted to the SCK•CEN (Research Center for Nuclear Power): advanced surveillance of the reactor pressure vessel (fracture toughness, corrosion, environmental fatigue), reactor dosimetry, environmental impact studies, etc.

The evolution of good practices and new legislation is monitored actively by Electrabel NV, ECNSD (Electrabel Corporate Nuclear Safety Department) and Tractebel Engineering.

The LTO study programme dealt with four major themes or areas, and followed a specific methodology for each aspect in order to fulfill the conditions, expectations and recommendations of the various regulatory bodies, specifically the FANC's strategic note of 2009 [REF 1].

Area	Summary of the methodology used
Preconditions	Compliance of the Doel 1 and 2 with the preconditions for LTO was reviewed. The related documents and support resources were listed and the evaluation criteria employed drafted, based on the relevant IAEA documents.
Ageing management	The SSC that need to be subjected to evaluation within the framework of ageing management were determined. The applied methodology allows the ageing of SSC to be evaluated in each domain: mechanical, electrical, instrumentation and monitoring systems, and structures and components, including architectural structures. This applies to both passive and active components. The results comprise a strategy and specific actions for the management of potential ageing during LTO. In addition, the lifetime-limiting design hypotheses, such as the embrittlement of the reactor pressure vessel due to irradiation, were re-examined.
Re-evaluation of the design	Based on six criteria, a set of items for improving the design of the Doel 1 and 2 NPPs was identified. These items for improvement are classified into eight safety issues and form the basis for a proposed set of design improvements - the Design Upgrade. This also includes the design improvements arising from the Belgian stress tests (BEST). Following verification by the regulatory authorities, this resulted in an ADU (consisting of design improvements agreed with the authorities).
Management of competences, knowledge and behavior	An evaluation was made as to whether human and organizational factors at the Doel 1 and 2 NPPs are adequate for LTO. A methodology similar to that employed for the preconditions was used for this.

3 Technical information

3.1 Reactor type and use

The Doel 1 and 2 NPPs are **Pressurized Water Reactors** (PWR) used to **generate electric power**.

3.2 Main features of the existing installations

The Doel 1 and 2 NPPPs are **twin units**, meaning that they are quite similar and share one common control room and various common safety and emergency systems.

	Doel 1 and 2
Architect / engineer	Tractionel (Tractebel Engineering) and Electrabel NV
Type of reactor	Pressurized Water Reactor (PWR)
Licence	Westinghouse
Owner	100% Electrabel NV
Start of construction	1969
Commissioning	1974
Commercial generation	1975
Net electrical power	Doel 1: 433 MWe Doel 2: 433 MWe
Major upgrades	1990: Construction of a common bunker with emergency systems
	2004: Replacement of steam generators in Doel 2 (+ 40 MW)
	2009: Replacement of steam generators in Doel 1 (+ 40 MW)

Both units have their own **Reactor Building** (**RGB**).

The RGB of each single unit houses the 2-loops primary circuit including the reactor itself, the pressurizer, the steam generators, the reactor coolant pumps and all of the pipes of the primary circuit.

It also contains:

- All necessary installations for the handling of nuclear fuel elements.
- A spray system.
- A polar crane used for installing reactor components and during overhauls to hoist the reactor pressure vessel head, reactor internals and various other equipment and loads.

The RGB consists of:

- A primary, airtight interior containment: this interior containment consists of a spherical steel structure with an internal diameter of 46 metres.
- A secondary, exterior containment is formed of reinforced concrete.
- Between both containments, there is an intermediate space (annulus): the annulus is maintained in an under-pressure condition with respect to the external atmosphere in order to make it impossible for any radioactive gases to escape. Any leakage from the primary containment is collected in the annulus and released outside only after filtering via the ventilation chimney.

In the event of a serious incident in which radioactive particles escape from the reactor, the secondary containment serves as an extra shield for the exterior environment against the radioactive radiation in the RGB.

This secondary containment enables the Doel NPP to meet very strict safety standards for protecting local residents against radioactive radiation.

The secondary containment was designed to withstand serious incidents of external origin.

