# NINTH MEETING OF THE CONTRACTING PARTIES TO THE CONVENTION ON NUCLEAR SAFETY

## NATIONAL REPORT

## August 2022

# KINGDOM OF BELGIUM

This report is produced by the Federal Agency for Nuclear Control on behalf of Belgium. Contributions to the report were also made by "Bel V", "ENGIE Electrabel", "Tractebel ENGIE" and "SCK CEN".

# Table of Contents

# I. Introduction

## I.A. Content of the Present Report

This Belgian national report, submitted for the ninth review meeting of the contracting parties to the Convention on Nuclear Safety (CNS), is based on its previous editions and has a similar structure. For each article of the Convention, relevant descriptions and explanations are provided on how the principles of the Convention are translated into the Belgian legal framework and how they are applied to its nuclear installations. In addition, in order to highlight relevant evolution since the last report, section I.C focuses on new developments since 2019.

Section I.D lists planned actions to improve safety from 2022 onwards.

When drafting this report, due account was taken of the appropriate guidelines in INFCIRC/572/Rev.6 (19 January 2018).

On a voluntary basis, information about the Belgian research reactors is included in the present National Report.

To keep the report to a reasonable size, rather than identifying for each article the particularities and characteristics of the Belgian power plants, it was deemed preferable to give in III a detailed description of the power reactors, highlighting their original design and the major modifications brought to them during the periodic safety reviews, which are mandatory under the Belgian regulations. IV contains similar information about the BR1 and BR2 research reactors.

A list of the acronyms used in the present Report is given in V.

VI gives the web site addresses of Belgian organisations playing an important role in the nuclear field.

VII lists the subjects which have been examined during the 10-yearly safety reviews of the Doel and Tihange units.

The principal nuclear Belgian actors have participated in drafting the present National Report:

- FANC, the Federal Agency for Nuclear Control, the safety authority;
- Bel V, the technical subsidiary of the FANC;
- ENGIE Electrabel as the licensee and operator of the seven nuclear power plants;
- Tractebel ENGIE, the engineering support organisation to the NPP's operator;
- SCK CEN, as the operator of the research reactors in Belgium.

Together, the above-mentioned organizations encompass the legal and practical competencies necessary to collect and to structure the information required to elaborate the national report.

The report is available on different Belgian web sites such as www.fanc.fgov.be, www.belv.be.

## I.B. History of Nuclear Energy Development in Belgium

Before the Second World War, Belgium was the world's largest radium producer, which gave rise not only to the related metallurgy, but also, in collaboration with the academic circles, to the development of metrology techniques. In the universities several teams worked on the latest discoveries in the field of particle physics and maintained close contact with their counterparts abroad.

By 1945, a Scientific Commission in Belgium examined the possibilities of civil applications of nuclear energy, and the "Institut Interuniversitaire de Physique Nucléaire" was created in 1947 to support the existing university laboratories and coordinate their activities. In parallel with nuclear physics research, this Institute also supported some related activities such as production of graphite and high-purity metallic uranium.

From 1950 onwards, Belgian engineers were trained in the UK and in the USA.

The Atomic Energy Commission was formed in 1950.

In 1952, several personalities of Belgium's scientific and industrial circles set up a private non-profit organisation -the "Centre d'Etude des Applications de l'Energie Nucléaire"-, which was to give birth to the "Centre d'Etude de l'Energie Nucléaire" (SCK CEN) at Mol (i.e. the Nuclear Energy Research Centre), and which became a public interest organisation in 1957.

Research reactors were built in Mol and became operational between 1956 and 1963. These are the BR1, a uranium/graphite reactor similar to the British experimental pile (BEPO), the materials test reactor BR2 (fuel assemblies with highly enriched uranium placed in a beryllium matrix shaped as a hyperbolic paraboloid, which ensures at the same time a high neutron flux and an easier access to the experiments from the top and the bottom of the reactor) and the 11.5 MWe BR3 which was the first Westinghouse-type pressurised water reactor built in Europe. This reactor, which went critical in 1963, served to develop the technology (e.g. reactivity control by boron dissolved in the water of the primary circuit, introduction of MOX and gadolinium fuel rods as early as 1963) and to train the first operators of the Belgian nuclear power reactors. The BR3 is now nearly completely dismantled.

From 1950, the private industry has also invested in nuclear technology and participated in the construction of reactors. The "Ateliers de Constructions Electriques de Charleroi" acquired the Westinghouse licence; "Métallurgie et Mécanique Nucléaires" manufactured enriched uranium fuel assemblies, and later became part of the "Franco-Belge de Fabrication de Combustibles" (FBFC). The FBFC fuel manufacturing facility in Dessel has been dismantled and released from regulatory control in March 2022.

Regarding the fuel cycle, the Mol Centre investigated several reprocessing techniques which resulted in the Eurochemic Consortium, – formed under the aegis of the NEA (OECD) – building its pilot reprocessing plant (adopting the PUREX process) in the Mol-Dessel region. This plant ceased its operations in 1975 and is now dismantled.

A consortium of industries was formed in 1954 to develop the nuclear technology; later giving birth to Belgonucleaire which developed the plutonium fuel technology. Belgonucleaire manufactured the first commercial MOX (Mixed Oxides) fuel batch for the French PWR power station Chooz A in 1986.

After having produced MOX fuel for 20 years, for both PWR and BWR reactors, Belgonucleaire definitively stopped its activities in mid-2006. Belgonucleaire produced more than 660 tons of MOX fuel for commercial nuclear power reactors. The dismantling of the MOX fuel fabrication plant at Dessel started in 2009. After a radiological end characterisation of the site, demonstrating there was no residual contamination of the site, the site was unconditionally released from regulatory control in December 2019.

In 1971, the "Institut des Radioéléments" (IRE) was built in Fleurus, manufacturing mainly radioisotopes for use in medicine. This facility is still in operation.

The Belgian power utilities and their architect/engineers closely followed-up the evolution in nuclear technology and, confident with their BR3 experience, they decided to take a 50 % stake in the construction of EdF's (Electricité de France) NPP "Centrale des Ardennes" at Chooz, connected to the grid in 1967. Seven Belgian units, spread over the Doel and Tihange sites, were put into service between 1974 and 1985.

The "Organisme National des Déchets Radioactifs et des Matières Fissiles Enrichies" – "Nationale Instelling voor Radioactief Afval en verrijkte Splijtstoffen" (ONDRAF/NIRAS) (i.e. the national organisation for radioactive waste and enriched fissile materials) was created in 1981. Waste treatment and storage activities are performed at the Mol-Dessel site through its subsidiary BELGOPROCESS.

This brief historic overview shows that, in addition to the nuclear power plants which are the subject of the present National Report, various aspects of the fuel cycle were present in Belgium.

Specific information on the safe management of spent fuel and on the safe management of radioactive waste and additional information about decommissioning programmes may be found in the Belgian report prepared for the 7$^{th}$ review meeting of the Joint Convention, available on the FANC, ONDRAF/NIRAS and IAEA (International Atomic Energy Agency) web sites.


Figure 1 : Nuclear sites in Belgium

The 7 NPPs on the Doel and Tihange sites are operated by ENGIE Electrabel, a member of the ENGIE group, created after the merger in 2008 of the 2 groups "Gaz de France (GDF)" and "Suez".

In 2016, GDF Suez changed its name and became ENGIE.

Table 1 and Table 2 give the main characteristics of the 7 Belgian NPPs:

| Units | Type | Thermal power (MWth) | Date of first criticality | Containment building characteristics | Steam generator replacement | Fuel storage pool capacity | Designer |
|---|---|---|---|---|---|---|---|
| Doel 1 | PWR (2 loops) | 1 312 | 1974 | Double containment (steel and concrete) | 2009 | 664 positions | Westinghouse |
| Doel 2 | PWR (2 loops) | 1 312 | 1975 | Double containment (steel and concrete) | 2004 | | Westinghouse |
| Doel 3 | PWR (3 loops) | 3 064 | 1982 | Double containment with inner metallic liner | 1993 | 672 positions | Framatome |
| Doel 4 | PWR (3 loops) | 3 000 | 1985 | Double containment with inner metallic liner | 1997 | 628 positions | Westinghouse |

Table 1 : Main characteristic of the units located at the Doel Site

| Units | Type | Thermal power (MWth) | Date of first criticality | Containment building characteristics | Steam generator replacement | Fuel storage pool capacity | Designer |
|---|---|---|---|---|---|---|---|
| Tihange 1 | PWR (3 loops) | 2 873 | 1975 | Double containment with inner metallic liner | 1995 | 324 positions + 49 removable positions | Framatome / Westinghouse |
| Tihange 2 | PWR (3 loops) | 3 054 | 1982 | Double containment with inner metallic liner | 2001 | 700 positions | Framatome |
| Tihange 3 | PWR (3 loops) | 2 988 | 1985 | Double containment with inner metallic liner | 1998 | 820 positions | Westinghouse |

Table 2 : Main characteristic of the units located at the Tihange Site

Article 4 of the **law of 31 January 2003 on nuclear energy phase out** limited the operational period of the Belgian NPPs to 40 years. However, to ensure the electricity supply of Belgium, the government and the parliament modified article 4 of this law in 2012 and in 2015, to allow a long-term operation of Tihange 1 and Doel 1 & 2 units by 10 years.

In March 2022, the Belgian government agreed to allow a long-term operation for the two most recent unit (10 years extra for Doel 4 and Tihange 3). The law of 31 January still has to be modified accordingly. Before taking this decision, the government formally asked the FANC for its opinion. The FANC gave its opinion in the document: https://afcn.fgov.be/fr/system/files/2021-11-28-afcn-position-lto-final-fr.pdf. Discussion with the licensee (ENGIE Electrabel) are currently (July 2022) ongoing.

The in the phase out law foreseen definitive shutdown dates of the Belgian reactors are given in Table 3:

| | |
|---|---|
| Doel 1 | 15nd February 2025 |
| Doel 2 | 1st December 2025 |
| Doel 3 | 1st October 2022 |
| Doel 4 | 1st July 2025 |
| Tihange 1 | 1st October 2025 |
| Tihange 2 | 1st February 2023 |
| Tihange 3 | 1st September 2025 |

Table 3: Definitive shutdown dates of the Belgian reactors

The definitive shutdown dates for Doel 4 and Tihange 3 may be modified in the near future, as a consequence of the recent government decision.

The construction of new NPPs in Belgium is forbidden by this law (Article 3).

## I.C. Summary of the developments since the last report

This section focusses on new developments since 2019.

The issues raised during the Belgian presentation at the Seventh review meeting (2017) and reported in the Country Review Report for Belgium are dealt with in the Belgian national report prepared for the 8th review meeting (2019).

### I.C.1. Changes to the regulatory framework

***a) During the period 2019-2022, the FANC issued several Technical Regulations (TR) to turn previous FANC guidance into binding acts. These TR relate to:***

- Notification of significant events (5 July 2019);
- Periodic Safety reviews (2 February 2021);
- Safety demonstration (27 May 2021);
- Surface clearance levels (18 August 2021);

- Declaration of modifications (6 December 2021);
- Facilities with installations belonging to different classes (6 December 2021);
- Intervention levels for radiological emergencies (23 February 2022).

### *b) In addition, during this period, several regulation projects were finalized:*

(1) The royal decree related to the design of existing reactors, their protection against natural hazards and other requirements

The royal decree of 30 November 2011 on safety requirements for nuclear installations (SRNI-2011) has been amended by the royal decree of 19 February 2020. It includes all the WENRA 2014 RHWG reference levels into the Belgian regulation. Significant improvements were made to the following requirements:

- Strengthening of the design basis
- Design extension
- Protection against natural hazards
- Continuous improvement of safety

Namely, this update legally enforces lessons learnt from the Fukushima-Daiichi accident.

(2) The royal decree completing the transposition of the EU Directive 2013/59/EURATOM

This royal decree has been published on 20 July 2020. It fully completes the transposition of the EU directive 2013/59/EURATOM into Belgian regulations and amends the GRR-2001: dose limits, exemption and clearance levels, ….

(3) The royal decree on exposure (doses) register and the radiological passport

Additional articles 25/1 to 25/15 were introduced in the law of 15 April 1994 to give the FANC the competence to set up and manage an exposure register and a radiation passport system, to set out the scope of the exposure register and the radiation passport as well as the data sources, the basic content of the exposure register, the rights of access to the exposure register and the time limits for the retention of the data contained in the exposure register. Those articles entered into force on 1 April 2017 in the case of the exposure register, and in August 2020 for the radiation passport.

Additionally, a royal decree laying down the form, content, terms and conditions and restrictions on access and use of the exposure register and the radiological passport and amending the GRR-2001, which details the content of the exposure register and the radiological passport, the provisions for protection and security of the personal data contained therein and provisions on the functioning and use of the radiological passport system has been issued on 20 July 2020.

On 17 November 2020, the FANC issued a technical regulation setting out the procedures for compiling the dose report and transmitting the results of individual dosimetry monitoring to the FANC, as well as the procedures for consulting the doses contained in the exposure register and for obtaining the radiological passport.

(4) The royal decree amending the licensing process for nuclear facilities

This licensing process for nuclear facilities described in article 6 of GRR-2001 has been updated on May 29th 2020, to complete the transposition of the European Directive 2014/52/EU amending Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment.

This update addresses:

- A clear delineation of scope of projects with EIA obligation and/or screening;
- Clarification of EIA process (experts, approval of EIA report, …);
- Reshaping public enquiry process.

(5) The royal Decree related to the Interface Safety-Security

On the basis of the WENRA TF Report on Interfaces between Nuclear Safety and Nuclear Security of 2 June 2021, a royal decree has been issued to amend the royal decree of 17 October 2011 on the physical protection of nuclear materials and nuclear installations and the royal decree of 30 November 2011 on safety requirements for nuclear installations (SRNI-2011), with the objective to introduce requirements on:

- The "security by design" concept;
- The management of safety-security interfaces in modifications;

- The management of potential safety-security conflicts.

c) ***Two projects related to the WENRA reference levels are still in progress :***

- Modification of the SRNI-2011 to include the WENRA reference levels for Research rectors: This project is ongoing; its finalization is expected end 2022 or early 2023
- Due to the recent decision of the Belgian Government to modify the law of 31 January 2001 opening the possibility for a long-term operation for the two most recent reactors, a project for including the WENRA – RHWG 2020 reference levels in the SRNI-2011 is being initiated.

### I.C.2. Preparations to support the final shutdown of NPPs and subsequent decommissioning

In 2018 ENGIE Electrabel started with the program for the preparation of the decommissioning of the Belgian nuclear fleet (Fleet D&D) with a focus on Doel 3 and Tihange 2 as these are the first units to be taken out of service end of 2022 and beginning of 2023 respectively (See Figure 2).


Figure 2: Timeframe for decommissioning and dismantling of NPPs

The choice of ENGIE Electrabel is to use first a breakdown logic by typology of decommissioning activities. Division by physical assets or project engineering lifecycle will be done at lower levels. The following decomposition (in 7 scope baskets) is used:

1) Program Management scope : all activities/deliverables to manage the decommissioning program and associated sub-programs. This Work Breakdown Schedule (WBS) Level 2 does not encompass the activities related to the management of the projects/work packages;
2) Post-Operations scope : all activities/deliverables necessary to safely shut down nuclear units and facilities - within a predefined perimeter and until a predefined end state - and maximally reduce nuclear risks;
3) Dismantling scope : all activities/deliverables to realize the dismantling end state of all facilities. This WBS Level 2 encompasses all nuclear and conventional dismantling activities, including activities related to release of facilities from nuclear controls, conventional demolition and site restoration. This WBS Level 2 encompasses the activities related to the modification of the existing installations in order to realize the dismantling activities;
4) Material & Waste Facilities Construction & Modification scope : all activities/deliverables to design, construct/modify, and commission all necessary new and existing waste facilities (WMUs, WAB, TDS/TEL, etc.);
5) Material & Waste Processing, Storage, & Disposal scope : all activities/deliverables for processing, storing, transferring, and disposing of all decommissioning waste (radioactive and conventional) under any form (solid, liquid, gaseous), coming from Post-Operations, Dismantling, and Operations for the waste that will not be transferred (physically and/or ownership) at the end of electricity generation;
6) Operation & Maintenance scope : all activities/deliverables for operating SSC supporting Post-Operations and other Decommissioning activities (excl. waste and spent fuel operations) and for performing the maintenance and maintenance-supporting activities related to SSC in operation;

7) Long Term Spent Fuel Management scope : all activities/deliverables related to Operation and Maintenance of Independent Spent Fuel Storage Installations until the end of Decommissioning.

In view of the future decommissioning of the Belgian nuclear power plants, the **regulatory body** started an internal competence building project in 2014. The purpose of this project is to develop and define a clear and structured approach for the regulatory body, covering all aspects of decommissioning and dismantling waste issues.

The project also dealt with the training of sufficient staff of the regulatory body on decommissioning activities and for the preparation of specific decommissioning processes.

This project dealt with five issues:

1) Building knowledge and experience on decommissioning activities and on waste from decommissioning;
2) Licensing and safety assessments during the post-operational and decommissioning phases of an installation or facility;
3) Regulatory supervision and inspections during the post-operational and decommissioning phases of an installation or facility;
4) Special attention to waste and to waste management from decommissioning;
5) Release of buildings and/or of site and end of regulatory control.

The FANC also established standard conditions that should be part of any dismantling licence and information about the end of regulatory control.

In 2018, the FANC started discussions with ENGIE Electrabel about the future decommissioning of its plants. The main purposes of those meetings are to clarify strategic decisions on (1) the "post-operational phase", (2) the preparation of the dismantling licence or (3) the discussion of the basic design of new facilities that will be needed on site to carry out the dismantling.

For point (1), article 17/1 of the SRNI-2011 requires a notification of permanent shutdown. The FANC communicated to the Licensee (ENGIE-Electrabel) its expectations concerning the drafting of a notification of permanent shutdown of a Class I nuclear facility, and its position on authorized activities during the post operational phase (POP) pending dismantling license.

Modifications to the installations will be processed according to the procedure of article 12 of the GRR-2001. The FANC may (based on procedure referred to in article 13 of the GRR-2001) propose to the King to impose additional conditions or to modify the conditions of the existing license in order to take account of the state of the facility as described in the notification of permanent shutdown.

Regarding this notification, most of the discussion focussed on:

- the description of plant modifications during the Post Operational Phase (adaptations to the Safety Analysis Report (SAR) and the Technical Specifications);
- the definition of the design basis of the nuclear island (which includes the reactor building, the nuclear auxiliaries building, the building of the deactivation pool) during the POP after permanent shutdown. The purpose is to ensure adequacy of the nuclear island with the residual risks mainly but not limited to spent fuel. During POP, with the evacuation of the spent fuel, risks should decrease progressively. Therefore, systems that are not required anymore to maintain the safety of the facility can be de-energised or shut down after cessation of operation, i.e. corresponding systems will be switched off and remain unpressurised and cold;
- the measures to maintain a good staffing level;
- the possible impact of decommissioning of one reactor on the other units that remain in operation.

The FANC received the notification of permanent shutdown of Doel 3 on 1st April 2022 and its review is currently ongoing. The notification for Tihange 2 is expected to be send by 1st August 2022.

For point (2), article 17 of the GRR-2001 fixes the different elements that should be part of the dismantling licence application. Priority chapters of the preliminary dismantling safety report have been identified. Exchanges between the regulatory body and the licensee already took place for Doel 3 and Tihange 2.

In 2021, the FANC also initiated the process to rewrite the authorisations per reactor of the licensee ENGIE Electrabel and to group them in one single authorisation for all the reactors on a site. Several reasons motivated the initiative. In the framework of the upcoming dismantling, one of the reason was to be able to establish links in a simple and uniform manner between the provisions of this new global license and the provisions of future dismantling licenses for nuclear reactors and the buildings and equipment attached to them.

### I.C.3. Licensee's action plans

#### *a) Completion of the European Stress Tests Action plan "BEST"*

The final Belgian national report was published in September 2020. Il is available (in English) on the FANC web site : https://afcn.be/fr/system/files/best-2020.pdf . A detailed list of the actions performed at the NPP has been given in Appendic 6 of the previous edition (2019) of this report.

The licensee, ENGIE Electrabel, had finalized the stress-tests action plan by mid-2020. The action plan can be found in 2019 edition of this report.

Since 2011, the sites of Doel and Tihange have witnessed several major achievements: reinforcement of structures, systems and components to face severe earthquakes, construction of protections against external flooding, additional mobile means, such as mobile pumps and mobile diesels. Both sites are now adequately protected against natural hazards, such as external flooding and earthquakes.

By the end of 2017, the strategy for the Complete Station Black-Out (CSBO) and for the Loss of Ultimate Heat Sink (LUHS) is well-defined on both sites and the related works were finalized.

The construction of filtered venting systems on all reactor buildings at Doel and Tihange was finalized in 2017 for most units, and in 2019 for the two remaining units (Doel 1 & 2) in the framework of their LTO action plan.

The sites are now also prepared against CSBO and LUHS events.

The new emergency response facility (backup to current site operation centre) in Tihange is now built and the licensee has completed final acceptance of the building.

A complementary assessment, issued from the review of closed actions, concerning the revaluation of the capacity of the sewage system in Tihange in case of heavy rains has been finalized and reviewed in 2020.

The last actions are complete. Some documentary work remains for the Regulatory body in order to validate the final acceptance of the last improvements.

#### *b) Completion of the Long Term Operation of Tihange 1, Doel 1 & 2 Action plan*

ENGIE Electrabel established action plans both for Tihange 1 and for Doel 1 & 2, which were assessed and approved by the FANC. The first part of these action plans was completed before the first restart of the reactors after the initially foreseen legal shutdown dates. The second part of these actions plans consisted of additional modifications related to ageing and more significant design improvements. The FANC made use of article 13 of the GRR-2001 (the "General Regulations regarding the protection of the public, the workers and the environment against the hazards of ionizing radiation") to propose license amendments to enforce these action plans.

Both at Doel 1&2 as at Tihange 1 the actions plans have been completed, resulting in a significant design upgrade, which is confirmed by PSA results. A selection of important improvement actions in the LTO action plan is given in Appendix VII.E. The synthesis reports have been published on the website of the FANC.

The D1&2 LTO action plan has been implemented during 2 long outages. The second LTO outage at Doel 1 and 2 (winter 2019-2020) globally was a success from a technical point of view. All modifications and commissioning tests were completed in accordance to the planning and without major difficulties. The action plan resulting from the After Action Review of the first LTO outage proved effective. However, the subsequent startup suffered a delay, amongst others due to an underestimation of the time needed for a thorough check of all commissioning tests and document adaptations. As a result, approval of the commissioning of all modifications by the Regulatory Body took significantly more time than planned.

The last phase of the LTO project at Tihange 1 involved a long outage to allow the "Système d'Ultime Repli Etendu" (SUR-E) to be installed, connected and put into operation. This SUR-E is an important design improvement and is designed to be an independent backup system that can bring the reactor to a safe cold shutdown state after common mode failures (like in the case of large-scale internal fires). It includes the necessary instrumentation and control systems as well as independent power supply systems. This outage, initially planned to start in August 2019, was postponed to the end of 2019 due to the significant delay in preparation, including delay in the delivery of essential safety equipment. Tests successfully demonstrated performance of the new systems and the qualification for the related functions. The outage and the implementation of the SUR-E were done according to standards and schedule. However, when taking systems gradually back into service at the end of the outage, a refueling water storage tank was severely damaged following drainage of the tank with the air intake being obstructed by an FME cover. The necessary repairs have delayed the start up significantly. Although this event had no real safety significance at that moment, the investigation revealed weaknesses regarding amongst others lack of control over the process to put systems back in service after maintenance and insufficient coordination of activities at project and team levels. As a result of the incident's root-cause analysis, a series of corrective actions were defined.

***c) Completion of the Fire safety improvement plan***

An integrated fire safety improvement plan, which combines the actions identified through the Fire Hazard Analysis (FHA) and the Fire PSA, has been implemented completely at Doel for all units and at Tihange 2 and 3. Only at Tihange 1 a limited number of actions, mostly to reroute cables, have been postponed and remain to be completed in 2022 to be able to fully close this action plan. This action plan included hardware improvements such as installing additional fire detection, fire extinguishers and sprinklers, improving physical separation in certain buildings, an additional firefighting pumping station, coating and rerouting of cables and procedure and work process improvements.

***d) WENRA 2014 action plan***

Following the publication of the Royal Decree of 19 February 2020 (See section I.C.1.b)(1) above) ENGIE Electrabel has submitted its official WENRA action plan, or so-called WAP, in April 2020.

Figure 3 shows an overview of the action plan.

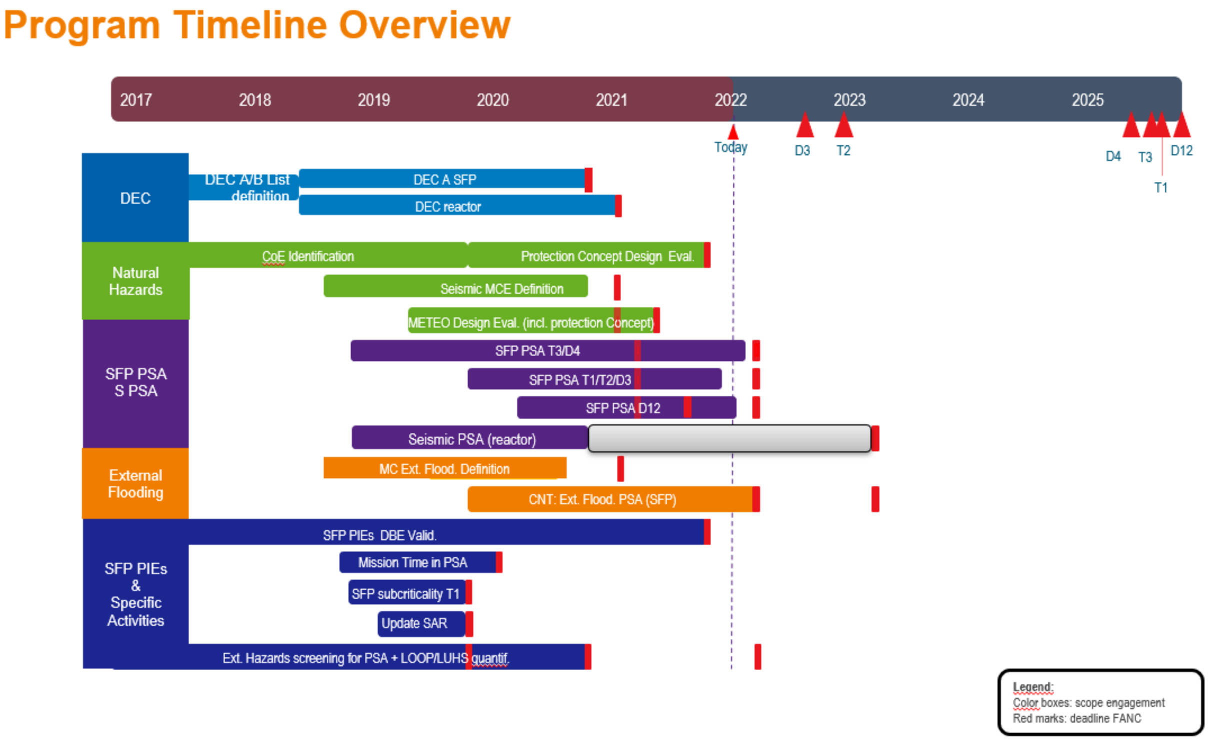


Figure 3: WENRA 2014 Action plan

It is to be noted that the seismic PSA, which was conditional on a lifetime extension of the considered units, has been stopped given that no new long-term operation after 2025 was allowed by the federal government. However, the seismic part of the spent fuel pool PSA has been continued.

The WAP aims at completing the safety demonstration of the Belgian units according to the WENRA 2014 Reference Levels and identifying potential improvements, to be implemented according to the principles of article 3 of SRNI-2011. This article considers the principle of continuous improvement and of the timely implementation of reasonably feasible safety improvements.

ENGIE Electrabel has put in place a process to make a justified choice of safety improvements from findings of the studies in the WAP, taking into account amongst others the remaining lifetime of the units, and to commit to the retained actions by sending a WENRA Implementation Plan, or so-called WIP, to the Safety Authority periodically. A first version was sent end of 2020, and updates in April and October 2021 and in April 2022.

## I.C.4. Other developments

### *a) Periodic Safety Reviews*

The operators of nuclear power plant(s) are obliged under the Royal Decree of 31 November 2011 and the provisions of their licence to conduct a Periodic Safety Review (PSR) every 10 years.

The next PSR is ongoing in the framework of final plant shutdown before dismantling and decommissioning.

Until the end of 2020, ENGIE Electrabel proactively considered a Long Term Operation instead of final shutdown for some units (Doel 4 and Tihange 3). These efforts were stopped at the end of 2020, given that no new long-term operation was allowed by the federal government. Depending on final decisions on future energy policy and consequences of the recent Government decision allowing to amend the law of 31 January 2003, efforts for the periodic safety review for Doel 4 and Tihange 3 may have to be restarted once there will be an agreement between the Belgian government and ENGIE Electrabel.

PSR reports are published from a FANC dedicated web page : https://afcn.fgov.be/fr/dossiers/centrales-nucleaires-en-belgique/surete/revisions-decennales

Reports on the specific actions plans linked to the long-term operation of Tihange 1 and Doel 1-2 are also published on this web page.

### *b) INES Events*

In 2019, 2020 and 2021, ENGIE Electrabel reported respectively 2, 5 and 4 events classified as level 1 on INES. There was no incident classified as level 2 or higher on INES during this period.

For research reactors, the number of events classified as level 1 on INES that was reported during the same period was respectively 1, 1 and 1.

One event in a research reactor was classified as level 2 in 2021. One of the protection systems of BR2 against overpower is realized using BF3 neutron measurement chains. Three of these chains in a 2 out of 3 voting logic give an automatic power reduction or stop of the reactor in case of high levels. If one of these chains is out of service, according to the technical specifications, the action must be given by the 2 remaining chains in a 1 out of 2 logic. The situation occurs regularly, as the measurement chamber can be close to a production device for $^{99}$Mo. These devices are loaded with fresh uranium during reactor operation and a measurement chamber nearby could reach its alarm level without reason. During the operation, the chamber is mechanically removed from the core, such that the reading becomes lower. The remaining chains are put in a 1 out of 2 voting logic. During a cycle in 2020, the reactor was operated using only two BF3 measurements chains for overpower protection, due to problem with the third one. This is allowed according the technical specifications. A certain moment in the cycle a production device had to be loaded and the chamber close to it was moved away from the core. As a consequence the reactor was operating using only 1 BF3 measurement protection system in a 1 out of 1 logic. This configuration is not allowed according to the technical specifications. The event was given a INES level 1 rating as there were no direct consequences. A number of other protections were still full operational. However, the rating was increased with 1 due to the fact that a similar event occurred already the year before. This gave a final INES level 2 rating.

### *c) Updates of PSA*

Recent updates of Level 1 and Level 2 Internal Events PSA models, taking into account the equipment installed following the stress tests and following the LTO programs for Doel 1 & 2 and Tihange 1, are available for all units.

The results of Level 1 and Level 2 Internal Events PSA are used to assess whether the plant risk is well balanced, and where appropriate, to identify further improvements to plant operation.

Level 1 Fire and Flooding PSA models have been established for all units in order to fulfil the requirements of the WENRA Reference Levels (2008), which have been translated into Belgian law under the Royal Decree of 30 November 2011. A fire safety improvement action plan, which combines the actions identified through the Fire Hazard Analysis (FHA) and the Fire PSA, has been implemented for Tihange 2 and 3 units and all Doel units ; the last remaining actions for Tihange 1 will be done by end of 2022. No actions resulted from the Flooding PSA.

Level 2 Fire and Flooding PSA models have first been elaborated for one representative unit, Doel 3. Some recommendations have resulted from the Level 2 Fire PSA. Afterwards, for level 2 Fire PSA, a graded approach was developed and applied to Doel 1&2, Tihange 1 and Tihange 3 based on an existing model for Doel 3. After discussion with the FANC, it has been decided to develop a specific Fire PSA Level 2 for Tihange 3, to be finished before the end of 2022.

Important new developments of PSA are done in the framework of the WENRA Reference Level 2014 action plan as described in section I.C.3.d), including spent fuel pool PSA including internal events, internal flooding, internal fire, seismic and (specifically for Tihange) external flooding.

#### *d) Supply Chain*

ENGIE Electrabel announced an "equipment qualification and obsolescence" project (EQO) in the previous edition of this report. This project has made significant progresses since then. It has resulted in validated processes and procedures identifying different possible solution paths for the replacements of obsolete QA items. These solution paths include amongst others like-for-like procurement from non-qualified suppliers through Commercial Grade Dedication, alternative methods mitigating the impact of the obsolescence such as extension of qualified lifetime and alternative methods to solve the obsolescence such as equivalent replacements (using Item Equivalency Evaluation) or Reverse Engineering. Given the planned phasing-out of the different units, guidance has also been developed to include the remaining time during which a safety function remains applicable in the post-operational phase in the prioritization of obsolescence issues.

### I.C.5. Peer reviews

Peer reviews are regularly organized in Belgium. A list of previous missions that took place during the period 2016-2019 can be found in the 2019 edition of this report. Due to the COVID-19 restrictions, no missions were performed in this reporting period. Planned missions are listed below:

- A second IRRS-Mission is planned in June 2023.
- An ARTEMIS-Mission, is to be hosted in the form of a back-to-back mission with the IRRS-mission in December 2023.
- An OSART-Mission to Tihange 2 is foreseen to be hosted in April-May of 2023.
- An INSSAR-Mission to the BR2 research reactor is planned in Q1 of 2023.
- The second Topical Peer Review organized in the frame of the European NSD Directive (2009/71/EURATOM amended by 2014/87/EURATOM), on fire protection in nuclear installations will take place in 2024, starting with a national self-assessment in 2022.

Belgian experts also regularly participate in IRRS and in other international peer review missions such as OSART missions.

### I.C.6. Communication with the Public

The **FANC** is in charge of disseminating objective and neutral information about radiation risks, as stipulated in article 26 of the law of 15 April 1994.

Interested parties that are informed by the FANC include:

- the general public and the media:
    - the FANC and Bel V have their own web sites. The FANC web site allows the general public to contact and ask questions to the FANC;
    - the media are informed by the FANC management and the FANC communication office. Important events give rise to press releases and conferences;
    - laws and regulations are published in the Belgian official journal ("Belgisch Staatsblad-Moniteur Belge"), as well as notification of decisions (licensing of class I facilities, recognition of experts in health physics …). A consolidated

version of the applicable regulations is available on the FANC web site (http://www.jurion.fanc.fgov.be);
  - the general public is consulted ("public inquiry") in the frame of the licensing process of high risk facilities (Class I), with the possibility to attend information meetings organized by the FANC;
  - the FANC and Bel V's annual reports are published on their websites.
- the supervising Minister and the Parliament through:
  - the answers proposed by the FANC to questions addressed by Members of Parliament to the minister;
  - the government commissioner who attends the meetings of the Board of Administrators;
  - the annual report made available to the Parliament;
  - the follow-up by the parliamentary commission on Home Affairs and the sub-commission on Nuclear Safety;
- the licensees: several formal and informal communication mechanisms are in place, including regular "Contact Commissions" with the licensee's management, "Stakeholder's Meetings";
- other interested parties: The GRR-2001 foresees that other parties are notified of the FANC decisions: For example, article 6.8 prescribes notification of the granted licences to local authorities, to some federal administrations, to the civil protection administration, to ONDRAF/NIRAS, to the European commission and other European countries when relevant.

The government and the public are also informed by the annual report of the FANC. This report is published on the FANC web site, together with the Bel V annual report.

The main communication tool of the FANC is its web site www.fanc.fgov.be. Several reports, information files about the radiation risk of different facilities and activities or about particular subjects are available. News Flashes are also regularly published on the web site.

**INES** (International Nuclear and Radiological Event Scale) has been used in Belgium for almost 30 years now.

Currently, a technical regulation of the FANC of 5 July 2019 determines the criteria and modalities for notification of events and the use of INES. This technical regulation replaces a convention between the licensees, the FANC and Bel V. As the convention did before, the technical regulation stipulates in which circumstances and how INES is to be used. The licensee has to perform the INES-analysis according to the latest INES manual, and this level has to be approved by Bel V and the FANC. Depending on the INES-level, a specific notice is issued. For events of level 1 or higher, the FANC publishes a short notice on its website ( https://fanc.fgov.be/nl/noodsituaties/ines-schaal/gebeurtenissen-belgie-ingedeeld-op-de-ines-schaal-van-de-laatste-12 ). For events of level 2 or higher, besides the notice on the website of the FANC, the licensee has to issue a press release about the event and the INES National Officer notifies the IAEA.

Finally, since 2012, the **radioactive releases** of all Belgian nuclear and waste facilities with their calculated radiological impact are published annually on the FANC web site : https://afcn.fgov.be/fr/dossiers-dinformation/radioactivite-dans-lenvironnement/surveillance-radiologique-du-territoire-0 (in French).

Information about the **Periodic Safety Reviews** is given on the following page : https://afcn.fgov.be/fr/dossiers-dinformation/centrales-nucleaires-en-belgique/surete/revisions-decennales

After each **review meeting of the CNS**, the FANC publishes on its web site:

- The National Report;
- Questions and answers on the national report;
- The national presentation at the Review Meeting;
- The Rapporteur's report for Belgium.

This information for the 7th review meeting can be found (in French and in Dutch) on the following web page : https://afcn.fgov.be/fr/lafcn/relations-internationales/conventions-et-traites-internationaux/convention-sur-la-surete-0

The results of the measurements performed by the **TELERAD** network (See article 16 of the CNS, section II.L.2.b) are available on the FANC web site as well. This provides the possibility to all interested parties to have an online overview of the measured radioactivity on the Belgian territory.

**ENGIE Electrabel** has taken several initiatives to inform the general public, in particular in the vicinity of the NPPs:

1) Communication policy

Doel and Tihange NPP's external communications are aimed at:

- Showing ENGIE Electrabel people, professionalism and focus on nuclear safety to the general public.
- Keeping on clarifying ENGIE Electrabel activities.
- Explaining to the public what a nuclear Decommissioning looks like and showing to the public that ENGIE Electrabel will handle the Decommissioning of the nuclear power plants with internationally recognized professionalism.

2) Website and Social Media

ENGIE Electrabel has a website that is fully dedicated to the nuclear activities in Belgium. Both Doel and Tihange NPP have a specific dedicated webpage on this website.

- https://nuclear.engie-electrabel.be/en
- https://nuclear.engie-electrabel.be/en/powerplant/doel-nuclear-power-station

https://nuclear.engie-electrabel.be/en/powerplant/tihange-nuclear-power-stationOn these webpages key figures on the plants can be found, as well as information on current big projects, press releases, publications, currently relevant information, … In case of specific subjects and questions on social media, the social media channels of ENGIE are also being used to give information on nuclear topics.

Specifically in 2021 efforts have been done to reinforce the external website with info, animations, visuals on the Decommissioning of ENGIE Electrabel power plants: The decommissioning of the Doel and Tihange power plants: a new industrial challenge in complete safety | ENGIE Electrabel (engie-electrabel.be)

3) Information magazine

"Doelbewust" and "Tihange Contact" are the community magazines of the Doel and Tihange nuclear power plant. All neighbours (respectively 71.000 and 47.000) get it through their letterbox a two times a year. The magazine contains information about the activities in and around the power station and shines a light on the important role of the staff.

The magazines are also available on the websites:

- https://nuclear.engie-electrabel.be/en/powerplant/doel-nuclear-power-station/doelbewust
- https://nuclear.engie-electrabel.be/en/powerplant/tihange-nuclear-power-station/tihange-contact

4) Consultative bodies

The 'Klankbordraad' and 'Comité de Riverains" are consultative bodies set up to reinforce the relations between the power plants and local residents (people living or working in the area). This consultative body is made up of members from various sectors: education, environmental organizations, social sector, etc. It meets several times a year. The members are kept informed of current news regarding the power plants on a regular basis.

5) Environmental declaration

Every year the Doel and Tihange nuclear power plant publish an environmental declaration describing it environmental impact and the measure taken to assure the protection of the environment, and guarantee the well-being of its staff.

The environmental declarations of both sites are available on the website:

- https://nuclear.engie-electrabel.be/en/powerplant/doel-nuclear-power-station/environmental-statement

- https://nuclear.engie-electrabel.be/en/powerplant/tihange-nuclear-power-station/environmental-statement

6) Social Media accounts

The nuclear power plants also use the social media channels of ENGIE Electrabel to promote their activities and show their professionalism and accomplishments to the general public.

- https://twitter.com/ENGIEelectrabel
- https://www.linkedin.com/company/engie-belgium/mycompany/
- https://www.facebook.com/ENGIEBelgium/
- https://www.instagram.com/engiebelgium/
- https://www.youtube.com/channel/UCmK4ptIBjmo59NbM_8mxQbQ

7) Social initiatives

The power plants support numerous initiatives in the neighbouring municipalities.

8) Guided tours for visitors

For specific stakeholders, visits to the power plants are still being organized. Due to legal access regulations and restrictions, visits are no longer possible for large groups.

9) Relations with the media

Journalists have a Single Point of Contact which can also be found on the website.

- https://nuclear.engie-electrabel.be/en/press

10) Information campaign of the Nuclear Forum

The Nuclear Forum was set up in 1972 and represents the majority of Belgian companies and institutions which devote efforts to the civil application of nuclear energy. ENGIE Electrabel is member of this Forum. The Nuclear Forum launches information campaigns on nuclear energy in Belgium.

## I.C.7. R&D Programmes in safety

The **Belgian Regulatory Body** (FANC and Bel V) is active in many R&D activities. Such R&D activities are performed to allow the Regulatory Body to take independent and informed safety positions and decisions, based on advanced and detailed scientific information, in most of the technical domains relevant for safety. Since the last report of 2016, the main efforts in the area of R&D for nuclear safety are given below.

Thermal hydraulic accident analysis: Bel V has since a long time developed the capabilities to perform independent accident analyses of Belgian nuclear installations by means of the CATHARE (mainly) and the RELAP5-3D codes. These codes are used to carry out safety assessments of the Belgian Nuclear Power Plants. Bel V also continues its important effort to participate in projects managed by OECD/NEA such as the experimental projects carried on scaled facilities like ATLAS (Advanced Thermal-hydraulic test Loop for Accident Simulation ) and PKL, including the active contribution to analytical working group activities. Bel V also participates to the IRSN's DENOPI project to better understand the behaviour of SFP in case of loss of cooling or loss of coolant accidents, and to the R2CA Horizon2020 project sponsored by the European Commission about the Reduction of Radiological Consequences of design basis and design extension Accidents.

In addition, Bel V participates also to several OECD/NEA Working Group activities on fuel safety including topics related to the use of 3D thermal-hydraulic system codes, passive systems for industrial use and topics related to Design Extension Conditions (DEC).

Fuel behaviour: Bel V continues its participation to the OECD/NEA Halden Reactor Project, with the objective to get information of post irradiation examinations of already irradiated material.

Severe Accidents Progression: Bel V holds the Cooperative Severe Accident Research Program (CSARP) agreement with USNRC for Belgium. In this context Bel V has access to the MELCOR code and provides access to the code to other Belgian organizations such as Tractebel ENGIE and SCK CEN. With the objective of strengthening the capabilities of independent severe accident safety assessment, Bel V developed a database of MELCOR input decks for accident analyses, which covers some Belgian nuclear installations, as well as experimental test facilities.

In support of Bel V's activities related to the hydrogen and fission-product-related issues in a containment under severe accident conditions, Bel V participates to the OECD/NEA BIP-3 and THAI-3 projects. Active participation to the analytical activities by means of Computational Fluid Dynamics (CFD) code simulations with the support of the von Karman Institute (VKI) for Fluid Dynamics is also ongoing based upon data issued from the THAI-3 project.

Bel V participates actively to the MUSA Horizon2020 project sponsored by the European Commission about the Management and Uncertainties of Severe Accidents, and as observer to the IVMR project about In Vessel Melt Retention in the same framework.

Fire protection: Bel V continues its involvement in the PRISME project series and FIRE databases of the OECD/NEA, by participating to benchmark activities and performing calculations using the Fire Dynamics Simulation CFD code and providing information from Belgian fire events.

Mechanical Safety: Bel V is co-lead (together with IRSN) in an international project in the framework of the Working Group on Integrity and Ageing of Components and Structures of the OECD, aiming at performing a benchmark of the extended Finite Element Method amongst different countries / codes.

Bel V is participating with IRSN to new experiments conducted at CEA, aiming to analyse the effect of biaxiality on the stress state and fracture mechanics behaviour of steel containing hydrogen flakes.

Ageing: Bel V participates to the ODOBA (Observatory of the durability of reinforced concrete structures) experimental project to study concrete pathologies and their consequences for nuclear structures (like reactor containments and waste disposal facilities) within the context of extending the service life of nuclear facilities. In addition, Bel V participates also to the EC/H2020 ACES project (Improved assessment of NPP concrete structures toward ageing) aiming to the assessment of safety performance of safety-critical concrete infrastructure for the safe and LTO of NPPs.

Waste and decommissioning: FANC and Bel V make a considerable investment in obtaining expertise in waste management related issues, required for the review by the Regulatory Body of future safety assessments for a geological disposal of high-level and long-lived radioactive waste.

Bel V actively participates in the Horizon 2020 first European Joint Programming on radioactive waste management and disposal sponsored by the European Commission, named EURAD.

Together with the Dutch National Institute for Public Health and the Environment, Bel V developed a methodology for the derivation of surface clearance levels from a controlled area of a nuclear facility called SUDOQU.

Emergency preparedness: In view of strengthening its expertise and competence in emergency preparedness & response, Bel V actively contributes to the Horizon 2020 FASTNET (FAST Nuclear Emergency Tool) project by participating to benchmark exercises with the aim to calculate the source term with the codes PERSAN, developed by IRSN, and RASTEP, developed by Lloyd's Register.

Small Modular Reactors (SMR)

Bel V started to collect information and data on existing and emerging SMR's technologies with focus on safety related topics, including evolution of safety standards and licensing and regulatory issues related to SMRs.

Cybersecurity

Bel V is pursuing the development of a small laboratory for the qualification of computer-based systems (CYBERUS), aiming at preparing Bel V to participate to the European RESYST project on cybersecurity and electricity transportation.

Sponsoring R&D: Bel V continues its effort to sponsor nuclear safety related research with universities and research institutes. These efforts are mainly undertaken by sponsoring doctoral thesis projects or post-PhD positions. The main areas in which projects are sponsored are fire protection, waste management, thermal hydraulic analysis and severe accident progression.

**ENGIE Electrabel** is also active in the field of R&D, in collaboration with other divisions of the ENGIE Group.

The Group has defined a roadmap with their R&D needs, covering the following areas that are relevant for Electrabel: long term operation, plant retirement, plant safety, operational excellence, flexible operations and grid requirements, fuel reliability, back-end cycle and waste, security and environmental issues. The R&D roadmap is being revised on a periodic basis.

Some of those projects are shortly listed below (this list is not exhaustive) for each field of research:

- Phenomena occurring during transient, incident conditions and accident conditions:
    - Participation in OECD/NEA WGAMA projects (e.g. ROSA, PKL, BEMUSE);
    - Participation in OECD/NEA Working Group on fuel Safety (WGFS);
    - Participation in the Halden Project and IAEA FUMEX fuel rod codes benchmark (high burn-up fuel);
    - Participation to MERCI experiment (reduction of uncertainties of short-time residual power).
- Phenomena during Severe Accidents:
    - Participation in SERENA (steam explosion) and Nugenia;
    - Participation in SARNET2 (uncertainties in severe accidents) and USTA;
    - Participation in BIP1-2-3 (iodine behavior);
    - VERDON program (Fission product behavior during release) part of ISTP (fission products and iodine);
    - Participation to MCCI, CCI, VULCANO and ROSAU (corium concrete interaction and ex-vessel coolability);
    - Air-SFP (spent fuel pool air-ingress scenarios) with MELCOR;
    - IVMR (in vessel melt retention) with a focus on Work Packages CFD use, RPV mechanical resistance and Reactor application (with MELCOR).
- Fuel Behavior:
    - Fuel Benchmark REGAL (Rod-Extremity and Gadolinia AnaLysis);
    - Axial gas flow in irradiated fuel rods (AGAF Project).
- Chemistry:
    - Optimization of $H^2$ concentration in the primary Circuit.
- Nuclear waste conditioning:
    - Conditioning of low-level radioactive evaporator concentrates;
    - Development of a process for the conditioning of ion exchange resins (REI) in a cement matrix Waste for MEDOC Project.
- Understanding and mitigation of materials ageing:
    - Protection of concrete subject to extreme conditions of T°, pressure and humidity;
    - Participation to the ECRAN project (Concretes carbonatation);
    - Extend and improve the experimental database on the surveillance materials to improve experimental techniques and evaluation procedures to keep them at the state of the art;
    - Improving understanding of Irradiation Assisted Stress Corrosion Cracking (IASCC) and Primary Water Stress Corrosion Cracking (PWSCC);
    - Effect of reactor coolant environment on fatigue life of reactor materials.
    - Extent of accelerated carbonatation in reinforced concrete due to microcracks.

Research agreements are set up with organizations such as the French CEA and SCK CEN. These research centers work on several projects linked to ENGIE Electrabel R&D.

## I.D. Planned measures to improve safety

In summary, for the **regulatory body (the FANC and Bel V),** the following measures to improve the regulatory framework and the safety are planned for the period 2023-2026 :

a) Finalization of regulation development projects:
    - Modification of SRNI-2011 to include the WENRA Reference Levels for research reactors.
    - Modification of SRNI-2011 to include the WENRA-RHWG 2020 Reference Levels (in case of LTO for Doel 4 and Tihange 3)

b) Continuation of international bilateral and multi-lateral cooperation activities, namely for supporting development of new standards, e.g. through the IAEA Safety Committees and the WENRA working groups;

c) Implementation of the action plan that will result from the self-assessment and the IRRS mission that will take place in December 2023;

d) Self-Assessment, participation in the second Topical Peer Review organized in the frame of the European Nuclear Safety Directive on fire protection in nuclear installations that will take place in 2024, and implementation of the possible resulting actions plan;
e) Ensure a high level of safety and ensure that the safety will remain the overriding priority during the post operational phase of Belgian NPPs that will definitively shut down starting end 2022 with the reactor Doel 3.