Between the two reactor buildings is the **Nuclear Auxiliary Services Building** (**GNH**), containing the primary auxiliary systems for both units:

- Component Cooling circuits
- Safety Injection System
- Systems for chemical and volumetric control of the primary cooling water
- System for storage and processing of gaseous waste (after radioactive decay, these gases are released via a chimney)
- A part of the SC systems in the GNH (including the SC pumps)
- The facilities for the storage of new nuclear fuel and spent nuclear fuel (pools)

Behind the Nuclear Auxiliary Services Building is the **Bunker** (**GNS**), which contains the second-level systems and emergency control rooms.

Attached to each reactor building are two **Water/Steam Buildings** (**BAR**) with the water/steam installation

The **turbine hall** (**MAZ**) contains the equipment of the secondary part of each of the two plants: turbines, alternators, condenser, preheater, etc.

Other main buildings are:

- **The Electrical Auxiliary Services Building** (**GEH**) contains electrical equipment such as supply panels, relays, transformers and batteries. This equipment guarantees the electrical supply for numerous circuits, auxiliary systems and installations in all foreseeable circumstances. It also guarantees the electrical supply of electrical control systems and safety devices.
- **The Mechanical Auxiliary Services Building** (**GMH**) for mechanical auxiliary services, for example, air compressors.

Both units share one single **control room**, located in the middle of the MAZ against the GNH, which enables the operator to control the two linked plants from separate tables and boards.

3.3 Main features of the fuel elements

For a typical operating cycle, the fuel elements for Doel 1 and 2 have the following characteristics. The fuel elements are of the same type than the fuel elements used during the previous cycles.

	Doel 1 and 2
Nuclear fuel elements	121
Number of rods per element	179
Nuclear fuel type	Uranium dioxide (UO_2)
[redacted]	
[redacted]	[redacted]
Nuclear fuel cycle	12 months

3.4 Characteristics of the moderator and reflector

The Doel 1 and 2 NPPs use light water as moderator and as primary coolant.

No reflector is applied at the Doel 1 and 2 NPP.

3.5 Characteristics of the primary and secondary coolant

Primary coolant system:

	Doel 1 and 2
Calculated pressure	172 bar
Pressure during operation	155 bar
Flow rate per loop	18,185 m^3/h
Calculated temperature	343°C
Temperature during operation	• Cold leg: 284.0°C • Hot leg: 315.2°C

Secondary coolant system:

	Doel 1 and 2
Steam pressure	• 0% power: 6.76 MPa • 100% power: 6.26 MPa
Temperature	• Inlet: 230°C • Outlet: 278°C
Flow rate	2,640 t/h
Condensated water flow rate	1,784 t/h
Circulating water flow rate	44,500 m^3/h
Turbine type	One high pressure stage and two low pressure stages with a double exhaust

4 References

All official documents regarding the LTO-D12 programme are available on the FANC website:

http://www.fanc.fgov.be/fr/page/exploitation-a-long-terme-des-centrales-nucleaires-belges/1544.aspx

All official documents regarding the BEST programme are available on the FANC website:

http://www.fanc.fgov.be/fr/page/stress-tests-nucleaires/1838.aspx

Reference number	Title
[REF 1]	Strategienota LTO van Belgische Kerncentrales Doel 1/2 en Tihange 1 (008-194 Herziening 2, FANC, 2009) See link: http://www.afcn.fgov.be/GED/00000000/2100/2170.pdf
[REF 2]	Long Term Operation Doel 1 and Doel 2: Rappel des exigences de sûreté pour approuver l'opération à long-terme des réacteurs de Doel 1 et Doel 2 en cas de modification de la loi de sortie progressive du nucléaire de 2003 (Note AFCN 2014-09-12-FH-5-4-2-FR)
[REF 3]	Long Term Operation – Synthesis Report - Doel 1 and Doel 2 (17 April 2015, version 0). See link: http://www.fanc.fgov.be/GED/00000000/3900/3910.pdf
[REF 4]	Etude sur la sous-capacité de production d'électricité en Belgique (CREG, (F)070927-CDC-715, 27 September 2007) See link: http://www.creg.info/pdf/Etudes/F715FR.pdf
[REF 5]	Quel mix énergétique ideal pour la Belgique aux horizons 2020 et 2030 ? (GEMIX, July 2012) See link: http://economie.fgov.be/fr/binaries/Gemix2_fr_tcm326-201917.pdf
[REF 6]	Energy Policies of IEA Countries – Belgium 2009 Review (9/03/2011) See link: https://www.iea.org/publications/freepublications/publication/energy-policies-of-iea-countries---belgium-2009-review.html
[REF 7]	Etude sur les perspectives d'approvisionnement en électricité 2008-2017 (Federal Public Service Economy, 15 December 2009) See link: http://economie.fgov.be/fr/modules/publications/general/etude_perspectives_electricite_2008-2017.jsp
[REF 8]	Long Term Operation: Technisch rapport – Doel 1&2 (30 June 2012, version 2.0) See link: http://www.fanc.fgov.be/GED/00000000/3200/3241.pdf