For the operator **(ENGIE Electrabel),** the planned actions to improve safety planned for the next period 2023-2026 are best illustrated in Figure 4.


Figure 4: Actions to improve safety

"Operate our plants as nuclear professionals" is concretised into the ambition to further improve our nuclear safety performance. This will be done through the continuous improvement cycle of the Nuclear Generation Management System (NGMS) on one hand and by the implementation of the following main abovementioned action plans on the other hand:

- WENRA Implementation action plan (WIP)
- Actions defined in the framework of shutdown notification and the associated Periodic Safety Review action plans
- Nuclear Safety Culture action plans.

The focus point "Keep our machines in shape" implies continuing efforts for ageing and obsolescence management of all installations.

Regarding the focus point "Take care of our people": this is done amongst others through implementing staff retention measures to safeguard the required critical competencies, intensive social dialogue and installing a wellbeing action plan.

This strategy was developed taking into account the scenario where all units are shut down in 2025. For the action plans focusing on the installations, this scenario has led to an increased focus on the spent fuel pools.

# II. General Provisions

## II.A. Article 4. Implementing Measures

> Each Contracting Party shall take, within the framework of its national law, the legislative, regulatory and administrative measures and other steps necessary for implementing its obligations under this Convention.

After being adopted by the Belgian Parliament, the law endorsing the Convention on Nuclear Safety of Vienna of 20 September 1994 was signed by the King on 26 November 1996 and published in the "Moniteur belge" (i.e. Belgium's Official Journal) of 22 August 1997. As a result, the Convention is incorporated in the Belgian national legislation.

After the ratification, the national legislator decided that the existing legislative and regulatory framework was sufficient to implement the Convention, without adaptations or completions deemed necessary. This does not alter the fact that the efficiency and effectiveness of the regulations are permanently evaluated by the public bodies involved and that they will be improved if necessary, in order to take into account the scientific, technological and social evolutions or to be in compliance with obligations resulting from other international conventions. Since the ratification of the Convention, the nuclear laws and regulations have undergone important modifications, related, among other to the European Directives and to the WENRA work.

## II.B. Article 6. Existing Nuclear Installations

> Each Contracting Party shall take the appropriate steps to ensure that the safety of nuclear installations existing at the time the Convention enters into force for that Contracting Party is reviewed as soon as possible. When necessary in the context of the Convention, the Contracting Party shall ensure that all reasonably practicable improvements are made as a matter of urgency to upgrade the safety of the nuclear installation. If such upgrading cannot be achieved, plans should be implemented to shut down the nuclear installation as soon as practically possible. The timing of the shutdown may take into account the whole energy context and possible alternatives as well as the social, environmental and economic impact.

### II.B.1. Nuclear Power Plants (NPPs)

Belgium's seven nuclear power units in operation are equipped with pressurised water reactors built either by Westinghouse or by Framatome, each time in partnership with Belgian manufacturers for the major equipment of the primary and secondary systems. These units were put into service between 1974 and 1985. More details on the seven nuclear power plants can be found in Table 1 and Table 2 of Section I.B and in III of this report.

The process applied for the licensing of these installations was described in previous reports for the Convention. Since the process would no longer be the same today and since many organisations and committees that played a role in this process have been replaced by other organisations and committees, it was deemed no longer appropriate to describe this historic information in this report. However, if needed, the reader can find the information in the 2007 Belgian report for the Convention (in particular in paragraphs II.B, II.D and II.J.1).

After the licensing of the plants, the safety of the installations was continuously reviewed through different processes.

The most important and systematic process is the series of periodic safety reviews (PSR) that have been performed for all seven nuclear power plants. The PSRs are imposed through the operating licence of the facilities and now by the Royal Decree of 30 November 2011 (SRNI-2011).

In addition, many other projects with important modifications have been executed, amongst others introduction of MOX fuel, pressure vessel head replacement and steam generator replacements at all units, in some cases accompanied by power increase.

Some important projects for the safety assessments of the installations took place in an international context. We refer in particular to the OSART missions undertaken at the Tihange site in 2007 and at the Doel site in 2010.

All Belgian plants were also subject to a so-called WENRA Action Plan. This plan resulted from the WENRA RHWG self-assessments and benchmarking project, for which the results were published early 2006. This action plan covered design as well as operational issues and is formally now completed

As mentioned in section II.C.6, a law relating to the phase-out of nuclear energy was voted by the Belgian parliament in January 2003. In July 2012 a governmental decision was taken to allow Tihange 1 to operate until 2025. An action plan has been drawn up for the improvement of Tihange 1, based on the safety assessment report established by ENGIE Electrabel and reviewed by the FANC and Bel V. On 28 June 2015, the phase out law of 2003 was modified to allow the LTO of Doel 1 & 2 up to 2025. As a result, the FANC published conditions, to which ENGIE Electrabel replied with an action plan in 2015. This action plan was based on the initial LTO-project (approved in 2012) and actions from projects (PSR, BEST, …) and operational issues form the period between 2012 and 2015. This action plan was divided into 2 parts: actions (necessary to prove the availability of the safety systems, structures and components (e.g. the qualification or the replacement by qualified equipment of insufficiently qualified equipment; inspections of mechanical or concrete equipment, installation of ageing management programs, … ) that had to be executed before the restart and other actions that ENGIE Electrabel had to finish before end 2019 (e.g. the installation of the filtered containment venting system; seismic upgrade of the Refuelling Water Storage Tanks, new seismic fire pump station, …). A selection of important improvement actions in the LTO action plan is given in Appendix VII.E.

The technical characteristics of each unit are described in detail in III to this Report. The original design is described together with the main modifications made since their construction.

A particular characteristic of the Belgian nuclear power plants, that merits to be described in some more detail, is their high level of protection against accidents of external origin. Indeed, for the four most recent units, it was requested at the licensing stage that accidents of external origin had to be taken into account, such as an aircraft (civil and military) crash, a gas explosion, a major fire and the effects of toxic gases. These requirements resulted in a duplication of a significant number of safety systems, installed in bunkered structures to withstand an aircraft crash, which is the most demanding loading case. Moreover, explosive or toxic gases detection systems isolate the ventilation systems in a redundant way in order to prevent the introduction of such gases in the control rooms and of explosive gases in the bunkered part of the installations.

This high protection against accidents of external origin resulted in a greater redundancy or diversity in some cases, of the protection and engineered safety systems. For example, the Doel 3 and 4 units, as well as Tihange 2 and 3, are three loop plants equipped with 3 independent and redundant safety trains (each train having its own safety diesel group in a non-bunkered building) and with 3 emergency trains to mitigate accidents of external origin (each train with a diesel located in a bunkered area and built by a manufacturer different from the one of the normal safety diesels, ensuring diversity). The safety trains and the emergency trains are not designed to cope with the same accidents (of internal origin or of external origin respectively) but the emergency trains provide an equipment diversity which can be very useful even for some accidents of internal origin, according to the probabilistic safety studies results.

Afterwards, the protection against external accidents for the older units (Doel 1 & 2 and Tihange 1) was also considerably improved, amongst others by adding dedicated and bunkered systems to these plants.

Following the Fukushima Daiichi accident, ENGIE Electrabel was asked to conduct Stress Tests. Safety assessment reports for the Doel and Tihange sites have been established by ENGIE Electrabel and reviewed by the FANC and Bel V and external experts. Action plans have been developed. Various modifications were made to the facilities. One of the most important ones is the strong improvement of the protection of the Tihange NPP against external flooding.

As a conclusion, the permanent in-service monitoring and inspection of the installations, combined with the periodic safety reviews during which the changes in regulations and practices and the systematic use of feedback of operating experience are also taken into account, ensures that the safety of the installations is maintained and even improved where possible. Ageing is systematically investigated in order to ensure the availability of all safety systems.

## II.B.2. Research Reactors

Several research reactors were operational in Belgium (5 at the Nuclear Research Centre SCK CEN and 1 at the University of Gent). At this moment 3 of these reactors (including VENUS, a zero power critical facility), are still in operation; among these, the BR1 and BR2 research reactors that are included in this report. A detailed description of BR1 and BR2 is given in Appendix 2.

Following the Fukushima Daiichi accident, SCK CEN was asked to conduct Stress Tests, which in Belgium were extended to include other nuclear installations than NPP's. Safety evaluation reports, among others for the research reactors in operation, have been established by the licensee and reviewed by the FANC and Bel V. The FANC National report was issued on April 16, 2013. All actions were finalized in 2021.

### *a) BR1*

The BR1 is a natural uranium graphite reactor, comparable to the reactors ORNL X-10 (USA) and BEPO (Harwell, UK). The reactor went critical for the first time in 1956. The core is composed of a pile of graphite blocks thus forming a cube with ribs of 7 meter. The reactor is air cooled. The fuel is metallic natural uranium with an aluminium cladding. Its design thermal power is 4 MW. However, since the start of BR2 this high power was no longer needed and since March 2018 BR1 is licenced to operate at a maximum thermal power of 1 MW using only the auxiliary ventilation system. Due to its very well thermalized neutron spectrum, the reactor is mainly used for neutron studies, such as neutron activation analysis and instrument calibration. Neutronography is also possible.

No significant modifications have been made to the reactor. The original fuel is still loaded. The burn up is still low and hence no replacement is foreseen at this moment. In 1963, after a long period of operation at higher power, the fuel was unloaded and the graphite matrix was heated in order to release the Wigner energy. In the current operating regime, using only the auxiliary ventilation, the graphite temperature is relatively high compared to the fast neutron dose, such that the Wigner energy is still decreasing.

### *b) BR2*

The BR2 is a heterogeneous thermal high flux test reactor, designed in 1957 for SCK CEN by NDA [Nuclear Development Corporation of America - White Plains (NY - USA)]. It has been built on the site of the SCK CEN in Mol. Its first criticality dates from 1961 and operation of the reactor started in January 1963.

The reactor is cooled and moderated by pressurised light water in a compact core of highly enriched uranium positioned in and reflected by a beryllium matrix. The maximum thermal flux approaches $10^{15}$ neutrons / ($cm^2$.s) and the ultimate cooling capacity, initially foreseen for 50 MW, has been increased in 1971 to 125 MW by replacement of the primary heat exchangers.

The reactor was originally designed for material and fuel testing and this still is an important activity. A number of irradiation devices are available. However, over the past years, isotope production (Mo-99, Ir-192 and others) has become an important activity. Besides that, two irradiation facilities for silicon doping are available.

The beryllium matrix swells under neutron irradiation due to the formation of gas (helium and tritium). This swelling causes cracking of the beryllium which is a brittle material. Furthermore, the build-up of the helium-3 isotope results in neutron poisoning. Due to these effects the lifetime of the beryllium matrix is limited. Three replacements were already performed. The first one took place in 1979 and the second one in 1996. The third replacement was done in 2015-2016 and the reactor was restarted by mid-2016.

During the lifetime of the reactor, continuous modernization projects have been executed. On the occasion of the third beryllium matrix replacement, a major refurbishment programme was realized including the conclusions of the stress test and the conclusions of the Periodic Safety Review of 2016 A new emergency diesel generator system was installed. In the framework of the Stress Tests, a monitoring system is installed that gives information of the state of the installation after a severe accident. The system is designed to work independent of all other systems for at least 72 hrs.

The effort for the conversion from highly enriched uranium to low enriched fuel is being pursued within the HERACLES collaboration, which regroups the concerned EU parties (CEA, ILL, TUM, CERCA). Specific efforts are expended on the industrialization of the LEU fuel fabrication and the development of a back-end solution. The first phase of the HERACLES roadmap is to perform a 'comprehension programme', i.e. understand the previous results and the difficulties encountered with the dispersed UMo fuel system under irradiation; then make the selection of the technical solutions for the qualification of high density LEU fuel and perform an appropriate irradiation programme. These irradiation campaigns were started in 2017 in the BR2 reactor and will continue up to 2023. Post Irradiation Examination for the first plates is started.

SCK CEN is also looking into an alternative road to conversion. One guiding line is the requirement of the FANC that a proven back-end solution must be in place for the new LEU fuel. Slight and acceptable geometrical modifications to the BR2 standard driver fuel element have been made in order to be able to adopt an evolutionary higher density version of the U3Si2 based LEU fuel system, which in lower density is already qualified for medium power research reactors. These fuel elements are qualified for routine operation and are used from cycle 01/2019. They contain also a different burnable poison, which allows longer irradiation cycles (up to 5 weeks).

## II.C. Article 7. Legislative and Regulatory Framework

1) Each Contracting Party shall establish and maintain a legislative and regulatory framework to govern the safety of nuclear installations.
2) The legislative and regulatory framework shall provide for:
   (i) the establishment of applicable national safety requirements and regulations
   (ii) a system of licensing with regard to nuclear installations and the prohibition of the operation of a nuclear installation without a licence
   (iii) a system of regulatory inspection and assessment of nuclear installations to ascertain compliance with applicable regulations and the terms of licences
   (iv) the enforcement of applicable regulations and of the terms of licences, including suspension, modification or revocation

### II.C.1. Introduction

The Belgian legal texts relevant for the safety of nuclear installations covered by this Convention are:

- The Law of 15 April 1994 on the protection of the population and the environment against the hazards of ionizing radiation and on the Federal Agency for Nuclear Control (amended for the last time in 2018),
- The Royal Decree of 20 July 2001 laying down the "General Regulations regarding the protection of the public, the workers and the environment against the hazards of ionising radiation" (GRR-2001, amended for the last time in 2018),
- The Royal Decree of 30 November 2011 on the Safety Requirements for Nuclear Installations (SRNI-2011 amended for the last time in 2018).

Besides these, other legal texts relate to aspects covered by the Convention, such as:

- The legislation with respect to Emergency Planning and Preparedness,
- The law with respect to the Phase Out of Nuclear Energy,
- The legislation on nuclear liability.

The scope of the GRR-2001 is very wide and covers practically all human activities and situations which involve a risk due to the exposure to ionizing radiation, and this at the level of the protection of the workers as well as at the level of the protection of the public and the environment. In particular, the risks associated with the natural radiation (e.g. radon) are integrated in the regulations. These regulations ensure the transposition of all the European directives regarding radiological protection (BSS).

The GRR-2001 implements many articles of the Law of April $15^{th}$, 1994 and made **the Federal Agency for Nuclear Control (FANC),** created by that Law, operational. The organisation of the FANC is explained under Article 8. The FANC, which is endowed with wide competences, **constitutes the Safety Authority.**

The texts of the regulations currently in force can be consulted on the website of the FANC (http://www.jurion.fanc.fgov.be).

A summary of the legislation is given below for each main topic. The texts referred to are not frozen, in the sense that they are likely to be replaced, completed or modified at any time by further regulations that amend the original texts, so as to limit the volume of texts to be referred to.

Information concerning the national framework for the management of spent fuel and radioactive waste can be found in the last Belgian National Report for the "Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management", available on the FANC and IAEA web sites.

### II.C.2. The Law of 15 April 1994

The Law of 15 April 1994 on "the protection of the population and the environment against the hazards of ionizing radiation and on the Federal Agency for Nuclear Control" constitutes the basic law that sets out the basic elements for protecting the workers, the public and the environment against the adverse effects of ionising radiation. The same law also creates the FANC as the Safety Authority.

- **Chapter 1** defines a number of terms used and clearly establishes (Art. 2) the "Federal Agency for Nuclear Control", abbreviated as "FANC" as the public interest organisation having legal personality to become the Safety Authority.
- **Chapter II** gives more detail regarding the competent authority. The King is the competent authority for all activities involving sources of ionising radiation, including transport. The King may take all measures aimed at protecting the public and the environment in case an unforeseen event presents a danger. The King also nominates the persons in charge of supervising the compliance with this law and its implementing decrees dealing with the medical surveillance of the workers and the health conditions at work (Art. 7-11). These persons trace and record infractions to this law; they can issue warnings and set deadlines for corrective actions; they have access to the nuclear installations at any time; they can proceed to the seizure of equipment or sources;
- **Chapter III** enumerates the various missions of the FANC. Those missions comprise a.o.
  - Control and supervision activities;
  - to perform all acts contributing to this law and to create legal entities contributing to his law;
  - to perform safety and security assessment of nuclear facilities and conduct inspections in those facilities;
  - to examine the licence applications for nuclear facilities; to grant licences for specific facilities, except those with the highest risk (class I facilities); the verification of compliance with licence conditions;
  - radiological surveillance of the territory;
  - to provide technical assistance to the Ministry of Home Affairs in case of nuclear emergencies;
  - to propose and prepare new regulations related to this law; the FANC can issue technical regulations in the cases determined by the King;
  - to gather a scientific and technical documentation in the field of nuclear safety; to stimulate and to coordinate R&D;
  - to maintain a national dose register and to issue dosimetry passports for exposed workers;
  - to issue neutral and objective information to the public.
  - The FANC may delegate, on a decision of its Board of Administrators, some of its surveillance missions to legal entities that it has created for this objective
  - The King determines: The missions that can be delegated to the entity; the surveillance of the FANC to the legal entity and the financing mechanism of the entity.
  - The Board the entity is composed of at least 50% of the Board of the FANC
- **Chapter IIIter** has been introduced on December 6$^{th}$, 2018, to transpose the dispositions of the European Directives 2011/92/UE and 2014/52/UE on environmental assessment of certain projects.
- **Chapter IV** deals with the organization of Health Physics.
  - the licensee has the prime responsibility for protection. In line with this responsibility, each licensee has to set up an internal health physics department;

- the King determines the missions, the organization and the working of the health physics department. He also determines the needed resources and competencies;
- The King determines which tasks have to be performed by a recognized expert. Licensees (of low risk facilities/activities) who have not such expert within their organisation may call upon recognized experts belonging to a recognized health physics organization (RHPO);
- the recognition of those organisations is based on criteria and process defined by the King;

- **Chapter V** deals with the funding of the FANC, which is based on
  - annual taxes on licence holders or future licence holders (e.g. the projects for disposal of radioactive waste); the amounts and the procedure for paying are fixed in this chapter;
  - fees related to the application for a licence, recognition or registration; the amounts are to be fixed by Royal Decree and are adapted annually to the price index;
  - administrative fines; amounts and procedures are detailed in articles 53 to 64 of the law;
  - fees for special (control) activities;
  - subsidies.
- **Chapter VI** describes the basic management mechanisms of the FANC
  - FANC is directed by a Board, whose members are appointed by Royal Decree;
  - the Scientific Council, whose composition and duties are fixed by Royal Decree, is established as an advisory body to the FANC;
  - the FANC must be organised is such a way that the regulation development function and the control and supervision functions are carried out independently;
  - day-to-day management of the FANC is entrusted to the General Manager
- **Chapter VII** describes some of the means of enforcement at FANC's disposal such as administrative fines.
- **Chapter VIII** describes some final clauses and some transitional arrangements

### II.C.3. The Royal Decree of 20 July 2001

This Royal Decree provides the basic nuclear safety and radiological protection regulations. Amendments are regularly proposed by the FANC in order to take account of scientific and technical developments, to transpose the European directives, etc.

The GRR-2001 introduce the concept of clearance and strict rules concerning the reuse and the recycling of very low level solid waste that also has an important impact on the design, the operation and the dismantling of the nuclear installations concerned by the Convention.

An outline of the GRR-2001 and the provisions that are most relevant in the context of the Convention is given below.

- **Chapter I** – General Provisions
  - Definition of the scope and field of application of the GRR-2001
  - Definition of physical terms.
- **Chapter II** – Categorised Facilities.
  - Facilities are categorised from Class I (the nuclear fuel cycle facilities, representing the highest risk) down to Class IV (very low quantities of radioactive material).
  - Prior licensing is mandatory for facilities from Class I to III.
  - Art. 6 describes the licensing system of the Class I facilities
  - Art. 12 and 13 deal with the licensing issues due to modifications to the facility or the additional licence conditions that can be proposed by the FANC or its scientific council.
  - Dismantling of Class I (and some Class II) facilities is also subject to prior licensing.

    - The competent authority may withdraw or suspend the licence in case of incompliance with the regulations and/or licence conditions
- **Chapter III** – General Protection.
    - The limitation of individual or collective doses is based on the fundamental radiological protection principles: justification of practices, optimisation of protection and individual dose limits. Art. 20 sets out those limits for occupationally exposed people, trainees and students, and for members of the public. It also addresses concerted exceptional exposure, accidental exposure and emergency exposure of the workers.
    - Art. 23 describes the role and duties of the Health Physics Department (HPD) that each licence holder of a facility or operator of a transport company must establish. Under the licensee's primary responsibility, the HPD is in charge of supervising the activities and organizing measures to ensure the protection of the population, the workers and the environment. Specific tasks to be performed by the HPD are listed in Art. 23.1.5. Experts in health physics control must be recognised by the FANC according to criteria and conditions set out in Art. 73.
    - Art. 24 to 26 deal with the medical surveillance of workers and with the requirements with respect to their training and obligations of the workers to comply with instructions and regulations.
    - Art. 27 to 32 deal with the general protection equipment and arrangements, including individual protection equipment, dosimetry and the use of warning signs.
    - Art. 33 to 37 deal with radioactive waste (solid, liquid and gaseous)
    - Art. 37 bis to 37quinquies deal with the access to nuclear facilities and with the protection of external workers when they are working in a radiation controlled area.
- **Chapter IV** - Dispositions related to legal entities that FANC can create in order to delegate some of its surveillance missions
    - Article 38.1 lists the surveillance missions that the FANC can delegate to Bel V. These missions include on-site surveillance and safety assessments of licensee's projects and activities. By the end of each year, a "control and safety assessment" plan is drawn up, that includes the foreseeable regular controls and safety assessments to be performed next year by Bel V. This plan is approved by the General Manager of the FANC and is send to the licensees in advance. The General Manager of Bel V has to be a recognized expert according to the specifications of article 73. Article 38 also includes provisions to avoid conflicts of interest and to ensure confidentiality of information.
    - The FANC is in charge of the surveillance over Bel V. A Management agreement between FANC and Bel V has to be concluded. Regular reporting is required, and Bel V must maintain a management system in line with international standards-. The FANC can perform audits on the working of Bel V.
    - The average hourly tariff of Bel V is fixed. This hourly tariff is adapted once each year to the consumer prices index in Belgium.
- **Chapters V and VI** – Medical applications
    - These chapters have been withdrawn from the GRR-2001 and replaced by the Royal decree of 13 February 2020 which deals with medical applications of ionising radiation and are not reported under this convention.
- **Chapter VII** – Transport
    - This chapter has been withdrawn from the GRR-2001 and replaced by the Royal Decree of 22 October 2017 concerning the transport of dangerous goods of class 7.
- **Chapter VIII** – Nuclear Propulsion
    - Construction of any ship or vehicle which is powered by nuclear energy is subject to prior authorisation by the King
    - Ship remaining in Belgian waters or passing through are subject to prior licensing

- **Chapter IX –** Bans and Authorisations deal with specific prohibitions or special licences for using ionising radiation (e.g. sterilisation of medical equipment)
- **Chapter X** – Exceptional Measures
    - Art. 66 deals with the measures against the loss or theft of radioactive substances.
    - Art. 67 deals with the measures relating to accidents, concerted exceptional exposures and accidental exposures.
    - Art. 68 deals with decontamination and,
    - Art. 69 deals with contaminated mortal remains.
- **Chapter XI** - Surveillance of the Territory, the Population and Emergency Planning
    - Article 70 deals with radioactivity monitoring of the territory, and of the doses received by the population, which is taken care of by the FANC.
    - Article 71 deals with the (radiological) monitoring of the population as a whole, the collection of all the data, including those from occupationally exposed workers.
    - Article 72 deals with the emergency response planning for nuclear risks and the information of the population.
    - Article 72bis deals with interventions in cases of lasting exposure.
    - Article 72ter deals with interventions in case of discovery of orphan sources.
- **Chapter XII** - **Recognition of Experts**, of Physicians and of Health Physics Organisations
    - Article 73 sets all the conditions for the recognition of experts in health physics control.
    - Article 74 deals with the Authorized Health Physics Organizations (RHPOs).
    - Article 75 deals with the recognition of doctors in charge of the medical surveillance of occupationally exposed workers.
- **Chapter XIII** – HASS Sources
    - This chapter has been added in 2006 as part of the transposition of Directive 2003/122/Euratom on the control of high-activity sealed radioactive sources and orphan sources

### II.C.4. The Royal Decree of 30 November 2011

The Royal Decree of 30 November 2011 on the Safety Requirements for Nuclear Installations (SRNI-2011) is the result of the WENRA-harmonisation activities with respect to regulation. It also ensures the transposition of the European Directive 2009/71/Euratom on nuclear safety. The SRNI-2011 is composed of several chapters so that it is possible to add specific chapters for specific installations. The following chapters are available:

- **Chapter 1- General Provisions** sets the scope of the Decree and defines terms.
    - The SRNI-2011 applies to nuclear facilities of Class I.
- **Chapter 2 – Generic Safety Requirements** is applicable to all nuclear facilities covered by the decree.
    - Section I – Nuclear Safety Management
    - The licensee shall formulate and communicate to all personnel a safety policy with primary importance to nuclear safety and including a commitment to monitor and to continuously improve nuclear safety (Art. 3)
    - Art. 3/1 and 3/2, added by the Royal Decree of 9 October 2018, introduces the Nuclear Safety Objective from article 8.a of the European Directive 2009/71/EURATOM, as modified by the Directive 2014/87/EURATOM. This Safety Objective is similar to the Vienna Declaration on Nuclear Safety. It also describes the Defence in Depth, in line with the European Directive 2009/71/EURATOM (as amended).
    - Art. 4 states that the organisational structure has to be documented and that nuclear safety management should follow a graded approach to ensure a safe operation of the facility by sufficiently qualified people. The human resources management must take into account the long-term objectives as well as retirement and other cutbacks.

- An integrated management system (Art. 5) giving priority to safety shall be established, implemented, assessed and improved on a continuous basis. This management system shall cover all the activities and processes which can have an impact on the nuclear safety of the facility, including the activities carried out by the subcontractors or suppliers. Complementary requirements about safety culture have been added by the Royal Decree of 9 October 2018.
- Art. 6 sets out the requirements with respect to training and formal qualification of the personnel.
  - Section II – Design
- Art. 7 sets the requirements related to the design basis of the facility. These requirements comprise a.o. the defence in depth concept, the identification of normal operating conditions, anticipated operational occurrences as well as accidents from postulated initiating events (internal and external), fail safe principle,… The design shall also include provisions for future decommissioning purposes.
- Art. 8 requires that a specific process for the classification and qualification of structures, systems and components is in place and that their design, fabrication and maintenance requirements are commensurate with their classification.
  - Section III – Operation
- Art. 9 sets the requirements related to operational limits and conditions. The operational limits and conditions form an integral part of the safety report and shall be reviewed and modified when needed. The limits shall be determined in a conservative manner. In case the operational limits and conditions cannot be complied with, suitable corrective measures shall be implemented and reported to the regulatory body.
- Art. 10 deals with ageing where both the ageing (physical and economic) as well as the ageing management programmes need to be addressed. The ageing management programme shall be reviewed at least during each periodic safety review.
- Art. 11 imposes the licensee to have an operational feedback process in place for collecting, analysing and documenting events that occur in his facility as well as in other similar facilities. This process shall also document the analysis methodologies, notification and distribution of relevant information as well as the process for continuous improvement.
- Art. 12 sets the principles, preparation and implementation of the maintenance-, test-, monitoring- and inspection programmes for structures, systems and components important to safety.
  - Section IV – Verification of Nuclear Safety
- A safety analysis report shall be prepared by the licensee during the licensing phase (Art. 13). The SAR reflects the installations and the activities that are carried out there. This safety report will serve as a basis for addressing the impact on nuclear safety due to modifications and will be updated on a regular basis, according to a specific procedure
- Art. 14 sets the requirements for the periodic safety reviews (PSRs). The main objective of the PSR is to perform a systematic assessment of the nuclear safety of the facility taking into account not only the ageing or modifications made to the facility, but also developments related to regulation and experience feedback. The PSR is to be carried out following a systematic and documented methodology. The PSR shall address 14 safety factors, as listed in the IAEA safety guide SSG-25 and in the WENRA SRLs 2014 publication. A summary report shall be transmitted to the regulatory body that includes the analysis for each safety topic as well as the safety improvement actions and the schedule for implementing these actions. It sets the frequency of the periodic safety reviews at a minimum of 10 years.
- Modifications shall be managed as to guarantee as a minimum the same level of safety as before the modification. Art. 15 details what changes are to be considered as a modification and sets some additional requirements with respect to the safety assessment and the execution of the modification.

- Section V – Preparation for Emergencies
  - Art. 16 sets the requirements related to the internal emergency plan that the licensee has to implement. It specifies the objectives, the preparation and organisational issues. It also states that adequate emergency infrastructure needs to be provided and that the internal emergency plan needs to be exercised at least once per year.
  - Art. 17 sets the requirements for the protection against internal fires. The design basis should take into account the main principles of fire protection and this has to be justified via a fire hazard analysis. Fire detection and alarm systems need to be in place as well as passive or active fire extinguishing systems and those systems will be regularly inspected and well maintained.
- Section VI- Decommissioning [update of August 2015]
  - Art. 17/1 is related to the notification of cessation of nuclear activities. It also lists the documents and information that has to be send to the FANC
  - Art. 17/2 is related to safety measures and justification of deferred dismantling
  - Art. 17/3 sets out requirements about maintaining and adapting the SSCs and the OLCs during the dismantling of the installations
  - Art. 17/4 is related to the preliminary qualification of new dismantling techniques
  - Art. 17/5 sets out requirements for radioactive waste from dismantling and for (on-site) waste storage
  - Art 17/6 sets outs requirements about the management of documents and inventories
  - Art 17/7 requires an experience feedback management process (form Belgium and abroad)
  - Art. 17/8 sets out requirements about the update of surveillance and maintenance programmes
  - Art. 17/9 sets out requirements about the update of the on-site emergency plan
  - Art 17/10 gives the tables of content of a dismantling safety report
  - Art 17/11 deals with Periodic Safety Reviews during the dismantling phase of the installations
  - Art 17/12 deals with the radiological characterisation of the final state and measures to be taken if this state cannot be reached. It also requires the licensee to establish a final dismantling report.

- **Chapter 3** sets the specific Safety Requirements for Nuclear Power Plants
  - Section I – Nuclear Safety Management
    - Art. 18 imposes an organisational entity within the licensee's organisation that is responsible for independent assessments.
    - Art. 19 stipulates specific requirements for operators working in the control room, such as an initial and yearly refresher training on a representative simulator and their authorization.
  - Section II – Design
    - Art. 20 deals with the design basis of existing reactors imposing a defence in depth approach to ensure the basic safety functions: control of reactivity, heat removal and confinement of radioactive materials. It specifies some internal and external events that have to be taken into account. The safety demonstration shall apply sufficient conservatism (e.g. use the most penalising single failure). The design of the safety functions must be such that an operator action is not required for the first 30 minutes. Instrumentation systems shall be used to measure the main parameters. A fall-back control room shall be provided, physically and electrically separated from the main control room. The safety systems shall provide sufficient redundancy and diversity to guarantee that no single failure will cause the loss of the safety system and that the shutdown of one component or one line will not cause the loss of minimum required redundancy. Emergency power supplies have to be available, capable of providing the necessary power.
    - Art. 21 deals with the design extension conditions (DEC), i.e. beyond design basis accidents and severe accidents (involving core damage). The selection process of DEC events is described. Methodology and objective for analysis of DEC accidents

is described. Specific instrumentation shall be provided for managing those accidents in both the main control room and the fall back control room. For specified DEC-A accident, the objective is to maintain the fundamental safety functions. For specified design extension (DEC-B) accidents, containment must be maintained as much as possible.

- Art 21/1 relates to natural hazards. Selected design basis natural hazards must have a return frequency lower than 10-4/year, for earthquakes, the considered horizontal acceleration for earthquakes is not less than 0,1g. A protection concept against natural hazards has to be developed. Natural hazards for design extension conditions (DEC) shall be identified and adequately analysed;
- Art. 22 states that interfaces shall be present to prevent that a failure of a structure, system or component of one class induces a failure on a system of a higher class.
- Art. 22/1 is related to the review of the design. A periodic and other appropriate review of the design is requested. When a review of the design is needed, the licensee has 2 months to introduce an action plan.
  - Section III – Operation
- Art. 23 imposes operational limits and conditions to cover all operational states of the nuclear power plants and that the personnel of the control room and the supervising personnel has sufficient knowledge of the limits and their technical basis.
- The licensee shall develop an ageing management programme (Art. 24) that takes into account a.o. the operational conditions and load cycles. The main systems, structures and components shall be monitored to detect effects due to ageing in a timely manner to allow for preventive or corrective measures.
- Art. 26 defines the minimal requirements for the leak tests of the reactor primary circuit and to verify the integrity of the containment.
- The licensee shall complete a set of accident management procedures including severe accidents (art. 27). Accident management procedures are to be used during accident conditions when there is no damage to the core and their main objective is to restore safe conditions, restore or compensate the loss of safety functions and to prevent or delay core damage. In severe accident conditions, or when there is damage to the core, the severe accident management procedures are to be used, with the aim to limit further core damage, preserve as much as possible the integrity of the vessel, limit the release of radioactive substances and to restore controlled conditions. The accident management procedures shall be developed on the basis of realistic scenarios, using deterministic and probabilistic analysis techniques. They shall be available, easy to identify and to use, and the transition from accident management procedures to severe accident management guidelines is clearly identified. They shall be inspected and validated, as well as updated periodically. Personnel that could be concerned by those procedures shall receive adequate initial training and refresher training.
  - Section IV – Verification of Nuclear Safety
- Art. 28 defines the minimal content (16 chapters) of the safety analysis report.
- A level 1 and level 2 probabilistic safety assessment (PSA) shall be performed for each reactor and for each operating mode (Art. 29). For level 2 the PSA could use however a representative unit. The PSA shall use realistic assumptions and shall take into account aspects such as internal fire hazard, external events, human interventions and human errors. Level 1 PSA shall include a sensitivity and uncertainty analysis, level 2 PSA at least a sensitivity analysis. The PSA results shall be used during the design and operation of the power plant e.g. as a decision making aid or to check the adequacy of modifications.
- Art. 30 has been withdrawn and transferred to article 14.
  - Section V – Preparation for Emergencies
- A coordination centre for managing on-site events shall provide communication equipment to the control room, the fall-back control room and with all major

locations on the site, as well as with on-site and off-site emergency organisations (Art. 31).
    - Art. 32 specifies specific requirements for protection against internal fires. These requirements include e.g. a fire PSA and the maintenance of the safety function during and after a fire occurrence.
- **Chapter 4** has been included in May 2018 and contains the WENRA reference levels related to the safety of radioactive waste and spent fuel storage and treatment.
- **Chapter 5** contains some final provisions and transitional arrangements

### II.C.5. The Royal Decree of 1 March 2018 on Emergency Planning

The law of 15 May 2007 defines the notion of Civil Protection and describes the roles and missions of the different entities involved. The Royal Decree of 22 May 2019 organises the emergency and intervention plans. The Royal Decree of 1 March 2018 lays down the nuclear and radiological emergency response plan and the tasks of each of the parties involved.

According to article 16 of the SRNI-2011, it is mandatory for nuclear installation operators to set up an internal emergency plan and to get it approved by the Regulatory Body. This plan shall be tested regularly to address possible accidents. The intervention of the Authorities outside the affected installations takes place under the authority of the Minister of Home Affairs, who supervises the Civil Protection.

The nuclear and radiological emergency plan for the Belgian territory aims at co-ordinating the protective actions for the population, the (emergency) workers and the environment in the event of a nuclear accident or any other radiological emergency situation that could lead to an exposure of the population above the routine limit (1 mSv/y) or to a significant contamination of the environment.

This document will serve as a guide for the protective actions to be implemented, should a radiological emergency occur. It establishes the tasks that the various departments and organisations would have to accomplish if the case arises, each within their legal and regulatory competences.

The provisions of the emergency plan apply in the cases where there is a risk of significant radiological exposures to the population in any of the following ways:

- external irradiation due to air contamination and/or deposited radioactive substances;
- internal irradiation by inhalation of contaminated air and/or ingestion of contaminated water or food.

The Nuclear and Radiological Emergency Plan for the Belgian territory (NEP) is mainly designed for emergency situations in the major Belgian nuclear installations: the nuclear power plants of Tihange and Doel, the Nuclear Research Centre in Mol, the Institute for Radioelements in Fleurus, the waste treatment and storage installations of Belgoprocess in Dessel and the European Joint Research centre in Geel. This plan is also activated for other emergency situations, which can occur during transport on the Belgian territory (accident during the transport of nuclear material from the nuclear fuel cycle or waste from fuel reprocessing) or radiological emergency resulting from a terrorist attack or a malevolent act.

The NEP also addresses events occurring in neighbouring nuclear installations located within a distance of 100 km from the border (i.e. Chooz, Gravelines and Cattenom NPPs in France and Borssele NPP in The Netherlands).

In case of an emergency, the off-site operations are directed by the National Crisis Centre, under the authority of the Minister of Home Affairs. The implementation of the actions decided at the federal level and the management of the intervention teams are under the leadership of the Governor of the Province concerned.

The plan describes the overall organisation. It has to be completed by concrete internal plans based on the intervention, at various intervention levels, of:

- the provincial authorities;
- the municipal authorities;
- all the intervening institutions.

### II.C.6. The Law of 31 January 2003 on the Phase-out of Nuclear Energy

According to article 4 of the law of 31 January 2003 on nuclear phase out, the operation of the Belgian NPPs was initially limited to 40 years. This law has been amended two times, on July 4th, 2012 and on June 28th, 2015 respectively to allow a continued operation for 10 more years for Doel 1, Doel 2 and Tihange 1.

The construction of new NPPs is forbidden (Article 3) in Belgium.

A possibility of amendment to this law to allow a lifetime extension for the two most recent unit (Doel 4 – Tihange 3) has been agreed by the federal government in March 2022. The law has still to be modified.

### II.C.7. The Licensing regime for nuclear installations

Since 2001, the new licensing process for facilities of class I comprises two phases, each one ending with a Royal Decree.

Nuclear facilities are licensed according to article 6 of GRR-2001. This licensing process has been updated for the last time on May 29th 2020 to complete the transposition of the European Directive 2014/52/EU amending Directive 2011/92/EU *on the assessment of the effects of certain public and private projects on the environment.* The license application contains four main parts:

- The first part consists mainly of administrative information, defining amongst others responsibilities, names and legal status of the applicant, …
- The second part of the application consists of an environmental impact assessment report, in accordance with the European directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment (as amended by European directive 2014/52/EU).
- The third part is the "waste and decommissioning files" giving the expected quantities of waste and their foreseen management, including those related to the dismantling, and preliminary plans for the future decommissioning.
- The last part consists of a preliminary safety analysis report containing preliminary data in relation with the SRNI-2011 and GRR-2001 requirements;

Belgium is a federal state composed of three Regions being legally competent for environmental protection on their territory (radiological aspects excluded) and thus also for the granting of related environmental licences. To coordinate the process and ensure the coherency of the application files, cooperation exists between the FANC and the competent regional authorities.

The licence application is examined by the FANC. The advice of the Belgian Waste Management Agency (ONDRAF/NIRAS) is requested for the waste and future dismantling of the facility aspects. The file is then presented for advice to the Scientific Council of the FANC. A mandatory international consultation (application of Article 37 of the Euratom Treaty on the trans-boundary impact) and/or a voluntary consultation of the European Commission may take place. Following the advice of the Scientific Council, the file is submitted to a public enquiry and to the involved municipal authorities for advice, and then to the executive of the involved provinces. The completed file is sent back to the Scientific Council for final advice. The Scientific council can propose particular conditions to be attached to the licence, related to the commissioning of the installations or in view of ensuring the safety and the wholesomeness of the future installation. This construction and operating licence allows the applicant to build the installations in conformity with the licence.

The second phase addresses the confirmation of the construction and operation licence. The licensee's Health physics department is primarily in charge of the acceptance of the installations. Bel V acting on behalf of the FANC verifies the acceptance of the installations before the start up. After a fully favourable acceptance, the FANC can propose to the King a confirmation decree allowing operation of the facility.

Partial confirmation decrees are possible, each based on a fully favourable acceptance report. The confirmation decree can also modify or complete the conditions attached to the initial licence.

Figure 5 below shows the licensing process for the Class I nuclear installations.

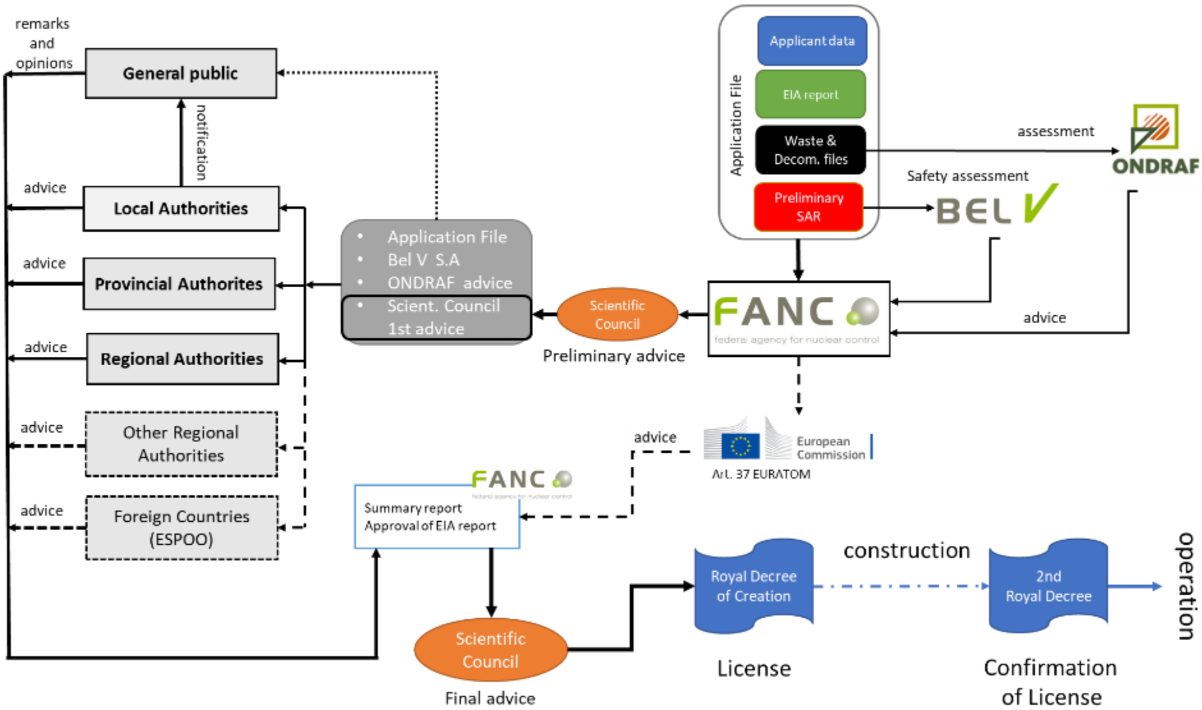


Figure 5 : Licensing process for Class I Facilities

*Appeal against the FANC decisions and authorisation decrees.*

The construction and operation licence of Class I facilities is granted by Royal Decree on the proposal of the Minister of Home Affairs. Like any decree, anybody can introduce an action for annulment of the decree, during 60 days after the publication of the decree.

The body in charge of treating the appeal against the decree is the "Council of State". If the situation is urgent or if it is needed, on request of the applicant, the council of state can suspend the decree immediately.

*Modification of the licence:*

The licence and the conditions attached to the licence can be modified in two ways:

- At the initiative of the operator. According to article 12 of GRR-2001, any project to modify the facility must be notified to the FANC. If the proposed modification has a significant impact, the FANC can decide whether the licence or the conditions attached to it, have to be amended.
- At any moment, at the initiative of the FANC or at the initiative of its Scientific Council, according to article 13 of GRR-2001.

In these cases, the process for modification of the licence is similar to the initial licencing process. Derogations from administrative formalities are possible, but advice of the Scientific Council is always mandatory.

## II.C.8. Conclusions regarding the provisions of Article 7

By becoming fully operational in September 2001, the FANC has taken over the tasks aiming at the enforcement of the Law of 15 April 1994 and its implementing decrees, in view of the radiological protection of the public, the workers and the environment.

In Belgium, there is a legal and regulatory framework for safety of nuclear installations for almost 50 years.

The laws and Royal Decrees are regularly updated, and completed or, if necessary, amended (for instance to take into account the Euratom Directives, the international treaties signed by Belgium, etc.).

The legislative and regulatory framework comprises:

1) a set of laws and regulations (cf. description above), including safety requirements based on the WENRA reference levels (which are based on the IAEA safety standards),
2) a licensing regime for nuclear facilities and activities, and the prohibition to operate an installation without a licence (cf. GRR-2001 and, among others, its articles 5, 6, 15, 16, 79,
3) a regulatory inspection and assessment system of the nuclear facilities and activities, to verify compliance with the regulatory provisions and conditions attached to the licence (cf. GRR-2001, among other its Articles 6, 12, 13, 15, 16, 23, 78).
4) Measures intended to enforce compliance with the relevant regulatory provisions and the conditions attached to the licence, including the suspension, amendment or withdrawal of licences (cf. GRR-2001, among other its Articles 5, 12, 13, 16) as elaborated in section II.D.2.

## II.D. Article 8. Regulatory Body

1) Each Contracting Party shall establish or designate a regulatory body entrusted with the implementation of the legislative and regulatory framework referred to in Article 7, and provided with adequate authority, competence and financial and human resources to fulfil its assigned responsibilities.
2) Each Contracting Party shall take the appropriate steps to ensure an effective separation between the functions of the regulatory body and those of any other body or organisation concerned with the promotion or utilisation of nuclear energy.

Since 1 September 2001 the supervision of nuclear activities is the responsibility of the Federal Agency for Nuclear Control (FANC), which constitutes the Safety Authority. This mission has been entrusted to the FANC by the Law of 15 April 1994. According to articles 14ter of this law (as amended by the law of 7 May 2017), the FANC can create legal entities to assist it in the execution of its missions. The FANC has made use of this provision and created Bel V in September 2007, a subsidiary with the statute of a so-called 'foundation' as defined in Belgian law. The FANC delegates several regulatory tasks to Bel V, a.o. on site routine inspections – albeit without associated enforcement powers – and independent safety assessments. Only Class I facilities (including NPPs and Research Reactors) and some higher risk Class II installations – the so called Class IIA – are inspected by Bel V.

It is through the association of the FANC on one side, and Bel V on the other that the function of regulatory body as stipulated in article 8, is ensured.

A control structure with 3 levels is in place: first by the licensee's Health Physics Department (HPD) - see above Section II.C.2, chapter IV of the law of 15 April 1994, then by Bel V which performs by delegation of the FANC a number of inspections and safety assessments, and finally by the FANC, who is the Safety Authority. This structure is illustrated in Figure 6:

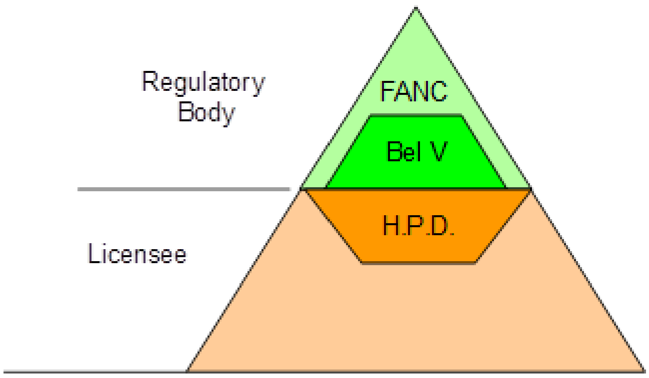


Figure 6 : 3-level control structure

The descriptions in this article focus on the tasks relating to the installations covered by the National Report, and consequently are not an exhaustive overview of all the regulatory functions assumed by various organisations.

### II.D.1. Mandate and Function of the Regulatory Body

Mandate and functions of the regulatory body are defined in the Law of 15 April 1994.

The Belgian regulatory body fulfils regulatory functions as described in the IAEA Safety Guide GSR part1:

The regulatory function "*development of regulations and guides*" is allocated exclusively to the FANC. The FANC has the duty to make regulation proposal to the King (i.e. the Government). Since 2017, the FANC can also issue binding technical regulations, of a non-policy nature and in cases foreseen in a Royal Decree. Both FANC and Bel V can also issue technical guidances but these guidances are not binding.

The regulatory function "*licensing*" is ensured by the FANC. For the nuclear installations covered by this Convention, the King (the Government) is the competent authority to issue licences. The FANC investigates the licence applications and proposes the licences and conditions attached to it.

The regulatory function "*safety assessment*" is allocated to the FANC, which delegates, for the installations covered by this Convention, parts of this function to Bel V.

The regulatory function "*Inspection*" is allocated to the FANC, which delegates, for the installations covered by this Convention, parts of this function to Bel V.

The regulatory function "*Enforcement*" is allocated exclusively to the FANC (see next section II.D.2).

Other additional functions are allocated to the FANC, with possible support from Bel V:

- radiological surveillance of the Belgian territory,
- participation to the national nuclear emergency planning and response,
- communication with the public and political authorities

Security matters are also within the mission of the FANC and are entrusted to its department "transport and security".

### a) Delegation of regulatory functions to Bel V

The list of regulatory tasks that can be delegated by the FANC to Bel V is fixed in article 38.1 of the GRR-2001. These tasks consist of:

- Regular on-site inspections on "Class I" facilities, for the permanent supervision of the good performance (including approbation of some decisions) of the licensee's Health Physics Department. This permanent supervision in practice consists of systematic, thematic and specific inspections devoted to defined subjects (operation, periodic tests, chemical control, radiological protection …) and specific items follow-up inspections, examination of modifications and incident analysis. An inspection report is written following each field inspection, which is also sent to the FANC.
- Safety assessments of licence applications and of acceptance of new installations and of modifications
- Safety assessments and on-site inspections of other licensee's projects (e.g. PSR, Licensee's action plans)
- Safety assessments of the files and safety analyses related to the SRNI-2011 that are submitted by the licensee.