[REF 9]	Belgian Stress Tests - National Action Plan for Nuclear Power Plants (FANC, 20 December 2012). See link: http://www.fanc.fgov.be/GED/00000000/3300/3357.pdf
[REF 10]	Syntheserapport van de derde tienjaarlijkse herziening Doel 12 See link: http://www.afcn.fgov.be/GED/00000000/300/387.pdf
[REF 11]	Long Term Operation: Statusrapport– Doel 1 en Doel 2 - (December 2015) See link: http://fanc.fgov.be/GED/00000000/4000/4068.pdf

5 Acronyms

Acronym	Explanation
AC	Alternating Current
ADU	Agreed Design Upgrade
BAR	Water/Steam Buildings
Bel V	Body responsible for inspecting nuclear installations (part of the FANC)
BEST	Belgian Stress Tests
BMI	Bottom Mounted Instrumentation (of reactor)
CAV	Cumulative Absolute Velocity
CC	Component Cooling
CFVS	Containment Filtered Venting System
CPR	Reactor Protection System
CR	Control Room
CREG	Commission for the Regulation of Electricity and Gas
CSBO	Complete Station Black-Out
CV	Chemical and Volumetric Control System
D12	Doel 1 and 2 Nuclear Power Plants
D&D	Decommissioning & Dismantling
DBE	Design Basis Earthquake
DC	Direct Current
ECNSD	Electrabel Corporate Nuclear Safety Department

EI&C	Electricity, Instrumentation & Control
ENSREG	European Nuclear Safety Regulations Group
EPRI	Electrical Power Research Institute
FANC	Federal Agency for Nuclear Control
FE	Fire Extinguisher
FHA	Fire hazard Analysis
FROG	Framatome Owners Group
FW	Feedwater
GEH	Electrical Auxiliary Services Building
GHG	Greenhouse Gas
GMH	Mechanical Auxiliary Services Building
GNH	Nuclear Auxiliary Services Building
GNS	Bunker
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
INPO	Institute of Nuclear Power Operations
IPCC	Intergovernmental Panel on Climate Change
ISI	In-Service Inspection
JCO	Justification for Continued Operation
LTO	Long-Term Operation
LUHS	Loss of primary and alternate Ultimate Heat Sink
MAZ	Turbine hall

MOVATS	Motor-Operated Valve Testing System
NPP	Nuclear Power Plant
OECD	Organisation for Economic Co-operation and Development
PGA	Peak Ground Acceleration
PSA	Probabilistic Safety Assessment
PPM	Process Performance Management
PSHA	Probabilistic Seismic Hazard Assessment
PSI	Potential Safety Issues
PSR	Periodic Safety Review
PWR	Pressurized Water Reactor
RAW	Radioactive Waste
RCM	Reliability Centred Maintenance
RGB	Reactor Building
RJ	Back-up cooling fueling system primary pumps
RLE	Review Level Earthquake
ROB	Royal Observatory of Belgium
RSQ	Rapport Synthétique de Qualification
RW	Raw Water
RWST	Refueling Water Storage Tank
SALTO	Safety Aspects of Long-Term Operation
SC	Shutdown Cooling (Residual Heat Removal System)
SCK•CEN	Research Center for Nuclear Power

SF	Safety Factor
SHR	System Health Report
SIP	Process Instrumentation System
SIN	Nuclear Instrumentation System
SP	Containment Spray
SSC	Systems, Structures and Components
TLAA	Time Limited Ageing Analysis
TUR	Ancillary Space
UNEP	United Nations Environment Programme
WAB	Water and waste treatment facility
WANO	World Association of Nuclear Operators
WENRA	Western European Nuclear Regulators' Association
WMO	World Meteorological Organization
WOG	Westinhouse Owners Group

6 Attachments

6.1 Description of the BEST programme for the site of Doel

As a consequence of the accident that occurred on 11 March 2011 at the Japanese Fukushima-Daiichi nuclear power plant (NPP), a wide-scale targeted safety reassessment programme was set up among the member states of the European Union operating NPPs. These stress tests were executed according to the specifications proposed by WENRA (West European Nuclear Regulations Association) and accepted by ENSREG (European Nuclear Safety Regulations Group).