The Board of Administrators of the FANC formally delegated those tasks to Bel V on March 1st, 2019.

A 6-year integrated inspection strategy is developed jointly by the FANC and Bel V. An annual programme for inspections is derived from this strategy and is communicated yearly to the licensees. A revision of this strategy is possible each year, to take into account experience feedback from the previous years.

The annual inspection and safety assessment programme of Bel V is approved by the FANC.

Bel V informs the FANC on its findings on a regular basis. Any situation that may have an impact on the public, the workers or the environment is immediately communicated to the FANC.

Each year, Bel V makes an evaluation of the safety of the installations it inspects and draws up the lessons learnt.

The FANC has several means to monitor the good performance of Bel V, see section II.C.2 (Chapter III of the Law of 15 April 1994) and II.C.3 (Article 38 of GRR-2001):

### *b) Collaboration FANC-Bel V*

A collaboration agreement between FANC and Bel V is established, and covers a.o. the following areas:

(1) Support to the FANC activities

Bel V supports the FANC for technical aspects related to public communication, including INES evaluations.

(2) Advice on regulation proposals

Bel V collaborates with the FANC to give advice on new regulation proposals, on the application of regulations, and on regulation gaps and shortcomings.

(3) Cooperation in international activities.

Bel V and FANC activities are coordinated in a structured manner in the field of international multilateral and bilateral activities and representations, in particular in the frame of WENRA, the Convention on Nuclear Safety and the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.

(4) Research and Development

A coordination is established between the FANC and Bel V for the research and development activities, in order to ensure complementarity, search synergies and ensure circulation of results.

(5) Knowledge management, improvement and development of knowledge.

A collaboration is established in the field of knowledge management.

(6) Emergency Preparedness and Response

In case of an emergency, Bel V collaborates with the FANC for technical and radiological evaluations of the emergency in the evaluation cell (CELEVAL).

Additionally, an internal crisis centre is set up and maintained by the FANC. The FANC and Bel V are jointly responsible for the setting up of the procedures, for the staffing and for allocation of resources during emergency situations.

(7) Finally, Bel V assists the FANC in the review of security plans or in the field of cybersecurity on request by the FANC.

## II.D.2. Enforcement of applicable regulations and of the terms of the licences

The enforcement power of regulatory requirements is given to the FANC by the legislation. The enforcement tools and measures are provided in the following legal documents:

- the Law of 15 April 1994;
- the GRR-2001;
- the Royal Decrees of December 20, 2007 related to administrative fines

Various coercive measures are used to reinforce FANC's orders. Two types of sanctions are foreseen in the Law of 15 April 1994 (articles 50 to 64): legal penalties (requiring a legal procedure by the Court) or administrative fines (nevertheless requiring an information to and a decision by the Public Prosecutor).

The FANC nuclear inspectors are nominated by Royal Decree. They have enforcement powers; they can also intervene on the request of Bel V inspectors. The FANC inspectors can also take any measure they consider necessary to reduce or eliminate hazards for workers, the public and the environment. These measures can include warnings, requests for corrective actions with a delay not exceeding 6 months (article 9 of the Law of 15 April 1994).

The choice of the enforcement measures is based primarily on the safety significance of the infraction or situation where corrective measure are required, applying the principle of graded approach. The enforcement policy is presented in the FANC management system.

The FANC nuclear inspectors have to take any necessary and urgent measures to avoid or eliminate a risk. Examples of those measures are:

- Impose technical modifications to the installation (additional shielding, installation of additional detection device);

- Proceed to the seizure or evacuation of radioactive sources, contaminated material or devices that present ionising radiation;
- Impose an administrative modification (as far as procedures, instructions or operating modes are concerned) or an organisational modification (obligation of additional personnel in relation to security and/or radiological protection);

In extreme cases and if a practice may result in a specific danger (e.g. detriment of health), the nuclear inspector has the power to interrupt the activity.

Bel V is delegated by the FANC to permanently supervise whether the operator complies with the regulations in force and with the conditions attached to the licence, but only has the power to make recommendations. Should the operator violate the conditions set in the licence and fail to correct that situation, or should the operation evolve towards an unsafe situation, this would be referred to the FANC who will proceed to enforcement measures.

Another possibility to strengthen safety is foreseen in article 13 of the GRR-2001: The Safety Authority (The Scientific Council or the FANC services in charge of the supervision) can, on its own initiative and at any moment, propose additional conditions to be attached to the licence with the aim of improving safety.

Finally, if the licensee does not comply with the regulations or with its licence, a process described in article 16 of GRR-2001 allows the FANC to propose to the King the suspension or the withdrawal of the licence, after advice of the Scientific Council for Class I nuclear facilities.

### II.D.3. Structure of the Regulatory Body, Financial and Human Resources

#### *a) The FANC*

The law of 15 April 1994 defines the statute, the missions of the FANC, as well as some requirements about its internal administration.

The Federal Agency for Nuclear Control (the FANC) is an autonomous public institution with legal personality.

The FANC is institutionally and financially independent. The FANC is led by a non-executive 14-headed Board of Administrators. The members of the Board of Administrators are appointed by Royal Decree, on the proposal of the Council of Ministers. In order to guarantee the independence of these board members, their mandate is incompatible with certain other responsibilities within the nuclear sector and within the public sector, as listed in the law of 15 April 1994. The governance charter of the Board of Administrators is published on the FANC website. The board, which meets about six times a year, is in charge of:

- the overall long-term and short-term strategy, with the approval of the medium-term and annual operational plan;
- the conditions of recruitment and employment of the FANC staff;
- the financing of the FANC.

The Board approves the FANC annual budget and staffing levels.

The FANC is supervised by the Federal Minister of Home Affairs via a government Commissioner who attends the meetings of the Board of Administrators. The Board delegates the management of the FANC to the General Manager (Director-General) who is appointed by Royal Decree for a term of 6 years.

The FANC, as a public body, reports to Parliament through the Minister of Home Affairs, thus ensuring legal independence with other government agencies and ministries that promote the use of ionizing radiation for a variety of purposes.

In order to perform its tasks, the FANC is assisted by a Scientific Council [established by article 37 of the law of 15 April 1994]; the composition and the competences of this Council are fixed by Royal Decree. The Council consists of high-level experts within the field of nuclear energy, nuclear safety and radiological protection.

The FANC exercises its authority with regard to the nuclear operators through one-sided administrative legal acts (the consent of the involved operators is not required) such as the granting, refusal, modification, suspension and withdrawal of licences, authorisations, recognitions or approvals. It organises inspections to verify the compliance with the conditions attached to the licences, recognitions and approvals. The FANC can claim any document in whatever form, from the facilities and companies under its supervision.

The operation of the FANC is entirely and directly financed by the companies, organisations or persons to whom it renders services. In practice this is done through non-recurrent fees and annual taxes at the expense of the applicants or holders of licences or recognitions. The amount of the taxes is set in article 30bis of the law of 15 April 1994, the amount of the fees is fixed by Royal Decree, as foreseen in article 30quater of the law of 15 April 1994. The receipts and expenditures of the FANC have to be in equilibrium.

The above-mentioned statute confers to the FANC the indispensable independence to enable it to impartially exercise its responsibilities as a regulator of the nuclear activities - as prescribed in art. 8 of the Convention on Nuclear Safety.

More information is available on the website: www.fanc.fgov.be

Below the General Manager, the FANC is organized in four departments: the Department "Facilities and Waste", the Department "Security and transport", the Department "Health and environment" and the Department "Support".

The FANC organisational chart is shown in Figure 7 below:

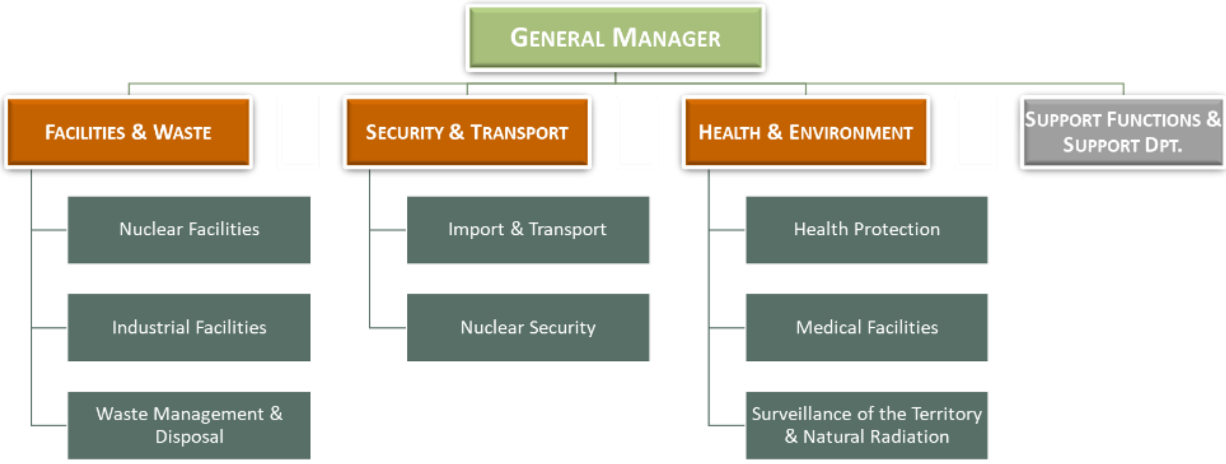


Figure 7 : Organisational chart of FANC

The missions of the department `Facilities & Waste' relate to nuclear and industrial facilities, management of radioactive waste, and recognition of qualified experts in Health Physics.

- The first mission includes the inventory, the analysis and the evaluation of licence applications. This mission consists of ensuring that ionizing radiation can be used safely and that a licence can be granted.
- The second mission involves the control, the inspections and the investigations that ensure that the activities carried out comply with the licence and its conditions, and, in a more general way, with the regulations in force. In addition, the department must also track down any illegal activity carried out without authorization. Synergy between these two missions mainly aims at improving: 1) the safety in general, and 2) the protection of the workers, the public and the environment against the hazards of ionizing radiation.
- The third mission includes the contribution to a regulatory framework for the disposal of radioactive waste of different categories, as well as the licensing of disposal facilities.
- Finally, the department makes regulation proposals in its field of activities and develops the related technical regulation and guidance

The department `Security & Transport' is responsible for the physical protection of nuclear material, and for the regulation of transport, import, transit and export of radioactive material. Here also, the licensing activity as well as the surveillance of a specific activity have been integrated in the same pillar, with the objective of optimizing the exchange of information and setting up a more effective control policy.

The department `Health & Environment' is in charge of the activities relating to man and his environment (including the radiological monitoring network TELERAD). This operational entity is directed towards the protection of the public, the workers and the environment in all fields, namely the medical and veterinary applications, the natural radiation sources, the radiological surveillance of the territory, the national nuclear emergency plan and the clean-up/restoration of contaminated sites.

The department `Support' is in charge of the activities at the organizational level and activities involving several departments (horizontal activities):

- human resources management at the FANC level;
- follow-up of FANC projects;
- coordination of international activities;
- finances and Information Technology.

At present, the personnel of the FANC is composed of about 150 persons. This figure is stable for around 10 years. More than 60 % of them are university graduates in different fields of science (physics, chemistry, biology, medicine), engineering, law, economics, social sciences and communication.

### b) The Management system of the FANC

After the IRRS-mission of 2013, the FANC started to develop a management system with the aim to comply with IAEA Safety Requirements, GS-R-3 (now GSR part 2).

This resulted in a new mapping of the management system and integrating policies, intention plans (strategy, operational objectives), and operational and support processes.

The FANC management system consists of:

- a governance document "Management *system policy*" which describes how missions and responsibilities entrusted to the FANC by the Law of 15 April 1994 are discharged through the different FANC departments;
- the "*Strategic plan*" which is established on a timeframe of 9 years. This strategic plan is translated into 3 years operational plans and finally in an annual operational plan including the assigned resources;
- *FANC policies*, developed in accordance with the FANC missions and the Strategic plan and validated by the senior management. They have committed themselves to follow the quality policy requirements and request every FANC employee to do the same.
- *procedures*, described in the FANC management system are derived from the legislation and the FANC policies.

The processes include licensing, inspections, incident and accident management, environmental surveillance, security, enforcement, development of regulations and guides, international relations, projects and development, human and financial resource management, communication, ICT management, legal affairs, and record and information management.

The concept of continuous improvement is being applied to the FANC organization, to the management system, and to the individual workers at FANC.

An annual Management Review is conducted on the quality aspects, including results of internal/external quality audits, corrective/preventive actions, non-conformities, complaints, and customer satisfaction surveys and financial aspects.

### c) Foundation Bel V: Overall organisation

Bel V is a non-profit 'foundation', created by the FANC.

Bel V, by delegation of FANC, must perform on-site inspections with inspectors that have to be recognised experts according to article 73 of the GRR-2001, ensuring the inspector meets the education and training requirements and has at least three years of experience in the nuclear field. Bel V's personnel training budget amounts to about 10 % of its overall budget in man-hours.

In view of ISO-certification, a process oriented organisation has been implemented. Among these processes, the most important ones from a safety point of view are: to manage projects/missions (manage safety assessment projects and inspection projects), to perform inspections, to provide and to manage expert services (perform safety assessment activities), to manage expertise and technical quality, to manage and to develop human resources. These processes are managed by process managers who are accountable for the realisation of goals and the quality of the activities performed in the process they are in charge of.

Bel V's technical personnel is composed of about 65 full-time equivalent university graduates (engineers and scientists), and recruitment is in line with the foreseeable workload. The workload consists of a more or less constant portion related to inspection of installations, and a more variable load in time related to the progress of the licensee's projects and the number of safety assessments to be performed, and also to the assessment of incidents or specific safety issues in the installations in Belgium or abroad.

### *d) Bel V: Technical Activities*

Bel V's technical staff, regardless of which main process they belong to, is attached to "Technical Responsibility Centres" (TRC), "horizontal" cells in charge of exercising nuclear safety and radiation protection expertise and of maintaining the knowledge in the various technical specialities.

As of 14 April 2008, Bel V's technical staff has carried out the technical activities within the operational processes as described above.

The management of all TRCs is performed within the process "Provide and manage expert services", managed by a process manager, in order to give it better support and have a harmonized approach.

The process "**Perform inspections during operation**" is in charge of inspections in all nuclear facilities supervised by Bel V. The activities performed in this process include also inspections in installations other than nuclear power plants, namely other class I facilities, as well in some high-risk Class II facilities (so-called Class IIA). This process includes Bel V activities in the frame of its participation in the national emergency plan. The "Operating Experience Feedback Committee" belongs also to this process.

The process also includes the Bel V activities related to its participation in the national emergency plan at the level of the evaluation cell (see article 16, section II.L.2). It also participates in the emergency plan exercises related to the Belgian nuclear installations (nuclear power plants and other facilities), as well as in the exercises of foreign nuclear power plants located near the Belgian border, through bilateral or international collaborations. The follow-up of all national and international projects linked to the operation of the installations is performed in the framework of the process "**Technical Management of the projects/missions**".

At the national level, examples have been the increase of the length of the cycles and the higher burn-ups, the power increase and the replacement of steam generators, the periodic safety reviews, the European "Stress Tests", the long term operation of NPPs, the pre-licensing process of the MYRRHA Accelerator Driven System, the pre-licensing process of new on-site interim spent fuel storage facilities for the Doel and Tihange sites, safety assessment of a waste disposal facility.

At the international level, the co-operation with the Safety Authorities of several countries outside the European Union (bilateral aid or INSC contracts of the European Commission) is continued.

In the frame of the periodic safety reviews, Bel V follows the evolution of the safety standards in the world (USA, Member States of the European Union, IAEA…) and examines with the licensees which new standards should be followed.

Safety assessment is performed in the framework of the process "**Provide and manage expert services**". It covers support to inspection activities, the analysis of significant modifications, and analysis having a more general character: generic studies valid for all nuclear power plants, probabilistic safety assessment developed specifically for each unit but where the analysis methodologies must be identical, applications of these probabilistic studies in particular to the analysis of operational events, severe accident management, safety requirements for future reactors, safety analysis for the disposal of radioactive waste.

Research and Development activities in which Bel V participates (international projects like research and development activities within programmes financed by the European Commission, bilateral and own developments in Bel V) are managed in the framework of the process "**Management of expertise and technical quality**".

Alongside its own experts, Bel V calls only very exceptionally on services from outside specialists (universities, research centres): on the one hand these should not have worked in the past on behalf of the operator on the subject, and, on the other hand, full definition of the scope, framework and precise objectives of the task or studies that would be subcontracted represents a non-negligible part of the overall effort and time that can be devoted to the job. Examples of Bel V's calling on outside expertise concerns the evaluation of neutron-ageing of the aluminium reactor vessel of the BR2 reactor or the reactor pressure vessel flaw issue of Doel 3 and Tihange 2 reactors or the recent concrete problems in the bunkered steam exhaust rooms of several nuclear power plants.

The organisation chart of Bel V is given in Figure 8 below:

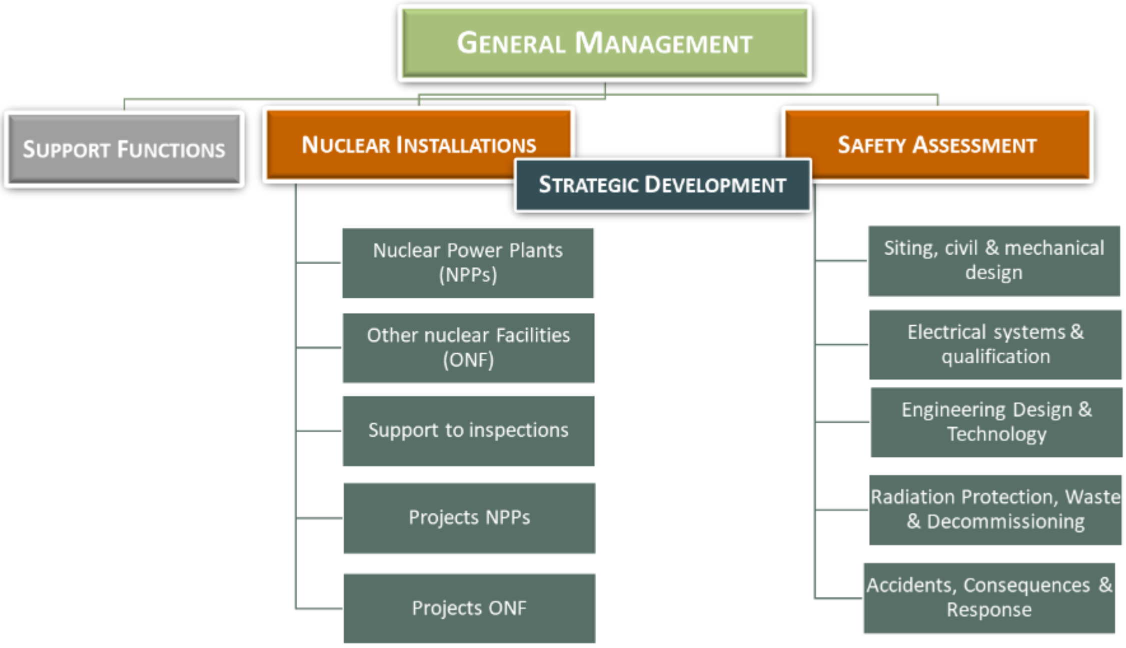


Figure 8 : Organisational Chart of Bel V

#### *e) Funding of Bel V*

Bel V is a non-profit organisation. It is funded by the licensee, for the on-site controls and safety assessments it performs as foreseen in the approved annual inspection and safety assessment programme, on the basis of a pre-defined average hourly tariff. This tariff has been fixed in article 38 of the GRR-2001, as modified by the Royal Decree of 6 December 2018.

Due to Bel V being a non-profit organisation, its financial resources are used for the payment of its personnel and related costs, for the participation in national or international working groups, for personnel training, for its research and development activities and for the maintenance of technical and regulatory documentation.

### II.D.4. Position of the Regulatory Body in the Governmental Structure

The Safety Authority (FANC) is a public interest body with a large independence that reports to its supervising minister, the Minister of Home Affairs.

The FANC has the duty to communicate with the public. Therefore, they answer for instance any questions and requests for information received from the Government, members of Parliament or from others.

The FANC annually presents its report of activities to the Parliament.

Bel V is a non-profit 'foundation' created by the FANC in accordance with articles 14bis and 14ter of the Law of 15 April 1994. Bel V is a 100% subsidiary of the FANC. The majority of the members of the board of Administrators of Bel V are also members of the board of Administrators of the FANC.

### II.D.5. Relations between the regulatory body and the organisations in charge of nuclear energy promotion and use

In Belgium the nuclear power plants are operated by a private operator. It promotes the use of nuclear energy, as does the sector organisation "Nuclear Forum", member of Foratom. The Regulatory Body (FANC and Bel V) plays no part in nuclear energy promotion.

Public organisations that operate nuclear installations or that deal with waste management, such as the nuclear research centre SCK CEN in Mol, or the Belgian Agency for Radioactive Waste and Enriched

Fissile Materials (ONDRAF/NIRAS) report to the Ministry of Economic Affairs and to the Ministry of Energy. As mentioned above, the Safety Authority (the FANC) reports to the Minister of Home Affairs.

However, the FANC has the mission to "stimulate and co-ordinate research and development activities". It establishes privileged relationships with the public organisations working in the nuclear field, with the scientific research circles and with the international organisations involved." (Art. 23 of the law of April 1994).

## II.D.6. International relations

International representations and participations have been optimized between FANC and Bel V, regular information exchange between FANC and Bel V take place, documentation/feedback is systematically shared and common positions are defined.

Belgium signed the main international conventions dealing with nuclear safety and is actively represented in numerous organizations and cooperation programmes.

### *a) Cooperation at international organisations level*

Belgium is a contracting party to:

- the Convention on Nuclear Safety;
- the Joint convention on the safety of spent fuel management and on the safety of radioactive waste management;
- the Convention on assistance in the case of a nuclear accident or radiological emergency;
- the Paris convention on nuclear third party liability and the Brussels supplementary convention, and subsequent amendments;
- the Convention on early notification of a nuclear accident;
- the European ECURIE system;
- the Convention on physical protection of nuclear material.
- International Convention for the Suppression of Acts of Nuclear Terrorism;
- The OSPAR Convention;
- The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (1972) and the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter;
- The Convention on Environmental Impact Assessment in a Transboundary Context (Espoo-convention);
- The Agreement concerning the International Carriage of Dangerous Goods by Road (ADR)
- The European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN);
- The Regulations concerning the International Carriage of Dangerous Goods by Rail (RID), which forms Appendix C to the Convention concerning International Carriage by Rail (COTIF);
- The Technical Instructions for the Safe Transport of Dangerous Goods by Air, published by the International Civil Aviation Organisation (ICAO);
- The International Maritime Dangerous Goods Code (IMDG), published by the International Maritime Organisation (IMO);
- Belgium made a "political commitment" to the Code of Conduct on the Safety and Security of Radioactive Sources.

The FANC and Bel V are also actively involved in other international activities:

At the **IAEA** level, the FANC participate in the Nuclear Safety Standards Committee (NUSSC), the Waste Safety Standards Committee (WASSC), the Transport Safety Standards Committee (TRANSSC), the Radiation protection Safety Standards Committee (RASSC), the Emergency Preparedness and Response Standards Committee (EPReSC), the Nuclear Security Guidance Committee (NSGC) and the INES advisory committee.

In this regard, it can be considered that the FANC and Bel V actively participate in the development and the promotion of the IAEA Safety Standards and will continue these activities in the future.

At the **OECD** level, the FANC also participates in the steering committee of the NEA and in the activities of the following NEA committees: the radioactive waste management committee (RWMC), the Committee on Radiation Protection and Public Health (CRPPH), the Committee on Nuclear Regulatory Activities (CNRA) and the Committee on the Safety of Nuclear Installations (CSNI).

Bel V participates in the activities of the following NEA committees and working groups:

CNRA, CSNI, the Nuclear Science Committee (NSC), the Working group on inspection practices (WGIP), the Working group on operating experience (WGOE), the Working group on fuel cycle safety (WGFCS), the Working group on risk assessment (WGRISK), the Working group on analysis and management of accidents (WGAMA), the Working group on human and organisational factors (WGHOF), the Working group on integrity of components and structures (WGIAGE), the Working group on fuel safety margins (WGFSM), the RWMC Integration Group for the Safety Case (IGSC), the RWMC Working Group on Decommissioning & Dismantling (WPDD), and in various NEA projects.

Bel V is the national coordinator for the incident reporting system (IRS) of the NEA, the incident reporting system for research reactors (IRSRR) of the IAEA, and the fuel incident notification and analysis system (FINAS) of the IAEA.

The FANC has a national coordinator for the International nuclear and radiological event scale (INES), allowing the exchange of information on significant nuclear safety and radiation protection events occurring in all types of industrial facilities.

### *b) Cooperation at European level*

At the European level, the FANC is an active member of the **ENSREG** (European Nuclear Safety Regulators group). Belgian representatives are members of the different working groups set up by ENSREG.

The FANC and Bel V are also members of the **WENRA**, the Western European Nuclear Regulators' Association, and participate in various WENRA activities and working groups. The Fukushima Daiichi accident significantly impacted the work of WENRA under the impulse of ENSREG, in particular for developing and harmonizing new approaches for safety requirements and emergencies management.

The FANC and Bel V have representatives and actively participate in sub-workings groups of the RHWG (WENRA Reactor Harmonization Working Group) dealing with different technical issues.

In addition, FANC is an active member of **HERCA** (Heads of Radiation Protection Authorities) which brings together 49 radiation protection Authorities from 31 European countries.

Furthermore, the regulatory body (the FANC and Bel V) participates in the European Clearinghouse on nuclear power plants experience feedback, set up to share and analyse international experience feedback at European level.

Finally, Bel V is also a founding member of ETSON (the European Technical Safety Organisations Network) and of EUROSAFE and has a cooperation agreement with IRSN and another one with GRS.

### *c) Cooperation at bilateral level*

At the bilateral level, several agreements are in force and the FANC has extended collaboration with foreign regulatory bodies.

Amongst others, Belgium has formal agreements with all its immediate neighbors:

- France: various exchanges and agreements exist since the 1980s;
- Luxembourg: an agreement was signed in April 2005 and completed in 2013;
- Netherlands: a Cooperation Agreement between FANC and ANVS was signed on 14 September 2017;
- Germany: a bilateral agreement was signed on December 6, 2016.

Under these agreements, bilateral meetings are held at least on an annual basis.

These bilateral meetings systematically address the operation of nuclear units that may have a transnational impact: in particular Chooz (France-Belgium), Gravelines (France-Belgium); Tihange (Belgium-France-Luxembourg-Germany) and Doel (Belgium-France-Netherlands).

Collaborative activities and exchanges of information are continuous and include:

- exchanges of information of a technical nature. For example, technical files related to the flaw indications in the vessels of Tihange 2 and Doel 3 were transmitted to the German authority and debated between Belgian and German experts;
- exchanges of media information, with the aim of informing and answering the questions of residents and/or local and national elected representatives;
- exchange of information on the of licensing processes of nuclear installations (or of modifications thereof) in progress;

- cross inspections: A Belgian nuclear inspector accompanies an inspection in a nuclear power plant in the foreign country, and vice versa. The use of national languages imply that these exchanges are more developed with France and the Netherlands;
- exchanges of training: experts from the safety authority participate in training courses organized by the French safety authority, and vice versa;
- cross-participation of experts in national emergency plan exercises, in addition to the necessary collaborations at the level of various local, regional and federal authorities, in particular for the Chooz French power station, considering its proximity to the Belgian border.

With respect to emergency planning and response, the Belgian provincial authorities are also regularly involved in foreign emergency exercises for the nuclear power plants that are close to the Belgian border.

### II.D.7. Conclusion

The legal framework and system described in section II.C and II.D offers a solid basis for effective and efficient implementation of regulatory responsibilities and duties.

The Belgian regulatory body has the legal powers and human and financial resources necessary to fulfil its assigned responsibilities including the powers and resources to:

- require the licensee to comply with national nuclear safety requirements and the terms of the relevant licence;
- verify this compliance through regulatory reviews, assessments and inspections; and
- carry out regulatory enforcement actions.

Independence of the regulatory body is strengthened by the legal structure of the FANC and by a clear and well defined relationship with the Government. As extensively discussed during previous review meetings of the CNS, while recognising that a regulatory body cannot be absolutely independent, it was stated and commented that both aspects of independence, de jure and de facto, are essential. It can be found in the literature[1] that those concepts rely on different important parameters like:

- clear safety objectives;
- appropriate financing mechanisms;
- defined accountability procedure and reporting;
- transparency, adaptability to industry and society changes;
- available competence;
- quality assurance;
- management of human resources in the regulatory body;
- access to expertise.

Since September 2001, when the FANC became fully operational, and in further developments of the Regulatory Body, particular attention has been devoted to implement the national structure in accordance with those values and concepts.

## II.E. Article 9. Responsibility of the Licence Holder

> Each Contracting Party shall ensure that prime responsibility for the safety of a nuclear installation rests with the holder of the relevant licence and shall take the appropriate steps to ensure that each such licence holder meets its responsibility.

In view of implementing certain IRRS recommendations, the Law of 15 April 1994 has been amended by the Law of 7 May 2017. Article 28 of this amended law explicitly states the prime responsibility of the licence holder:

"*Art. 28. § 1.*

*The licence holder is responsible, in all circumstances, to ensure the protection of the workers, the population and the environment against the hazards or health disadvantages which could arise from the exercise of its practice. This responsibility cannot be delegated.*"

[1] INSAG-17 Independence in regulatory body decision making

In addition, the licensee has to comply with the regulations in force dealing with nuclear safety and radiation protection. The legal and regulatory framework expresses in several statements the prime responsibility of the operator for safety.

- Article 5.2 of the GRR-2001 also indicates that the licensee is responsible for complying with the conditions set in the licence. For the nuclear Class I facilities, the licence requires conformity with the Safety Analysis Report. Moreover, the operator must commit himself in the licence application to register with ONDRAF/NIRAS and to conclude with this organisation an agreement on radioactive waste management.
- The operator must also conclude a civil liability insurance (Article 6.2.5 of the GRR-2001); the law of 22 July 1985, which makes the conventions of Paris and Brussels and their additional protocols applicable, and the law of 13 November 2011 set the maximum amount of the operator's liability for the damage at some Euro 1.2 billion per site and per nuclear accident.
- The licensee must organise a Health Physics Department in charge of nuclear safety and radiological protection and must also organise the safety and health at the workplace as well as in the neighbourhood. A detailed description of the duties is given in Article 23 of the GRR-2001 (Article 7- section II.C.3 of this National Report).

Other obligations of the operator include information and training of the workers (including external workers) who might be exposed to radiation, and implementing the policy to limit individual and collective doses (respectively Articles 25 and 20 of the GRR-2001).

The Belgian law also requires that the Regulatory Body permanently controls the proper implementation of the duties of the operator's Health Physics Department. Article 23.1.2.2 of the GRR-2001 specifies a number of specific tasks in that respect.

## II.F. Article 10. Priority to Safety

> Each Contracting Party shall take the appropriate steps to ensure that all organisations engaged in activities directly related to nuclear installations shall establish policies that give due priority to nuclear safety.

### II.F.1. NPPs Licensee Safety Policy and Safety Culture

#### *a) Nuclear Safety policy Declaration*

As described in section II.C.4, article 3 of the SRNI requires the licensee to formulate and communicate to all personnel a safety policy with primary importance to nuclear safety and including a commitment to monitor and to continuously improve nuclear safety.

In order to state precisely the nuclear safety policy during operation, the Director-General Manager and the Chief Executive Officer (CEO) of ENGIE Electrabel have established and support the following "Policy Declaration on Nuclear Safety", which is included in the Safety Analysis Reports of the nuclear units:

"*In operating our nuclear power stations we attach the utmost importance to protecting the public, the environment and all of our personnel. We therefore support a strong nuclear safety policy that forms an integral component of our operations. We work with our partners and contractors to implement a safety policy based on the following principles :*

***Nuclear Safety = top priority***

- We ensure that safety takes precedence over production, at all times.
- We integrate safety into all operational processes.
- We anticipate new nuclear safety legislation and guidelines, implement them as quickly as possible and comply with them in full.
- We develop and promote a high level of safety culture.

***Nuclear Safety = a continuous improvement process***

- We set targets and develop action plans to ensure that nuclear safety measures are continuously improved.
- We continuously assess the level of safety of our activities, comparing it to national and international standards.

- We analyse and exploit operational experience and research findings in nuclear safety with a view to the timely implementation of feasible safety improvements.
- We involve all employees in the continuous improvement process and ensure that they participate actively.

***Nuclear Safety = thorough inspections***

- We maintain a constructive dialogue with the authorities and safety bodies and with all other stakeholders.
- We continuously monitor the effectiveness of our safety policy.
- We regularly undergo external audits and international benchmarking "

### *b) Safety Culture*

The ENGIE Electrabel approach for implementing "Safety Culture" is based on the Nuclear Safety Policy, the Management System and the Leadership and Human Performance Programmes.

(1) Values and Behaviours promoted by the Nuclear Safety Policy Declaration

The first principle stated in this Nuclear Safety Policy is "Nuclear Safety = top priority".

This Nuclear Policy is posted in many places on both sites and at least at the entrance of each building. The document is also integrally copied in the management expectations booklets. During the initial training in nuclear safety, all employees receive the Nuclear Safety Policy document and a specific module is devoted to explaining this policy.

The way to implement the principles defined in the Nuclear Safety Policy is described in the management system. The role, responsibilities and accountabilities of each level of the management regarding nuclear safety are clearly defined by following the INSAG-4 "Safety Culture" from the IAEA.

(2) Organizational and individual behaviours supported by the Management System

Below the Nuclear Safety Policy, on a second level, the Management System provides structure and direction to the organization in a way that permits and promotes the development of a strong safety culture together with the achievement of high levels of safety and excellent performance.

The organizational and individual behaviours described in the "Reference Book" and "Governance Nuclear Activities Electrabel" are declined through the Management System. Process owners are in charge to integrate these behaviours into the processes they are responsible for.

The management system promotes a working environment in which staff can raise safety issues without fear of harassment, intimidation, retaliation or discrimination.

The change management covers both the management of organizational changes and the willingness of teams and individuals to adapt to organizational changes that improve safety business performance.

The process of continuous improvement which is embedded in the organisation by the NGMS plays a key role in the objective to improve nuclear safety improvement. For each functional area of the NGMS there is an improvement cycle with management and strategic review resulting in actions plans, which are systematically challenged by the Independent Nuclear Safety Oversight (INSO) organisation.

(3) Nuclear leadership program

Figure 9 illustrates the nuclear leadership program of ENGIE Electrabel. This program is supported by a manager in-the-field program. All managers have followed a training program on how to implement on their level the principles of the nuclear leadership program.

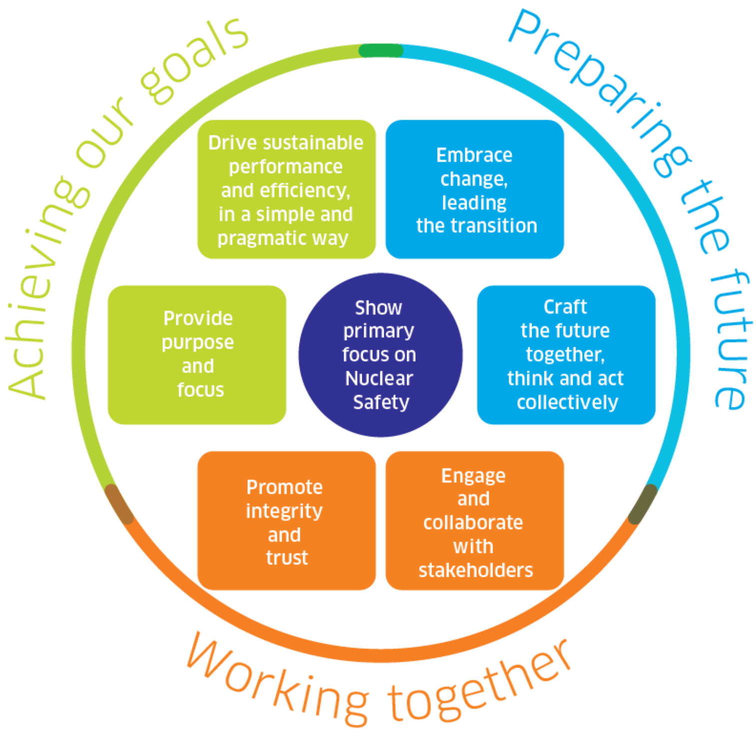


Figure 9: ENGIE Electrabel leadership model

(4) Human performance programme within ENGIE Electrabel

Tihange and Doel power plants have developed a common human performance policy which is based on two approaches:

- A bottom-up approach, which analyses the root causes of events (including the human factor)
- A top-down approach, which relies on human performance tools, safety culture awareness, and tasks observation.

Efficient implementation of the human performance policy in the field requires training and coaching, as well as transparency, trust, and mutual respect (no blame culture).

***c) Organisation***

Nuclear activities within ENGIE Electrabel are managed on a three level structure:

a) Nuclear Generation level
b) Nuclear Power Plant level
c) Health Physics Department

The departments at **corporate level** playing a major role that are most noteworthy with regard to nuclear safety are:

a) The **Nuclear Generation level**. The Chief Executive Officer (CEO) is responsible for the safety, reliability and performance of the Nuclear Plants of ENGIE Electrabel. The corporate level includes the following departments:
   - "Engineering"
     - o Ensures the development and implementation of the governance of the process "project development and realization" of the nuclear activities, including "Design Authority" and "Configuration Management". This governance is applicable to all projects related to studies and changes and is transposed into local procedures and instructions;
     - o Ensures also the performance monitoring of the process "project development and realization". Ensures the control and monitoring of the portfolio of nuclear projects in close collaboration with the sites: coherence with the defined strategy, respect of the planning, priorities;

    - Ensures the central activities related to nuclear fuel management;
    - Ensures the development and the implementation of the governance related to Equipment Reliability, as well as the evaluation of the performance within this field;
    - Develops a special program for the final shutdown and dismantling and decommissioning (DECOM).
- "Nuclear Decommissioning and Radioactive Waste" who is active in the following fields:
    - Management of nuclear liabilities, waste and decommissioning;
    - The request for final shutdown of nuclear activities.
- "Nuclear Fleet performance and Purchasing" who is responsible for the following activities:
    - Strategic Asset Management of the nuclear facilities;
    - Process Management.
        - E.g. developing and improving an integrated management system (NGMS) that fosters the continuous improvement of nuclear generation activities.
    - Operational Fleet Management
        - E.g. the periodic evaluation of the performance with respect to Nuclear Safety (Culture), using the self-assessments performed within the nuclear organization.
    - IT applications;
    - Purchasing and Warehousing.
- The Human Resources Department is located on the corporate level. The activities of Human Resources are mostly focused on the competency development, training and knowledge management of the personnel of ENGIE Electrabel.
- The Nuclear Security Department reports also hierarchically to the CNO and is responsible for developing and implementing the governance in the following areas:
    - Information security, People security, Physical Security and Cyber security

b) At the **Nuclear Power Plant level**, the organisation is structured in 3 departments:

- The **Maintenance** department is in charge of ensuring the short and long term availability of the installations and equipment. It is also responsible for the management of contractors.
- The **Operations** department is in charge of the safe conduct of the energy generation process and of the installations.
- The **Care** department is in charge of surveillance in radioprotection, measurements, protection of the workers (industrial safety), fire protection, environment and safety of the installations (including the setting up and the management of the emergency planning and preparedness). It also is in charge of Human Factors and Operational Experience activities. It is the local section of the centralized Health Physics Department (as required by the GRR-2001) and has the appropriate delegation from this department to perform the formal approvals required by the regulations. It ensures also the local independent nuclear safety oversight of the site by e.g. the execution of independent technical checks.

Additionally 3 local sections support these departments:

- The Continuous Improvement Management (CIM) section
- The Nuclear Fuel site section
- The DECOM (Decommissioning) section

c) The **Health Physics Department (HPD)** is headed by the Chief HSSE & Nuclear Safety. Besides the Local Health Physics departments on sites (CARE), there is also the Corporate Health Physics Department (HPD).

The Corporate HPD department is

- in charge of supporting the increase of the effectiveness of the management of nuclear safety for the nuclear fleet.
- responsible for the Corporate Independent Nuclear Safety Oversight (see below). In this perspective it's performing independent audits and assessments and delivers the operational line – up to the board of Directors – with a current perspective of the Nuclear Safety performance of the nuclear fleet.

- responsible for the governance, oversight and support for the Radiation Protection in Doel and Tihange

### d) *Monitoring & Assessment of safety performance*

In order to ensure optimum efficiency, the internal assessment of Safety is organised into different levels of control where each level corresponds to the different levels of the operational hierarchical line.

The basic elements of the Nuclear Safety Oversight (NSO) by the line and by the independent line (INSO) are schematically depicted in Figure 10:

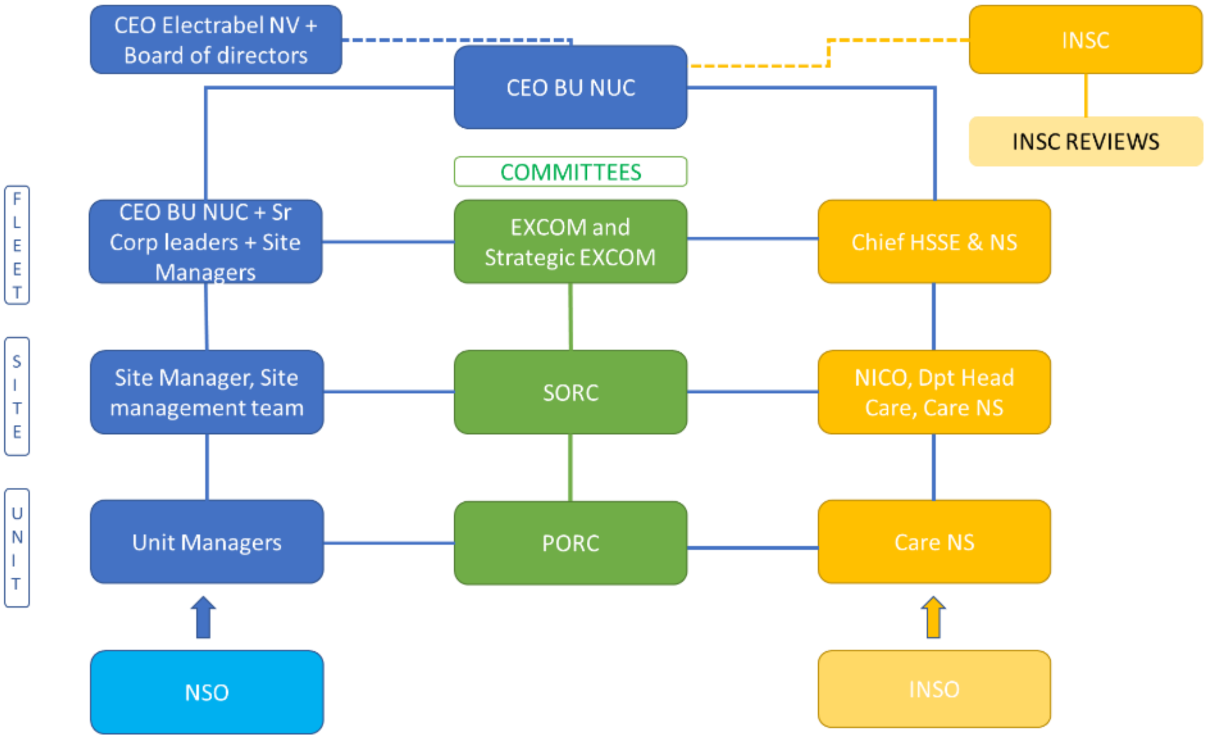


Figure 10 : Internal Safety Assessment

The left-hand side of the figure shows the operational line, which has the final responsibility for nuclear safety.

**NSO:** In line with the internal governance, the operational line executes its Nuclear Safety Oversight at least via:

- The yearly Process-Reviews, Self-Assessments, Management Reviews and Functional Area Health Reviews. These are conducted by the Process Owners, Functional Area Managers and Fleet Managers (in support of the line management).
- The follow-up of the nuclear safety performance via different Committees. E.g.
  - On Plant level: the Plant Operational Review Committee (PORC).
  - On site level: the Site Operational Review Committee (SORC), the Site Contract Performance Dialogues (SCPD), the Nuclear Project Committees (NPC).
  - On fleet level: Executive Committee (EXCOM and COMEX), Fleet Performance Reviews (FPR), Strategic Project Committee (SPPC) and the Nuclear Safety Committee (CSN).

The right-hand side of the figure relates to the **INSO**, which has the task of providing **independent** oversight of nuclear safety, so executed by people, which are independent from the operational line (or the HPD). This independent Nuclear Safety Oversight is mainly performed on three levels;

- The **Local INSO** (by the local HPD departments or CARE departments) by challenging the daily operations, executing technical reviews and independently analyzing and approving the safety assessments of modifications, managed on site.

- The **Corporate INSO** (by the Corporate HPD department) by executing in depth process reviews, independently analyzing and approving the safety assessments of modifications managed on Corporate level, performing QA-Audits and challenging the NSO-assessments.
- The **external INSO** (by the Independent Nuclear Safety Committee or INSC). This committee is made up of various external members and members of the internal INSO line. The INSC analyses the activities, events, projects and processes having a major impact on nuclear safety and reports its conclusions to the ENGIE Electrabel management team, the CEO and the Board of Directors.

The figure also shows the NS oversight committees (PORC, SORC, FPR's…) for the various levels. Members of the INSO-line participate also to these committees, and challenge the NSO decisions in these committees, and present their own nuclear safety messages and conclusions.

**Specifically for nuclear safety culture** a 2-yearly basis a survey is initiated by Fleet Management in order to poll the personnel (ENGIE Electrabel staff and important contractors) about their experiences related to traits of Nuclear Safety Culture. The result of the survey makes it possible to conclude about the evolutions of our Nuclear Safety Culture status, more than the absolute situation. Focused communication of the survey results to the managers and employees of organizations and teams makes it possible to develop targeted action plans for smaller groups.

These surveys give complementary information to the yearly self-assessment about nuclear safety culture that is conducted within the yearly improvement cycle (NGMS), where the internal event and incident reports are being evaluated.

Finally also INSO executes Safety Culture evaluations, independent from the nuclear safety culture survey and the organizational self-assessment.

These different inputs are used to challenge the site objectives of the year N+1, in order to continuously improve the nuclear safety culture at Doel and Tihange.

### II.F.2. Research Reactors

SCK CEN's general management adheres to a published an integrated policy statement for Safety, Security, Health, Environment and Quality, stating the importance of these aspects in a safe, secure and environmentally friendly operation of the installations. This is supported by a coherent integrated management system with the focus on Safety, Security, Health, Environment and Quality.

The culture for safety in the broadest sense is assessed periodically including topics such as overall organization, management of incidents, engagement & responsibilities, risk management, trust & openness, etc. The most recent assessment was performed and completed in 2021 resulting in an action plan sustaining and improving the culture for safety. The results of the survey are reported at corporate level, but also at the level of the different institutes. Besides the corporate improvement plan, each institute has to draw up its own action plan for improving their (local) results.

Some of these improvement initiatives taken are e.g. executing monthly management walkdowns, usage of incident dashboard as a management tool, launch of a monthly safety, security, health, environment or quality theme reviewed and promoted via management through a culture for safety steering group.

An important point of attention is the learning from operational experience feedback (OEF), both from internal and from external events. A centralised reporting, analysis and action tool enables the learning organisation in support of the culture for safety. The toolbox is recently extended to include human factor analysis.

The personnel is encouraged to report facts with a potential to stimulate culture for safety. Specifically for the external OEF, special attention is paid to the IAEA incident reporting system for research reactors. Information from incidents from power reactors is used insofar the subject is applicable to BR1 or BR2.

The training of the personnel also included ways for risk analysis, for use during the preparation of a task or just before and during the execution of the task. Operating procedures, especially the procedure for executing non-standard tasks, include a risk analysis.

A last important action is to maintain the knowledge of the installation. The SCK•CEN has an operational history of more than 70 years. Consequently, people that were involved in the design and building of the installations are no longer available. This emphasises the importance to maintain all documentation and records on the installations in good condition and readily available. Special attention is given to maintain the documentation and assure its accessibility.

### II.F.3. Regulatory Body

The FANC is responsible (amongst other duties) for the supervision and control of all the activities concerning radiological protection and nuclear safety.

Radiological protection, and implicitly nuclear safety, is emphasised in the general principles of the GRR-2001. However, special emphasis has been put on safety by the FANC.

The FANC governance document STI-21-01: "*Missions, activities and reporting of the section in charge of the surveillance of Nuclear Facilities*" is quite explicit regarding priority to safety, and lists the following specific missions:

1. Ensure that (nuclear) facilities have an adequate level of safety, taking into account the current standards for nuclear safety and radiation protection, in their design, during their operating phase and their decommissioning and dismantling. This is achieved with the full cooperation with Bel V, respecting the role and responsibilities of each other.
2. Ensure that all events having a potential impact on nuclear safety or on radiation protection are properly managed and contribute to the process of experience feedback at national and international level.
3. Ensure that people in charge of Health Physics Control in nuclear facilities, including on behalf of Bel V, have the necessary skills and knowledge to ensure nuclear safety and radiation protection, and that these skills and knowledge are maintained at a high level at all times.
4. Contribute to the establishment and / or to the improvement of national and international regulations by proposing useful and adequate requirements and rules to continuously improve the level of nuclear safety.
5. Exchange of a correct, independent and transparent technical information with all stakeholders to improve the level of nuclear safety and radiation protection.