This "stress tests" programme was designed to re-evaluate the safety margins of the European NPPs 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.

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 Belgian stress tests programme, even though the assessment of these man-made events does not fall under the scope of the European stress tests programme.

The Council Directive 2014/87/EURATOM of 8 July 2014 amending Directive 2009/71/EURATOM has been analyzed afterwards, and this analysis confirmed that the BEST action plan is in line with the recommendation of this directive.

1. Methodology

A specific methodology was defined by ENSREG, gathering the regulatory authorities from 27 European countries.

According to this methodology, the stress tests of the Belgian NPPs were performed in three phases:

- Electrabel NV applied the stress tests programme at both Doel and Tihange sites. Each final report (one per site) was submitted to the Belgian regulatory body by 31 October 2011.
- The Belgian regulatory body reviewed Electrabel NV's final reports, wrote its own national report and communicated it to the European Commission. This phase was completed on 30 December 2011.
- All reports issued by national regulatory bodies were reviewed by the ENSREG. This phase was completed on 26 April 2012.

The approach is meant to be essentially deterministic, focusing on the prevention of core damage as well as on mitigative measures after a beyond-design accident leading to core damage (severe accident management).

The stress tests reports issued by Electrabel NV and by the Belgian regulatory body are available on the FANC website:

http://www.fanc.fgov.be/fr/page/stress-tests-nucleaires/1838.aspx

The final synthesis by ENSREG on the follow-up of the stress tests performed on European NPPs is available on the ENSREG website:

http://www.ensreg.eu/EU-Stress-Tests/

The last national progress report regarding BEST is available on the FANC website:

http://www.fanc.fgov.be/GED/00000000/4000/4093.pdf

2. Main results

The Stress Tests have confirmed that the Belgian units were able to withstand most extreme natural events and their potential consequences. The existence on most Belgian units second-level protection systems (bunker) appeared to be a valuable asset therefore. Nevertheless, the stress tests analysis led to define a wide safety improvement action programme described hereafter.

3. Safety improvement programme

a) Earthquake

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

In the range of frequencies to be considered to evaluate the resistance of buildings, the new evaluation produces a substantially lower value for the acceleration at ground level than those taken into account in the design of Doel 1 and 2 as well as Doel 3 and 4. In the range of frequencies significant for equipment inside buildings, the new value is slightly higher than the design values of Doel 1 and 2 and lower than the design values of Doel 3&4. This small difference is of little significance since all seismically qualified equipment is designed and constructed with due observance of extensive safety factors.

Due to the stringent timeframe of the European stress tests, the PSHA of the ROB had to be conducted in a short time. As suggested by the ROB, the regulatory body requested Electrabel NV **to carry out a more elaborate study** with due consideration of:

- Other elements such as the use of a more recent ground-motion prediction equation or such as a cumulative absolute velocity (CAV) filtering.
- External reviews by international experts.
- Results from other international studies.

This more elaborate study of the seismic hazard has been completed in 2015. Its results are currently under assessment by the regulatory body. They confirm that both Tihange and Doel are adequately protected against seismic hazards.

A **safety margin assessment** for the Doel and Tihange NPPs was performed based on a review level earthquake (RLE) of 1.7 times the peak ground acceleration (PGA) of the current DBE. It showed that the SSC are robust enough to achieve and maintain a safe shutdown state, except for a few mechanical and electrical elements.

For the Doel 1 and 2 NPPs, Electrabel NV planned, in the framework of the LTO-D12 programme, to check the seismic qualification of the RWST and its piping to comply with the RLE level.

b) Flooding

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

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

c) Extreme weather conditions

In addition to the earthquake and flooding hazards, the resistance of the NPPs against extreme weather conditions was evaluated in the BEST framework. Additional hazards such as tornadoes, heavy rainfall, lightning, snowfall, etc. have also been taken into consideration. BEST resulted in a list of actions to enhance the protection of the site.

- The regulatory body recommended re-assessing the capacity of the **drainage systems** (five separate networks at the Doel site) using a detailed hydrodynamic model in order to cover both short-duration heavy rainfall and long-lasting rainfall.
- Electrabel NV finalized its re-evaluation of the impact of heavy rainfall in 2014 and concluded that the site is satisfactorily protected against the potential impact of heavy rainfall.
- The robustness of the second-level system of the Doel 1 and 2 NPPs against a beyond-design **tornado** had to be confirmed, given the fact that high intensity tornadoes have been observed in the past years in neighboring countries. Electrabel NV finalized this action in 2014.
- 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 are ongoing, such as drilling additional grounding points. The modifications should be finalized in 2016.
- In 2012-2013, Electrabel NV improved its intervention procedures in case of **heavy snowfall** to remove snow layers of more than 30 cm from non-bunkered buildings.

d) Power and water supply

Initial situation

Considering the numerous and redundant power supply sources and heat sinks available, every reactor unit in Doel has a high level of robustness. More specifically, the Doel 1 and 2 NPPs can use three independent heat sinks, which are all capable of independently keeping the units cooled:

- the River Scheldt.
- The atmospheric forced draught cooling towers.
- The heat exchangers cooled by the ambient air.

In every unit of the Doel NPP (Doel 1, 2, 3 and 4) there are two internal electrical power supply levels. These two levels function independently from one another and are physically separated. For the power supply of the safety equipment, there are 19 diesel generators across the site 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 of the Doel NPP is equipped with a feedwater pump, powered by a steam turbine, in order to continue supplying cooling water to the steam generators. This cooling water is available in various tanks and in the cooling ponds.

The cooling of the reactor core and the spent fuel pools is 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 in these extreme scenarios is negligible. In conclusion, the NPP has emergency equipment and sufficient autonomy to manage these kinds of hazards for a long time. This time period is sufficient to restore off-site power supply or to bring in off-site resources.

Planned improvements

Nonetheless, some measures were considered to further enhance the robustness of the facilities. Consequently, several actions have been taken to enhance the power and water supply.

Power and water supply

CSBO consists of 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, Electrabel NV has proposed a set of additional measures to avoid cliff-edge effects.

Electrabel NV commits to using non-conventional means:

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

Therefore, in the action plan, an alternative power or water supply for non-conventional means or safety equipment had to be implemented.

The CSBO strategy is already being implemented. Several actions have been realized 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.

Figure 7: Construction completed of the new storage building at Doel NPP.

The mobile pumps and the mobile generators (purchased or hired) are now operational and are stored in this building or stored in the vicinity of the unit where they are needed.

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.

Figure 8: Mobile pumps training at the Doel NPP in the framework of the CSBO strategy.

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, Electrabel NV defined in 2013 which equipment and facilities can be stopped in case of an 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, Electrabel NV 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 and the steam generators via this system. Since these equipment are now available, this part of the CSBO strategy is now fully operational.

Loss of primary and alternate ultimate heat sink (LUHS)

LUHS, a beyond-design accident, has been studied in the original design basis of all Belgian units when one unit is affected by this accident. To avoid cliff-edge effects, several measures have been proposed. 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. Specifically for Doel 1 and 2, connections were made to seismic watertanks for this purpose.

In addition, Electrabel NV justified that the water capacity of the second level of protection is sufficient when all of the site's units are affected by the loss of primary UHS. This justification has been presented in 2013 for both sites and has been analyzed and confirmed by the regulatory body in 2014.

Spent Fuel Pools

Alternative water supply for the spent fuel pools (PL) using supplementary nozzles, connections and the mobile pumps has been made operational by Electrabel NV in 2014-2015.

Electrabel NV is currently working on the enhancement of the prevention of a loss of water inventory of the spent fuel pools. In this framework the size of the siphon breakers has been revaluated to avoid fast uncovering of the fuel assemblies. The modifications should be realized in 2016.

e) Emergency preparedness

As a result of the Fukushima accident, Electrabel NV re-assessed its organization so that it is able to face situations that are far beyond the design basis and that could affect several units simultaneously and lead to the unavailability of some parts of the emergency management infrastructure or affect the access conditions and the environment.