The list of regulatory tasks that can be delegated by the FANC to Bel V is fixed in article 38.1 of the GRR-2001. These tasks consist, for Class I and high-risk Class II (so-called Class IIA) facilities, of:

- Regular on-site inspections, for the permanent supervision of the good performance (including approbation of some decisions) of the licensee's Health Physics Department. This permanent supervision in practice consists of systematic, thematic and specific inspections devoted to defined subjects (operation, periodic tests, chemical control, radiological protection …) and specific items follow-up inspections, examination of modifications and incident analysis.
- Safety assessments of licence applications for and of acceptance of new installations and of modifications
- Safety assessments and on-site inspections of other licensee's projects (e.g. PSR, Licensee's action plans)
- Safety assessments of the files and safety analyses related to the SRNI-2011 that are submitted by the licensee.

The Board of Administrators of the FANC formally delegated those tasks to Bel V on March 1st, 2019.

A 6-year integrated inspection strategy is developed jointly by the FANC and Bel V, based on the risk of the installations to be inspected and with the frequency of the different inspection topics defined in function of the installation risk. The overall goal is that all topics are inspected during the course of the mid-term inspection program (6 years) at all facilities.

FANC and Bel V inspections are declined in "thematic inspections" (FANC/Bel V), "systematic inspections" (Bel V) (respectively process-oriented, performance-based and both with defined frequencies) and "specific inspections" (FANC/Bel V) without specified frequencies and which could be initiated by incidents, new regulations,…

The content and frequency of inspections have been adjusted to the relative importance of the considered theme for the concerned installation and to the associated risk.

An annual programme for inspections is derived from this strategy and is communicated yearly to the licensees. A revision of this strategy is possible each year, in order to take into account experience feedback from the previous years.

The annual inspection and safety assessment programme of Bel V is approved by the FANC.

When performing an inspection, four steps are systematically applied: preparation, inspection, reporting and follow-up actions. Two important documents are used in support of an inspection: 1/ the notification to the operator of the inspection scope and specific regulation covered by the inspection (technical fiche), 2/ inspection guide that supports the inspectors in their specific inspection goals.

Bel V's inspections reports are written following each inspection and are also sent to the FANC. Bel V discuss its findings with the FANC on a regular basis. In particular, any situation that may have an impact on the public, the workers or the environment is immediately communicated to the FANC.

Each year, Bel V makes an evaluation of the safety of the installations it inspects and draws up the lessons learnt.

FANC performs also FLITS-inspections (Fast and Limited Inspection with Thematic Scope). The announcement of FLITS-inspections is very close to the completion of the inspection itself (approximately 3 days delay), with the aim that the operator cannot prepare for it.

## II.G. Article 11. Financial and Human Resources

1) Each Contracting Party shall take the appropriate steps to ensure that adequate financial resources are available to support the safety of each nuclear installation throughout its life.
2) Each Contracting Party shall take the appropriate steps to ensure that sufficient numbers of qualified staff with appropriate education, training and retraining are available for all safety related activities in or for each nuclear installation, throughout its life.

### II.G.1. NPPs

#### *a) Operator's Financial and Human Resources to use the Installation throughout its Industrial Life*

The main activities of ENGIE Electrabel are the generation and commercialisation of electricity and gas in Europe. In Belgium, ENGIE Electrabel is the owner of the twin units 1 and 2 (100%) and the units 3 and 4 (89.8%) of Doel, and of the unit 1 (50%) and of the units 2 and 3 (89,8 %) in Tihange. Belgium's nuclear generating units account for some 40% of electricity production in Belgium.

About 2200 people (about 300 at corporate level and the remaining equally distributed on the NPP sites) are devoted to nuclear power plant operation among ENGIE Electrabel's total workforce in Belgium of around 4300. The business unit ENGIE Benelux, of which ENGIE Electrabel is a part, has around 16700 employees in Belgium. In September 2002, the company Elia System Operator was appointed by the Belgian Government as the Manager of the electricity distribution network. This activity is now completely separated from the activity of electricity generation. ENGIE Electrabel has signed specific contracts with Elia. In accordance with the legislation on deregulation of the electricity sector in Europe, all distribution activities in the three regions of Belgium have been separated and turned into independent companies.

The ENGIE group also has an Engineering division, Tractebel ENGIE, which is the Architect-Engineer of the Belgian nuclear power units (and of most of the fossil fired plants) and which houses know-how accumulated over sixty years of nuclear technology, which started with the construction of the first research reactors at the SCK CEN.

#### *b) Financing of Safety Improvements during Operation*

Major safety improvements to the Belgian nuclear power stations emanate from the periodic safety reviews (ten-yearly) and are financed through annual provisions (1/10th each year). Cost of specific projects and for replacement of aged or obsolete components are amortized on the remaining lifetime of the concerned power plant.

### c) Financial and Human Provisions for Future Decommissioning and for Management of the Waste produced by the Installations

The existing mechanisms are described in the Belgian report for the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. More details can be found in that report, available on the FANC and IAEA web sites.

### d) Rules and Requirements for Qualification, Training and Re-training of Personnel

The SRNI-2011 requires that the Licensee identifies in a systematic and documented way, the needs with regard to the qualification and training of personnel executing safety-related activities.

The GRR-2001 requires an annual retraining of the whole personnel on the basic rules of radiological protection, including the good practices for an efficient protection and a reminder of the emergency procedures at the work site.

The Safety Analysis Report (chapter 13) deals particularly with personnel qualification, training and re-training. Qualification of the personnel is inspired from the ANS 3.1 standard, though adapted to the Belgian educational system. The Safety Analysis Report defines the level of qualification corresponding to each safety-related function. It does not state the individual qualifications of each person in the organisational chart. However, proof of qualification of all the operating personnel is available to Bel V. The functions and qualifications prescribed by the US regulations are transposed in function of the educational system structure and curricula existing in Belgium.

The training programmes are defined in the Safety Analysis Report, which includes a "function-programme" correlation chart. Chapter 13 of the Safety Analysis Report lists exhaustively all posts for which an authorization is required. This authorization is based on the positive opinion expressed by an Assessment Committee, which examines the candidate's knowledge. This qualification is reviewed every two years or when an authorized person has ceased for four months or more to perform the function for which he/she was qualified. It is renewed on the condition of, among other, a favourable advice of the Assessment Committee on the basis of the individual's training and activity file.

Bel V is member of the Assessment Committee, with veto right.

A knowledge re-training programme for all authorized personnel is defined in function of the occupied position. The contents of this programme which is discussed with Bel V, is essentially operation-focused and includes, among other, a refresher course regarding the theoretical and practical knowledge (two weeks per year), training on the full-scope simulator (two weeks every two years) and, in teams, a review of the descriptions of the different systems (two weeks per year).

### e) Training at ENGIE Electrabel

(1) <u>ENGIE Electrabel training policy</u>

The ENGIE Electrabel policy statement on competency development and personnel training recognizes that the training of personnel and the continuous development of their skills are essential for the on-going safety and optimal performance of both the on-site plant staff and the installation.

Through this policy, the Doel and Tihange NPP management ensures that every employee receives appropriate training and only qualified personnel is assigned to tasks involving risks.

Every new employee follows an initial training programme aligned with their job description.

Every staff member of ENGIE Electrabel has an individual development plan. The content and implementation of this plan follows a four-step approach:

1. Analysis of the gaps between the competences required and the level as assessed by the individual and their manager
2. Creation of individual development plans
3. Implementation of development actions
4. Coaching and monitoring, evaluation and feedback

Managers regularly check that the aims of the training courses are being met and suggest improvements. To do so, they participate in training, perform verifications and/or gather feedback and evaluation results.

Article 6.2 of SRNI-2011 (WENRA Reference Level D.2.1) states: "Only qualified persons that have the necessary knowledge, skills, and safety attitudes shall be allowed to carry out tasks important to safety. The licensee shall ensure that all personnel performing safety-related duties including contractors have been adequately trained and qualified". All employees in question, including contractors, have obtained a competence pass (‘Bevoegdheidsverklaring’ in Doel, ‘Passeport Métier’ in Tihange), which shows that they have received adequate training and are fully qualified. The acquisition of competences during a training program is formally checked.

**Training Facilities:**

Each site has a Training Centre (on site or off-site) with a number of training facilities. It includes:

- A field simulator for work practices and human performance tools (the Human Performance Simulator);
- A room for hands-on training, for instance on the operation of pneumatic valves and controllers;
- A room for the initial training of operators featuring a large number of demonstration tools;
- Simulators (full-scope or multifunctional): Both Doel and Tihange have full-scope simulators.
- In Tihange, there are 2 full-scope simulators, one is a precise replica of Tihange Unit 1, and the second one of Tihange Unit 2. Extensions such as additional hardware panels and screens have been added to the equipment of the Unit 2 simulator in order to provide the best possible training of Unit 3 operators.
- Doel has two full-scope simulators: these are precise replicas of Doel Unit 1 (and thus also of Unit 2) and unit 4. The full-scope simulator of Unit 4 can be used in Unit 3 mode.

(2) Training Requirements

The training cycle is subdivided into two parts:

1. Initial safety training;
2. Refresher safety training.

Initial safety training includes course on nuclear safety, health and safety and environmental issues and must be completed by each NPP employee before they start their job. The initial training programme is tailored to the nature of function that will be occupied by the employee. Three levels have been defined accordingly.

Refresher safety training is given on an annual basis and is mandatory. It keeps employees informed about changes and operating experience in the areas of nuclear safety, industrial safety, radiological protection, environmental safety, human performance and management expectations. For technical functions, an additional refresher course has been developed but runs over 5 years.

(3) Training programs

Training programs have been developed for operations personnel, maintenance personnel, technical and support personnel and management and supervisory personnel.

More details are given below on the training programs for Operations and Maintenance personnel:

**Operations personnel:**

Members of staff who are directly responsible for the operation of the reactor units must receive an operator’s authorisation. This certification must be obtained before the person is nominated for a position.

The training programme for authorised operators (Shift Supervisors and Control Room Operators) is in line with legal requirements. It comprises a basic training package, training in emergency procedures, and complementary training courses. The training programme includes:

- Control room training under the supervision of a Shift Manager;
- Hands-on training through integration in a team of Shift Supervisors and/or Control Room Operators;
- Simulator training given by the Operations Support Service;
- Training on specific installations, covering aspects such as firefighting and first aid.

The periodic retraining of authorised operators also meets legal requirements. It is established by the Operations Service and comprises the following elements:

- One week refresher course, per year, in classroom and in other installations suited for exercises, in line with the function;
- Two week internal team training, per year, under the supervision of the Shift Supervisor;

- Two weeks of full-scale simulator training, per year, given by the Operations Support Service.

As with certified operators, the training program for Field Operators is in line with legal requirements. It also comprises a basic training package, training in emergency matters, and complementary training courses. The training program includes:

- Classroom training under the supervision of a Shift Supervisor. This training covers thermodynamics, electrical and electrotechnical principles, systems and components, circuits, instrumentation, and safety principles;
- Hands-on training through integration in a team of Field Operators;
- Training on specific installations, covering aspects such as firefighting.

The annual retraining programme of Field Operators is established by the Operations Service and is based on a two day refresher course in a control room and in other installations suited for exercises, in line with the function.

**Maintenance personnel:**

After the initial generic training course, future technicians follow a specific training programme. This programme specifically addresses mechanical, electrical and I&C technicians. It lasts approximately one year. Other team-specific training courses are provided in addition to this programme.

The switch from a technician to a first technician and further to team leading function requires completion of specific training courses.

(4) ENGIE Nuclear Training Programme

In 2005 GDF-Suez decided to develop its nuclear activities and created a dedicated Nuclear Activities Division. This Division is now called ENGIE Nuclear Development (DDN). One of its missions is to:

- Anticipate needs in junior engineers (max. 2 years of professional experience) for replacing retiring managers and for staffing new nuclear projects
- Build up a Nuclear Training Programme (NTP):
  - **NTP Junior programme**: for **junior engineers** by giving them a general view on all the aspects of the nuclear activities and to help them build a strong network through the ENGIE Group.
    This programme (400 hours) consists in different types of trainings in order to improve 3 types of competencies (métier – behavioural – functional)
  - **NTP Majors programme**: a similar training programme of three weeks was launched in April 2010 for senior engineers coming from several entities of the ENGIE Group, but having no specific nuclear knowledge. This will enable them to subsequently reinforce the nuclear activities of the ENGIE Group and their comprehension.
  - **NTP Support programme**: a training programme of two days for managers in support departments like Legal, Finance, HR, Procurement to explain the specificities of the nuclear energy sector. During this training, trainees also better understand their contribution to nuclear safety.

(5) Contractor Training and Qualifications

Contractors are responsible for the training of their own personnel. Nevertheless, ENGIE Electrabel shall ensure that all contractors performing safety-related duties have been adequately trained and qualified. All contractors in question have obtained a competence pass ('Bevoegdheidsverklaring' in Doel, 'Passeport Métier' in Tihange), which shows that they have received adequate training and are fully qualified. The acquisition of competences during a training program is formally checked. Moreover, training in radiological protection is legally required and is made specific to the site where they will work. They must pass an examination at the site before they are allowed to the workplace. An intensive training programme for all personnel of contractors has been put in place, focussing on nuclear safety and work in a nuclear environment. The successful completion of this training is mandatory before being allowed to work on the site of the nuclear power plants.

A general training programme is set up for all contractors. This general training programme focuses on safety culture (both nuclear and industrial safety), is carried out partly on a theoretical basis and partly on a hands-on approach using the Human Performance Simulator (see also II.H.1.d). It covers the 4 tools for the effective application of the human performance principles, as the adherence to procedures (stressing the need for a strict respect of prescribed steps), the interrogative attitude (the principle to correctly apply the instructions using the STAR methodology: Stop – Think – Act – Review), the use of secured communication and the use of the pre-job briefing methodology.

### II.G.2. Research Reactors

#### *a) Financial resources*

SCK CEN, the Belgian Nuclear Research Centre is a "Foundation of Public Utility " (FPU) with a legal status according to private law, set up according to the code of associations and companies, under the supervision of the Belgian Federal Minister in charge of Energy and the Belgian Federal Minister in charge of Economy. SCK CEN has to apply the principles and rules prescribed by Belgian accounting rules, as well as to the ESA-reporting. The turnover and the operating profit of the previous years are defined in accordance to BE-GAAP (Belgian Generally Accepted Accounting Principles). The adequacy of the SCK CEN's financial system and internal controls is a.o. assessed by an external auditor. According to the safety and security charter, the management hereby is committed to provide all necessary financial means to enhance safety and to ensure all required security measures.

The future cost for dismantling is covered by funds. With respect to these technical liabilities, the following rules for funding apply. All dismantling costs for installations built and in operation before 1989 are covered by a special 'Technical Liabilities Fund', which is administered outside the SCK CEN and financed by the Belgian federal government. All technical liabilities after January 1989, the so called 'Neo Technical Liabilities', are financed by the SCK CEN by means of setting up the necessary provisions. The total liabilities are periodically reassessed, and total amounts have to be available at the moment of dismantling and decontamination. SCK CEN is consolidated in the national accounts of Belgium and also has to comply with the accounting standards of ESA 2010[2] .

b) Human resources

The minimum requirements for operating personnel are detailed in the safety analysis report both for BR1 and BR2. These requirements are the necessary education and training of the personnel. The minimum number of personnel necessary for operating the reactor is also specified. For BR2 additional requirements for training are defined. Each reactor operator has to receive two weeks training every year. The initial authorisation as a reactor operator is given on advice of a committee, in which the Health Physics Department and Bel V, are represented with veto power. Reauthorisation is necessary every three year or after a longer period of non-activity as an operator. The requirements for BR1 personnel are less formalized. The appointment of the BR1 reactor manager has to be confirmed by the Health Physics and safety Department. The training of the operators is defined by the BR1 reactor manager on a case by case basis. This is acceptable due to the limited number of operators for BR1.

### II.G.3. The Belgian education programme in nuclear engineering

As a joint effort to maintain and further develop a high quality programme in nuclear engineering in Belgium, the Belgian Nuclear higher Education Network (BNEN) has been created in 2001. Currently it exists as a cooperation project between six Belgian universities (UC Louvain, KU Leuven, VUB, ULB, ULiège and UGent) and the SCK CEN.

In the framework of the new architecture of higher education in Europe, the BNEN created a 60 ECTS "Master of Science in Nuclear Engineering" programme. To be admitted to this programme, students must already hold a university degree in engineering or equivalent education.

The BNEN programme is given in Table 4.

[2] The European System of Accounts (ESA 2010 or ESA) is an internationally compatible accounting framework for a systematic and detailed description of a total economy (that is, a region, country or group of countries), its components and its relations with other total economies.

| | ECTS[3] |
|---|---|
| **Compulsory modules** | **31** |
| Introduction to nuclear energy | 3 |
| Introduction to nuclear physics | 3 |
| Nuclear materials | 3 |
| Nuclear fuel cycle | 3 |
| Radiation protection | 3 |
| Nuclear thermal-hydraulics | 5 |
| Nuclear reactor theory | 6 |
| Safety of nuclear power plants | 5 |
| | |
| **Elective modules (9 ECTS to be chosen from the list below)** | **9** |
| Advanced nuclear reactor physics and technology | 3 |
| Advanced nuclear materials | 6 |
| Advanced radiation protection & radiation ecology | 3 |
| Advanced courses of the nuclear fuel cycle | 3 |
| Nuclear and radiological risk governance | 3 |
| Advanced course elective topic | 3 |
| | |
| **Master thesis** | **20** |
| | |
| **Total** | **60** |

Table 4 : BNEN Curriculum

More information can be found on the BNEN web site: http://bnen.sckcen.be

With BNEN as example, SCK CEN is one of the founding members of the European Nuclear Education Network (ENEN) (www.enen.eu), which is now an international association of 67 member organisations including universities and other stakeholders (industry, regulators and research centres). ENEN is strongly supported by the European Commission. Students registering to any of the participating institutions are offered the opportunity to coherently take a part of their basic nuclear education at different places in Europe while cumulating credit units.

In addition to the BNEN Master-after-Master academic programme, the SCK CEN Academy also organises the Radiation Protection Expert course (20 ECTS) in collaboration with the Hasselt university: https://www.sckcen.be/en/sck-cen-academy/training-courses/academic-education#anchor-post-graduate-education-programme-radiation-protection-expert.

In the academic year 2019-2020, the Hasselt university kicked-off of the remodelled Master in Nuclear Engineering Technology in cooperation with the SCK CEN Academy. In this programme, there is a strong SCK CEN contribution foreseen to the teaching, practical exercises and technical visits.

For students and professionals in (non-) nuclear industry, the medical sector, governmental and policy institutions and research organizations, the SCK CEN Academy also offers customized training courses on all topics that are subject of the R&D portfolio of SCK CEN. Examples related to the nuclear industry are

- Nuclear technology: 60h course for reactor operators of NPP Doel and introduction to reactor theory (60h) for employees of NPP Tihange;
- Radiation protection: initial and refresher courses for NPPs in Doel and Tihange;

[3] ECTS stands for "European Credit Transfer and Accumulation System", 1 unit corresponds to approximately 10 learning hours

- Decommissioning and decontamination: organization of a tailor-made course on decommissioning for ENGIE personnel and participation of NPP personnel in the open course which is regularly organized;
- Waste and disposal: participation of NPP personnel in this open course which is regularly organized in strong cooperation with FANC/AFCN, NIRAS/ONDRAF and Belgoprocess;
- Nuclear emergency management: organization of an initial or advanced training on the nuclear emergency plan for NPP Doel and Tihange.

## II.H. Article 12. Human factors

| |
|---|
| Each Contracting Party shall take the appropriate steps to ensure that the capabilities and limitations of human performance are taken into account throughout the life of a nuclear installation. |

Accounting for human factors at the design stage is discussed in Article 18 of the present National Report. The text below is centred on human factors during the operational period of the power plants.

### II.H.1. NPPs Human Performance Programme

As already mentioned in II.G.1.d), the human performance policy is based on two approaches:

A bottom-up approach

- Everyone is encouraged to report suggestions and anomalies or human errors in a software application (OESAP). These reports are used to improve the performance.
- Root cause analysis of errors and malfunctions cover both technical aspects and human and/or organizational factors (HOF) in order to reinforce defence barriers. Such an analysis therefore:
  - Highlights and explains all deviations linked to an event;
  - Identifies the real and potential consequences of these deviations;
  - Analyses the direct, apparent and root causes of the event;
  - Defines the corrective actions to be implemented to avoid recurrence of the event;
  - Second layer HOF analysis.

A top-down approach

- The top-down human performance approach is based on leadership, values, change management and organisational behaviour.

The focus is to ensure the integration of good safety behaviour and use of human error reduction tools (HU tools):

- <u>Management expectations and Site (or department) Fundamentals</u>: The HU tools are embedded in the Management Expectations and Site (or department) Fundamental booklets, specific procedures and execution aids (e.g. pre-job documents, work permit, observation forms, etc.). Films were made to clarify specific expectations (e.g. for alarm management in the control room).
- <u>Tasks observation</u>: Managers and supervisors frequently conduct task observations in the field in order to:
  - Reinforce management expectations, including human performance, by valuing the appropriate behaviour and correcting deviations;
  - Identify and correct deviations;
  - Reinforce contacts with the field.
- <u>Communication:</u> Specific HU communication is achieved by using electronic Public Address display, newsflashes, films, magnetic posters and during training sessions.
- <u>Training</u>: Workshops and training for leaders and teams have been delivered to enhance leadership and coaching skills. After the initial Human Performance training, the HU training was embedded into initial training, control room training and field simulator training. HU also became part of the improved self-assessment approach, making the link with operating experience thus closing the learning loop (with special attention for using observation results).
  - "HU Clock" (reset of the day count, each time a significant event is caused by human error and two performance indicators (HU Index and HU Ratio).

- <u>Specific action plans</u> to improve the Human Performance: For instance:
    - From 2016 to 2018 a comprehensive action plan was established and executed. One of the main purposes of this action plan was to decrease the amount of human errors during the execution of the operational tasks (e.g. by increasing the questioning attitude, self-checks, improving the use of the procedures, reinforcing the expectations in the field, giving and following awareness trainings,…).
    - Yearly HU Action Plan containing behavioural focus points within each department to improve the human performance, taking into account the lessons learned from events that occurred within the department in the previous year.

### a) Use of human error reduction tools (HU tools)

The focus is to ensure the integration of good safety behaviour and use of human error reduction tools (HU tools):

- Situation awareness: includes workplace screenings, questioning attitude, anticipation and time-outs (pause before starting an activity if anything is uncertain).
- Self-control: revolves around the STAR concept of 'Stop-Think-Act-Review'.
- Pre-job briefings: interactive dialogues that cover the task to be carried out – taking into account experience, risks and error precursors, as well as the worst-case scenarios. In some cases, Pre-job briefings are referred to as "Tool box meetings".
- Post-job debriefings: reporting that a task is completed, notifying any abnormality, reviewing the paperwork fully and highlighting lessons learned (input for operating experience, for future pre-job briefings and optimization of procedures).
- External verifications on practices: peer checks, concurrent and independent verifications to safeguard quality and safety.
- Effective communication: taking into account basic principles of good communication (such as informing all parties involved), favouring direct dialogues, securing understanding by three-way communication, phonetic alphabet.
- Careful decision-making: includes anticipating, evaluating options, checking assumptions, conservative decision taking and thinking as a team.
- Intelligent use of procedures: making sure that procedures are correctly understood and applied in practice. In case of doubt, one stops and changes are only made after appropriate consultation and red-marking.

### b) Operating experience feedback

Operating experience feedback is communicated as extensively as possible and integrated as soon as possible into the relevant training courses. Yellow stickies exercises are used periodically within the teams to perform from the Operating Experience (OE) reporting database trend analyses and define the actions for improvement.

### c) Task observations

In addition, task observations are held to:

- Reinforce management expectations, including human performance, by valuing the appropriate behaviour and correcting deviations.
- Identify and correct deviations.
- Reinforce contacts with the field.

Programs are ongoing to increase the effectiveness of these task observations. For instance, managers and leaders are receiving different trainings and coaching to perform these task observations or 'support visits' in the field more effectively.

### d) Human Performance Simulator

Tihange and Doel NPP are equipped with their own "human performance simulator". This training facility is an excellent training tool to model safety behaviours. This training model comprises essentially all important parts that are typical for an intervention in a nuclear installation like:

- A dressing room: to prepare entrance and exit of a nuclear zone with appropriate suits, including clothes, dosimeter, and contamination checking before and after intervention.
- A briefing space: where teams can prepare preliminary works or give some orders before an intervention exercise.

- A tool store: to store necessary tools, or spare pieces.
- A radioprotection room: located next to the entrance of the nuclear zone, where staff can find a radioprotection supervisor, and contamination monitors.
- An electrical room: local with electrical board and batteries.
- A control room: with control panel from which staff can operate equipment.
- A mechanical room: where mechanical equipment such as pumps, valves, tanks, etc… is present.

Trainees enhance their safety attitudes and behaviour by responding to simulated problems and changing conditions being encountered during an intervention. Different scenarios of intervention have been developed for training purposes. Trainees are recorded on video and followed by instructors to coach them and improve their safety behaviours.

Figure 11 : Human Performance Simulator

### II.H.2. Research Reactors

#### *Organizational aspects*

Training programmes and knowledge management are centralized in one service, the expert group communication, education and knowledge management. Training programmes with safety aspects are defined in cooperation with the health physics and safety expert group.