BEST highlighted that the NPPs' operational management could be improved. In this respect, several procedures have been modified in order to enhance operator response:

- In 2013, the earthquake procedures have been modified to speed up the detection and mitigation of induced flooding on site.

- Electrabel NV 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. Most of these procedures have been finalized at the Doel site in 2014, except for the spent fuel pools where the procedures are in their final validation step for Doel 3 and 4.

So far, Electrabel NV'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 BEST, Electrabel NV re-assessed this organization in order to face far-beyond-design situations that could affect several units simultaneously.

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 the Doel and Tihange NPPs. Electrabel NV 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, Electrabel NV implemented the modifications and thus strongly adapted the emergency management organization as requested by the regulatory body which has closed this action.
- Several additional actions have been or are being carried out in order to enhance the emergency management. These actions include the harmonization of site-training programmes, the construction of on-site resistant storage for mobile means, 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 2014.

f) Severe accident management

The scenarios involving severe accidents have been re-assessed from a defense-in-depth perspective during BEST. 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 CFVS for each nuclear reactor:

- The feasibility study for installing a CFVS for each unit was started in 2012 and has been finalized in 2013. Filtered vent systems will be installed on all reactors in operation. Electrabel NV opted for a scrubber design that does not require important work in the reactor buildings.
  The basic design has been carried out in 2014 and the realization phase began early after. The filters and containment isolation valves have then been ordered. The forthcoming work consists of a progressive installation of the CFVS from 2015 up to the end of 2017 for Doel 3 and 4, taking into account NPP outages.
  The installation of CFVS at the Doel 1 and Doel 2 NPPs is included in the LTO-D12 programme and is scheduled in 2018-2019.
- Concerning the estimation of the radiological release in case of a multi-event, the emergency plan model developed by SCK•CEN has been upgraded. Although the action fell far behind schedule in 2014 and 2015, the Factory Acceptance Tests have been done in 2015. Site Acceptance Tests and final upgrade of the model were completed in March 2016.

4. Financial overview of the BEST Programme

The total investment related to the BEST safety improvement programme is currently estimated at 218.9 M€, for both Doel and Tihange sites (excl. the CFVS for Doel 1 and 2, and Tihange 1).

The actual investment realized between 2011 and March 2016 reaches 149 M€ (68 %), for both Doel and Tihange sites.

The investment schedule related to the Doel site and to corporate activities can be summarized as follows:

[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

[redacted]

[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]		[redacted]

[redacted]

5. Conclusion

Five years after the Fukushima-Daiichi accident and four years after the finalization of the stress tests, both Doel and Tihange sites are now adequately protected against most natural hazards, such as flooding and beyond-design earthquakes.

The construction of a CFVS is currently ongoing in all units so as to maintain the containment building integrity in the wake of a beyond-design accident leading to core damage. These final works should be finalized in 2018.

Whereas the rest of the action plan is almost completed in Doel, some final works are still ongoing in Tihange to enhance the protection of the site against scenarios such as CSBO and heavy rainfall.

6.2 Description of the PSR programme for the site of Doel

Improving the installations serves two objectives:

- Optimizing the nuclear safety
- Increasing the availability and reliability

The main modifications in the framework of nuclear safety are the result of the PSR.

First PSR (PSR 1 – 1985)

PSR 1 was a milestone in the evaluation of the plants' design in the framework of nuclear safety, following NUREG-0737 (http://pbadupws.nrc.gov/docs/ML0514/ML051400209.pdf). The most important improvement was the construction of a bunker that houses the emergency systems (GNS), in line with the concept of the new Doel 3 and 4 NPPs, which were under construction at the time.

The design of the GNS is based on extensive external accident studies such as earthquakes, gas explosions, impact of a plane crash. The GNS emergency systems are designed to ensure the following functions: retaining the water inventory in the reactor circuit, retaining the under criticality of the reactor, residual heat removal, and emergency control room.

Other important modifications resulting from PSR 1 are:

- Increase of the resistance to earthquakes of important parts of the nuclear installations.
- Increase of the fire resistance of the control room and adjustment of the control room's ventilation to address the risk of toxic fumes and radiactive contamination.
- Reinforcement of the high-energy pipes to limit the consequences of a pipeline break and to bring the unit to a safe cold shutdown.
- Replacement of the safety valves of the pressurizer with hydraulically controlled safety valves to ensure that overpressure is managed in both hot and cold conditions.
- Installation of passive catalytic hydrogen recombiners in the reactor buildings to avoid the risk of hydrogen explosions.
- Replacement of the four main steam isolation valves to improve the reliability of the fast isolation of the main steam lines.

Second PSR (PSR 2 – 1995)

During PSR 2 experts investigated whether the safety level was still as high as during PSR 1. It marked the starting point of the follow-up of ageing and wear.

Some important examples:

- Upgrade of the low-pressure safety injection pumps/shutdown pumps in order to increase their reliability.
- Expansion of the recirculation filter of the safety injection system in the reactor buildings (there was a second major expansion campaign later on).
- Upgrade of certain equipment to improve their resistance to earthquakes.

- Evaluation and validation of the qualification of thermal stratification of the piping of the reactor pressure vessel and the steam generators.
- Re-evaluation of the accident studies, following the PSR 1 modifications.
- Probabilistic Safety Assessment (PSA) to map potential weaknesses of the installations. The PSA revealed the positive impact of the improved accident procedures and the installation of the catalytic hydrogen recombines in the reactor buildings.

Third PSR (PSR 3 – 2005)

The report and resulting action plan of PSR 3 is available on the FANC website [REF 7].

Taking into account the experience from the previous PSRs for the various Electrabel NV NPPs, a new global approach was applied to all units, in consultation with the FANC. The focus was on the following aspects: confirmation of the safety level, evaluation of the equipment's ageing, and integration of internal and external operating experience feedback. These aspects were studied simultaneously for all Belgian NPPs.

Some examples of important improvements:

- Adjustment of the polar cranes in the reactor buildings in order to comply with the evolved rules and regulations.
- Replacement of the cooling batteries of the ventilation systems in the reactor building and electrical building.
- Replacement and improvement of the reactor coolant system's Loose Part Monitoring System.
- Application of a new coating to the exterior concrete shell of the reactor building.

In addition to the improvements resulting from the PSRs, the equipment has been subject to numerous other modifications and improvements prior to the fourth PSR as a result of:

- Internal inspections, maintenance and internal operating experience feedback.
- External sources such as external operating experience feedback, engineering company Tractebel Engineering, the research and competence center Laborelec, international memberships.
- Nuclear incidents and major accidents such as Three Mile Island, Tsjernobyl and Fukushima (BEST project).

Some important examples:

- Replacement of the steam generators in Doel 2 and Doel 1 respectively in 2004 and 2009 in order to improve the reactor coolant system's integrity.
- Expansion of the air cooling of the safety diesels, and the possibility to flood the reactor cavity in case of a nuclear meltdown.
- Replacement of the safety diesels in conformity with the strongly evolved qualification requirements that apply to such safety equipment. In addition, the control logic has been thoroughly modified. Until now, the diesels were controlled using a complex crossed logic. The new design uses a mono-train logic: each diesel will feed its own electrical polarity as is the case in the more recent NPPs.
- Major investments were made with regard to supporting equipment outside the nuclear part of the NPP, e.g. the condensors in the turbine hall have been replaced with titanium condensers and various heat exchangers have also been replaced.

These are a limited number of examples from a long list of improvements. This list is continuously updated according to the continuous improvement principle.

Fourth PSR (PSR 4 – 2015)

PSR 4 was executed according to a new IAEA methodology, which had already been applied to other Belgian NPPs such as Doel 3 and 4. This new methodology is based on the assessment of 14 safety factors (SF) with respect to a reference framework of regulations and good practices. Both internal and external assessors, with the necessary qualifications in their field of expertise, were involved.

Subject area		Safety Factor
Plant	1	Plant Design
	2	Actual condition of systems, structures and components
	3	Equipment qualification
	4	Ageing
Safety analysis	5	Deterministic safety analysis
	6	Probabilistic safety analysis
	7	Hazard analysis
Performance and feedback of experience	8	Safety Performance
	9	Use of experience from other plants and research findings
	10	Organization and administration
Management	11	Procedures
	12	The human factor
	13	Emergency planning
Environment	14	Radiological impact on the environment
		Global assessment

During the various assessments, the assessors not only evaluate the results (e.g. performance indicators, physical condition of the installations), they also assess underlying processes. The assessors had access to the entire installation, all procedures, all witnessing documents and experience reports. They interviewed the operational staff and the engineering company (Tractebel Engineering). Per safety factor, the conclusions were registered in extensive reports that have been supplied to Bel V and the FANC.

PSR 4 came shortly after the PSRs of Doel 3 and the WAB, and Doel 4. Because all units of the Doel NPP are operated in a similar way and share the same supporting processes the conclusions of the PSR report for Doel 1 and 2 are similar to the conclusions of the Doel 3 and 4 PSRs, as far as the processes are concerned. In most cases the same strengths, best practices and opportunities for improvement have been identified.

For some areas the PSR assessment of Doel 1 and 2 differed from the Doel 3 and 4 assessment because of the LTO-D12 programme. Design, actual condition of the SSC, SSC qualification and ageing were even more thoroughly assessed for Doel 1 and 2. The assessments of the related processes were analogous to the assessments performed during the Doel 3 and 4 PSRs, as these are common for the four units.

The PSR is not the only moment in time at which the operator evaluates the safety and actual condition of the plant. Internal and external audits are performed continuously, resulting in related improvement plans. Every day, internal and external experience feedback are analyzed regarding their applicability, and personnel participates actively in studies and R&D programmes. All these efforts led to numerous modifications to the installations and other improvement projects that went hand-in-hand with considerable investments. Besides the attention paid to the installation, various programmes were started to address the human factor during operation and maintenance, increasing the professionalism and continuous quality of the performed work. In addition, there are numerous continuous improvement initiatives that aim to improve the operation, maintenance and supportive services and processes.

Comparison with international best practices revealed a number of strengths, including the strong human performance programme and the openness to external experience feedback and audits. The assessments also revealed a number of best practices:

- The significant amount of projects to ensure the safety of the installation.
- The expansion of the Engineering Department.
- The creation of the ECNSD.
- The creation of Process Performance Management (PPM).[3]
- The introduction of System Health Reports (SHR) and Ageing Summaries.
- The introduction of a follow-up system for Potential Safety Issues (PSI) and the use of detailed incident reports.
- The introduction of the PSA[4] for daily operations.

These strengths and best practices are the result of the continuous improvement that Electrabel NV has valued since the very beginning. Electrabel NV always aims to achieve the highest level of high maturity regarding nuclear safety, general safety, health and care for the environment.

The LTO action plan already includes numerous improvements to the installations. The PSR assessments revealed that this list of improvements is effective and practically complete. The assessors also identified other opportunities for improvement, especially regarding procedures and working methods, including:

- Extension of the methodology for monitoring the qualification of mechanical equipment.
- Execution of some specific safety studies such as the steam generator tube rupture.
- Re-evaluation and optimization of the performance indicators.
- Continuous follow-up of the impact of the expansion of the port of Antwerp.
- Check of the effectiveness of the actions resulting from the experience feedback and incident reports.
- Evaluation of the applicability of the newest standards for fire protection.
- Optimization of the radiological measurements and reporting.

The findings of the assessors have been checked with the legal obligations and international best practices. This pointed out that Doel 1 and 2 fully comply with the legal obligations.

The proposed objectives of the PSR have been achieved. The LTO action plan, the PSR action plan, the ongoing actions from other projects and the continuous improvement of the processes in the organization allow to maintain the safe operations of Doel 1 and 2 until the next PSR.

The final synthesis report and action plan have been submitted to the FANC and Bel V and are currently under review. The report and action plan will be submitted to the Scientific Counsel by the end of May 2016. Afterwards, the action plan will be rolled out in a three, maximum five, year period, monitored closely by the FANC.

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[3] PPM is currently known as Continuous Improvement Management (CIM).

[4] PSA is the evaluation of nuclear risks based on modelling accident studies. The objective is to calculate the frequency of core fusion (PSA level 1), the frequency of containment failure and categorization of atmospheric emissions (PSA level 2). The evaluation of the impact of these emissions on the population and nearby communities (PSA level 3) is not included in the Belgian rules and regulations.

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