#### *Training*

Most of the training is given in-house, but external training is possible. For BR2 operators, two weeks training per year is foreseen. Training on a simulator, as is the practice in power plants is not possible for BR1 or BR2. However, the activities of the BR2 reactor requiring at least 5 to 6 starts per year and the measuring program requiring critical approaches enable the personnel to train on the job.

BR2 operators receive 2 weeks training per year. Training subjects can be theorical lessons and practical exercises. During the training sessions modifications of the installation are discussed. In overview of incidents with possible lessons learned is also included. Training requirements for personnel of BR1 are less formalized and are evaluated in the current periodic safety review. The number of operators for BR1 is very limited and the reactor is not operated outside normal working hours nor during holiday periods

#### *Knowledge management*

For an organisation with an operating experience of more than 50 years, knowledge management is an important issue. People present at the start of the installations are no longer available. Being a research environment, a number of modifications are made and new experiments are set up. An action is taken to collect all design documentation of the installation and make it readily available. For persons with a key function a backup must be available, with an equivalent knowledge or with capacity to get this knowledge quickly.

## II.H.3. Safety Culture Observations by the Regulatory Body

The Federal Agency for Nuclear Control and Bel V have jointly developed and implemented a Safety Culture observations process. Observations are performed by Bel V's inspectors or safety analysts during any contact with a licensee[4]. These observations are filled in an observation sheet aimed at describing fact and context issues. These observations are linked to Safety culture attributes based on IAEA standards[5].

On a monthly basis the "Safety Culture coordinator" within Bel V analyses observations (with a quality of description and classification perspective) and gives a feed-back to the observation maker. In case of an important Safety Culture discrepancy, a direct reporting to the licensee could be considered.

On a quarterly basis, the "Safety Culture coordinator" provides a mainly quantitative synthetic report. The aim of this report is to identify early signs of problem. Then, it could be decided to analyse a plant's performance more deeply in order to understand the underlying causes of a problem or to focus inspections on specific dimensions.

On an annual basis but also every three years for a larger assessment, the "Safety Culture coordinator" provides a detailed report on the observations (with a safety perspective). The aim is to identify persistent signs of problems or good practices. These statements feed the next annual inspection programme. A synthesis is presented to the licensee. The discussion objective is to be sure that the licensee understands the regulator's concerns.

In terms of regulatory body evaluation, Safety Culture observations are then central pieces of a broader oversight process trying to identify and analyse Safety Culture dimensions.

Yearly evaluations of the process are performed as well. The process is now fully operational.

# II.I. Article 13. Quality Assurance

> Each Contracting Party shall take the appropriate steps to ensure that quality assurance programmes are established and implemented with a view to providing confidence that specified requirements for all activities important to nuclear safety are satisfied throughout the life of a nuclear installation.

## II.I.1. NPPs

### *a) Background*

As the USA safety rules were applied for the 4 most recent Belgian units as early as at their design stage, 10 CFR50 Appendix B requirements were adopted for these units, as well as the ASME code quality-assurance stipulations for pressure vessels. The 50-C-QA codes and the resulting safety guidelines (including 50-SG-QA5) developed in the scope of the IAEA's NUSS programme were also taken into account.

At the time of putting into service the Doel 1 & 2 and Tihange 1 units, i.e. 1974-1975, that level of quality-assurance formalism was not yet required. However, during the 1$^{st}$ periodic safety review of these units, the request was formulated to apply to them the same quality-assurance rules as were applied to the more recent units: accordingly, any new installations, modifications, repairs and replacement at the earlier units were from 1985 on made consistent with the formal QA requirements.

The responsibility for applying the quality assurance programme is assumed by the operator who subcontracts the related tasks to his Architect-Engineer during the design and construction phases of the power stations, up to and including their start-up tests.

While following the evolution of the international practices, ENGIE Electrabel evolved from its quality assurance system during operation to a quality management system, in September 2006. This management system includes the previous applicable quality assurance system. The elaboration of the quality management system was based primarily on a general safety requirement published by the IAEA (GS-R-3: "The management System for Facilities and Activities", 2006).

[4] Inspections (routine, topical and reactive), meetings with licensees, training activities, formal and informal discussions with plant staff at various levels, document review, review of event reports (including low level) and corrective actions implemented, observation of activities and conditions in the field…

[5] IAEA/CNCAN (2010). *Guidelines for Regulatory Oversight of Safety Culture in Licensees' Organisations*.
IAEA/BNRA (2011). *Guidelines for Regulatory Oversight of Safety Culture in Licensees' Organisations*.

The Nuclear Safety management system of ENGIE Electrabel was updated in 2017. In this update, a clearer description of the roles and responsibilities related to the Governance, Oversight, Support and Performance (GOSP-model) for the different processes and functional areas, important for the Nuclear Safety, is given. The improvement cycle for the different processes and functional areas is reinforced as well.

The term "management system" encompasses the initial notion of "quality control" and its extension to include "quality assurance" and "quality management". A management system is a set of interdependent or interactive elements aimed at establishing policies and objectives, and which helps achieve objectives in a safe, efficient and effective manner.

The management system for nuclear safety is described in chapter 17 of the Safety Analysis Report which deals with the design and construction phases, followed by the operation period. As there is no unit under construction at present in Belgium, emphasis is put on how the integrated management system is applied during operation.

### ***b) ENGIE Electrabel's global approach***

The principal goal of ENGIE Electrabel's management system is to ensure and to improve safety at ENGIE Electrabel's Doel and Tihange power stations through a common approach and via plant-specific approaches.

To fulfil its mission and achieve its objectives, ENGIE Electrabel establishes, implements, assesses and continually improves a management system that meets the following basics:

- Nuclear Safety is the overriding priority within the management system, taking precedence over all other considerations;
- It fosters the development of, and promotes the improvement of, a strong Nuclear Safety culture by improving behaviour and attitudes both among individual workers and line management;
- It identifies and integrates coherently all requirements that are applicable to its activities and processes, especially as regards Nuclear Safety, Quality, Nuclear Security, Health and Safety and Environmental protection.
- It is based on the identification, development, implementation, assessment and continuous improvement of the processes needed to achieve the goals and meet all requirements applicable to ENGIE Electrabel.
- To deploy appropriately its resources, ENGIE Electrabel implements the requirements of its management system following a graded approach.

The implementation of this management system allows ENGIE Electrabel to:

- Improve its Nuclear Safety performance through the planning, monitoring and control of its safety-related activities;
- Ensure that Quality, Nuclear Security, Health and Safety (H&S), Environmental protection requirements and Economic considerations are not considered separately from Nuclear Safety, to help preclude their possible negative impact on Nuclear Safety
- Describe the planned and systematic actions necessary to provide adequate confidence that it conforms to all its applicable requirements;
- Allocate appropriate resources to carry out its activities and provide the countermeasures to be put in place in order to offset any process or activity failures.

The effectiveness of the management system is monitored and measured to confirm the ability of the processes to achieve the intended results and to identify opportunities for improvement.

Opportunities for the improvement of the management system are identified and actions to improve the processes are selected, planned and recorded.

Actions for improvement are monitored until their completion and the effectiveness of the improvement is checked.

### ***c) Applicability***

The integrated management system applies to any safety-related structures, systems, components as well as to any activity that may affect nuclear safety. It applies also to the safety-related activities or processes affecting nuclear safety, e.g. human performance, organisational performance, safety culture, radiological protection, radioactive waste management, fire detection and protection, environmental monitoring, nuclear fuel management, emergency intervention and site security.

These structures, systems and components and activities are known as safety-related. They are identified in the Safety Analysis Report of each unit.

### ***d) Key documents***

ENGIE Electrabel's management system for Nuclear Safety is described in a number of documents that move downwards from broad principles towards technical specifications and daily practices:

- Chapter 17.2 of the Safety Analysis Report
- The Policy Manual or the Nuclear Generation Management System Reference Book
- Governance Nuclear Activities ENGIE Electrabel
- Execution documents

(1) The "Reference Book" and the "Governance Nuclear Activities ENGIE Electrabel"

The "Reference Book" is the cornerstone of the ENGIE Electrabel internal governance regarding Nuclear Safety and describes the Nuclear Safety Management System of the Nuclear Production of ENGIE Electrabel (NGMS). Through the management system, ENGIE Electrabel guarantees and continuously improves its nuclear safety performance based on standards and expectations, evolving with changing regulatory requirements and performance enhancing decisions.

Internal governance means « the needed organizational structures, policies, processes and programs to establish high standards for executing the nuclear activities of ENGIE Electrabel, including the operation, maintenance and organizational support of the nuclear power plants. »

The NGMS is structured by grouping these activities & processes in a number of Functional Areas (FA), in which processes important to Nuclear Safety are clearly identified.

The standards & expectations for each of those FA's integrate all (regulatory) requirements related to nuclear safety and other specific (regulatory) requirements that could interact and could have a negative impact on nuclear safety during operation of the NPP, coming from industrial safety (ISO 45001), environment (ISO 14001) or any other governance applying to the FA.

The NGMS reference book is build up in compliance with regulatory requirements and includes:

- the company's policy statements on Nuclear Safety, H&S, Security and Environment
- the organizational structure of the nuclear activities
- a description of the management system NGMS and its Functional Areas (FA)
- a description of the method used to measure, assess and improve performance in the different FAs (including NGMS as a management system)
- functional responsibilities and responsibilities of Senior and Line Management
- a description how all related documentation is structured and managed
- an identification of the interactions with requirements other than Nuclear Safety related that apply to the operator (e.g. ISO 45001, ISO 14001,…).
- the standards & expectations per FA.

The standards and expectations per Functional Area, are described and kept up to date in the "Governance Nuclear Activities ENGIE Electrabel" document.

### ***e) Competence development***

A general training is given regarding the quality assurance objectives and the means for achieving these to all personnel who perform safety-related activities in the various services. This training is maintained and updated when necessary.

### ***f) Evaluation***

Quality assurance is integrated directly in the different processes and procedures, important for the nuclear safety. Basics elements are the necessity to perform self-checks and peer-checks during the execution of the tasks, and to execute tests, inspections and verifications to provide evidence that a structure, system or component will perform satisfactorily in service.

*(1)* Nuclear safety oversight

Corporate oversight and monitoring are used to strengthen Nuclear Safety and improve performance. Plant safety and reliability are under constant scrutiny through techniques such as assessments, performance indicators, and periodic management meetings.

(2) Self-assessment (Management Reviews and Functional Area Strategic Reviews)

Management at all levels (Line Management, and Functional Area Management) carry out self-assessment with the objectives to:

- Evaluate the performance of work;
- Verify compliance with all aspects of the management system (legal and performing enhancing requirements).
- Prevent, identify and correct weaknesses that hinder the achievement of ENGIE Electrabel's objectives;
- Improve the management system;
- Enhance the Nuclear Safety culture and the effectiveness of processes and activities.

(3) Management System Review

A management system review is conducted at planned intervals at the Generation BE level to ensure the continuing suitability and effectiveness of the management system and its ability to enable the objectives set for ENGIE Electrabel to be accomplished and the Nuclear Safety policy to be met.

(4) Independent Nuclear Safety Oversight

The Health Physics Department ("Service de Contrôle Physique/Dienst voor Fysische Controle") is established with the responsibility for conducting these independent assessments. It has sufficient authority to discharge its responsibilities and has direct access to the Senior Management. Within this service, the roles and responsibilities of the Care departments and the ENGIE Electrabel Corporate Nuclear Safety Department are clearly defined. Independent oversight provides the ENGIE Electrabel Senior Management with an ongoing perspective of performance at the nuclear stations and in the corporate organization compared to the industry, with a principal focus on Nuclear Safety, plant reliability, and emergency response effectiveness.

The Independent Nuclear Safety Oversight embodies a comprehensive system of planned and periodic audits and assessments, to verify compliance with the different aspects of the management system.

(5) Nuclear Safety Committees

Within ENGIE Electrabel, Nuclear Safety Committees are defined at different levels (see Section II.F.1.D). Their objectives are to evaluate and continuously improve the Nuclear Safety performance and the Safety Culture of ENGIE Electrabel.

## II.I.2. Research Reactors

The development of and integrated management system (IMS) started from the existing quality assurance system for commercial isotope production. The IMS principles are defined and a number of important processes is described. A framework of procedures is available. In the future , the system will be further developed to include more detailed processes concerning reactor operation and its utilization (commercial isotope production and development of experiments). This process can be considered as a continuous action. The IMS is applicable to all installations, and thus also includes the reactors.

## II.I.3. Activities of the Regulatory Body

Since the SRNI-2011 came into force on the 1st March 2013, article 5 of SRNI-2011 imposes to the licensees of nuclear facilities to set up an integrated management system. This article is based on the WENRA reference level "issue C – Management System", which is itself derived from the IAEA Safety standard GS-R-3. The new WENRA 2020 RHWG reference level will be included in SRNI-2011, to take into account the more recent GSR part 2 IAEA safety guide (See section I.C.1).

In 2014 and 2015, an inspection campaign was conducted to verify the compliance of the management systems of the Belgian NPPs and other nuclear facilities (Belgoprocess, IRE and SCK CEN).

The conclusion of the inspection campaign was that management systems were on the whole compliant with the regulatory requirements. Action plans were, however, set up in order to correct some issues related e.g. to documentation and performance indicators.

Bel V performs systematic inspections, with some dedicated to the assessment of the management system procedures related with the operation of the plant. The management system is also reviewed during examination of modifications to the installations, incident reports, etc.

## II.J. Article 14. Assessment and Verification of Safety

> Each Contracting Party shall take the appropriate steps to ensure that:
> 1) comprehensive and systematic safety assessments are carried out before the construction and commissioning of a nuclear installation and throughout its life. Such assessments shall be well documented, subsequently updated in the light of operating experience and significant new safety information, and reviewed under the authority of the regulatory body;
> 2) verification by analysis, surveillance, testing and inspection is carried out to ensure that the physical state and the operation of a nuclear installation continue to be in accordance with its design, applicable national safety requirements, and operational limits and conditions.

### II.J.1. NPPs

#### *a) Licensing Process*

The process initially applied for licensing of the Belgian nuclear power plants was described in previous reports for the Convention. Since the process would no longer be the same today and since many organisations and committees that played a role in this process do no longer exist (being replaced by other organisations and committees), it was judged no longer appropriate to describe this historic information in this report. However, if needed, the reader can find the information in the 2007 report for the Convention (in particular in paragraphs II.B, II.D and II.J.1).

In section II.B.1 of this report, more information can be found concerning an important outcome of the original licensing of the NPPs, being the high level of protection against external accidents (airplane crash, explosion, large fire, toxic gases).

Furthermore, it is worthwhile to note that the Safety Analysis Report (SAR) of all plants have been drawn up according to the standard format and content as applied in US, i.e. in accordance to Regulatory Guide 1.70 (revision 2 or 3). This was the case from the very beginning for the four more recent units (Doel 3 and 4, Tihange 2 and 3), while for the older units (Doel 1 & 2 and Tihange 1) the SAR was rewritten in this format afterwards, although minor deviations from the standard table of content of RG 1.70 may exist.

The table of content of the SAR was also extended:

- To include a new section (in Chapter 3) on the Probabilistic Safety Assessment performed for that plant (a consequence of the periodic safety reviews).
- To include a new section (in Chapter 3) on the Ageing Management Programme (a consequence of the WENRA Action plan, in particular WENRA Reference Level N.2.8).

Article 13 of the SRNI-2011 stipulates that the SAR shall be kept updated throughout the life of the installation so that the SAR exactly reflects its present state.

#### *b) Periodic Safety Reviews*

Article 14 of the SRNI-2011 requires a ten-yearly periodic safety review for each nuclear unit. The general objectives of these periodic safety reviews are as follows:

- to demonstrate that the unit has at least the same level of safety as it had when the licence was granted to operate it at full power, or since its latest periodic safety review;
- to inspect the condition of the unit, devoting more particular attention to ageing and wear and to other factors which may affect its safe operation during the next ten years;
- to justify the unit's current level of safety, taking into account the most recent safety regulations and practices and, if necessary, to propose appropriate improvements.

The list of technical subjects examined during the successive periodic safety reviews is given in extenso in VII to this Report.

(1) <u>Rules followed up to 2007</u>

The initial licence of each nuclear unit made it mandatory to conduct periodic safety reviews. These safety reviews must "compare on the one hand the conditions of the installations and the implementation of the procedures that apply to them, and, on the other hand, the regulations, codes and practices in force in the United States and in the European Union.

The differences found must be identified, together with the necessity and possibility of remedial action and, as the case may be, the improvements that can be made and the time-schedule for their implementation".

The topics to be studied in these safety reviews are detailed in a report submitted by the licensee to the FANC; in this way the rules retained become mandatory.

The feedback of operational experience of nuclear power plants at the international level is also considered; in this respect the "Bulletins" and the "Generic Letters" of the USNCR, as well as information available from other regulatory bodies, are examined, if their follow-up has not yet been required in the frame of the permanent supervision during operation of the installation.

From this, one can conclude that all the new rules of the USNRC are not automatically applied in the Belgian plants, and that non-American rules, guides and practices can also be retained for implementation in Belgium.

(2) Additional rules followed from 2007 onwards

In 2007, the FANC has required that the future safety reviews of all nuclear units are carried out by using the IAEA Safety guide NS-G-2.10 superseded by SSG-25. In October 2018, the SRNI-2011 has been modified to require the use of 14 Safety Factors in line with the WENRA reference levels of issue P.

The objectives of the safety review are multiple. In the review, the operator should assess, for each safety factor, the state of the installation and the organisation in relation with international legislation, standards and good practices. Furthermore, strong points and weaknesses should be identified, as well as compensating measures in the case that some weak points possibly cannot be modified. Finally, the assessment should show to what extent the safety requirements of the Defence in Depth (DiD) concept are fulfilled, in particular for the basic safety functions of reactivity control, fuel cooling and the confinement of radioactive material.

At the end of the process, an action plan including the associated deadlines is established and has to be approved by the FANC. The action plan should then be implemented within a defined delay (3 to maximum 5 years).

***c) During operation of the installations***

According to the requirements of article 23 of GRR-2001, the proposals for modifications to the installation are examined and approved by the Health Physics Department of the operator. Each proposal is classified into one of the three following categories, according to the principles of the FANC guidance 006-029, now superseded by a FANC technical regulation of 2 February 2021 (see section I.C.1) for the treatment of modification projects in the context of article 12 of the GRR-2001 for Class I facilities:

- Major modifications that change the basic characteristics of the unit. These modifications are subject to the application for a licence under the provisions of Article 6 of the GRR-2001. A major modification requires a new licence application and follows a licensing scheme similar to that described in section II.C.7 : The safety assessment performed by Bel V is presented to the FANC. The results of this assessment are presented to the FANC's Scientific Council, who will produce its conclusions on the acceptability of the modification and will propose, if deemed necessary, additional operational conditions. A new Royal Decree of Authorisation is prepared by the FANC and finally signed by the Minister of Home Affairs and the King. After a fully favourable acceptance report of the modification, reviewed by Bel V, a new confirmation decree, allowing operation, is issued (see II.C.7);
- Less important modifications that have a potential impact on safety. In a first phase, the requesting department of the licensee, indicating the justification for the intervention, presents a proposal for modification. In a second phase, the proposal is examined on its technical merits, and later on also by a multidisciplinary team including a.o. the Health Physics Department. In the next phase, studies are completed and approval of both the Health Physics Department and of Bel V is sought before the implementation of the modifications. Further activities then imply the implementation and testing of the modifications. Commissioning of the completed modification is subject to a positive

acceptance, issued after validation of the modification and re-qualification of the portion of the installation that was modified, and updating the operational documents. The Health Physics Department formally approves of the modification when all the files, procedures and the Safety Analysis Report have been adequately updated. This decision of the Health Physics Department has then to be confirmed by Bel V before operation, on the basis of its independent safety assessment. Such modification can either be a hardware modification or an organisational modification;

- Modifications without impact on safety, that usually do not imply modification of the Safety Analysis Report and which comply with all the safety rules of the installation. These modifications have to be approved only by the Health Physics Department of the unit, without formal involvement of Bel V, except for the possible sections of the Safety Analysis Report to be updated.

The decision in which category a specific proposal for modification should be treated is done by Bel V, based on a motivated proposal made by the Health Physics Department of the licensee.

### *d) Certain studies relating to the modifications*

Certain studies relating to modifications or initiated in the scope of the periodic safety reviews were so substantial that they had to be tackled as projects having their own specific structure:

- Severe accident analyses: ultimate strength of the containment in case of internal overpressure, installation of autocatalytic recombiners to prevent containment hydrogen build-up (installed in all the Belgian units), reactivity accidents during operation and during shut down states, installation of the filtered containment venting system.
- Power increase and burn-up cycle extension studies.
- Use of mixed core (presence in the core of fuel assemblies from different suppliers) requiring detailed studies regarding mechanical, neutronic and thermal-hydraulic compatibility.
- Replacement of the steam generators, whether or not linked to a power increase.
- Replacement of technologically obsolescent systems (instrumentation and control systems) addressing software qualification issues.
- Set up of an integrated ageing management system, in order to assure that safety related structures, systems and components remain qualified within their defined service life.
- Replacement of reactor pressure vessel head.
- Evaluation of the safety cases related to the reactor vessel flaws
- Continuous development of probabilistic safety analyses (PSAs) of L1 and L2 for the Doel and Tihange nuclear power plants (NPPs) performed by Tractebel ENGIE, on behalf of the utility ENGIE Electrabel.
- Extension of the PSA-models to include internal fire and flooding hazards
- Operational use of the PSA-models as additional tool for safety decision making
- The BEST action plan with a dedicated structure for the filtered containment venting systems
- Preparation for decommissioning and dismantling of Doel 3 and Tihange 2

More details on the topics mentioned can be found in previous national reports.

### *e) Verification Programmes*

The technical specifications (chapter 16 of the Safety Analysis Report) were examined at the time of the licensing process; their amendment during operation falls under the prescriptions for modifications that are subject only to approval by the operator's Health Physics Department and by Bel V. These technical specifications are reviewed in the frame of the period safety reviews. They have been completely rewritten at least once during the life of each nuclear power plant.

These specifications indicate for each status of the unit the operational limits and conditions, specifying also the actions to be taken if limits are exceeded. They also list the inspections and tests to be performed and their periodicity.

Specific programmes are established, in particular for:

- examinations and tests required by the ASME Code;
- inspection and repair of the steam generator tubes;
- fire protection;
- tests of ventilation filters;

- inspection of the primary pump fly-wheels;
- examination of irradiation samples of the pressure vessel.

Each safety-related equipment has a qualification file that contains all the qualification test requirements and results. In this file are also recorded the results of ageing tests or experience feedback of similar equipment, so defining the qualified life of the equipment. The qualified life determines the frequency of replacement of that equipment, which can be re-assessed in function of the real operational conditions and location of that equipment.

The reactor coolant pressure boundary is treated in a specific way. It was originally designed to ensure a minimum useful life taking into account a limited number of transients during normal, incidental and accidental operation. As for the reactor vessel, it is monitored according to the transition temperature evolution (NDT) based on an irradiated samples withdrawal programme. The occurrence rate of the design transients is strictly recorded under the close supervision of Bel V.

An In-Service Inspection programme is permanently implemented by personnel specifically qualified for these inspections, which are carried out during power operation of the unit or in shut down states.

All these tests and inspections are performed under fully detailed documented procedures.

#### *f) Updates of PSA*

ENGIE Electrabel uses PSA on a continuous basis as an additional tool to support nuclear safety decisions. It is for example provided in the utility procedures that PSA has to be used to assess plant modifications, procedural modifications and Technical Specifications modifications. It should be highlighted that PSA is nevertheless not a motive for changes in Technical Specifications.

### II.J.2. Research Reactors

#### *a) Main Results of Continuous and Periodic Safety Monitoring*

The continuous safety monitoring can lead to modifications. These are treated by the same process as above described for the NPPs.

Experimental devices are not necessarily considered as a modification of the reactor. A dedicated stepwise approval system was developed and is currently under review for further improvement. The experiment is at first discussed in an internal advisory committee. Based on the advice, the experiment has to be approved by the Health Physics Department and Bel V has to confirm this decision.

The installations of the SCK CEN are also subject to periodic safety reviews. Previously the reactors BR1 and BR2 had to undergo a 5 yearly safety review according to the licence for operation of the SCK CEN installations. In 2003 the periodicity of the safety reviews was changed by Royal Decree to 10 years for all the SCK CEN installations, as is the practice for nuclear power plants. The current (2016) periodic safety review is based on IAEA SSG-25. The action plan PSR 2016 has been finalized and the preparation of next PSR (report to be ready by June 2026) will start in 2023.

#### *b) BR1*

The latest safety review of BR1 included the following important topics:

- Study of reduction and optimization of storage of combustible radioactive waste and feasibility study for storage of spent fuel from BR1.
- SSCs: Identification, classification, ageing and study of replacement by state of the art components.
- Re-evaluation of standard accident and DBA's: Complete loss of cooling and Reactivity Insertion at start-up.
- Organisation and procedures: Evaluation of tasks and functions of the operation's team for BR1 (and VENUS) and GAP-analysis with existing procedures and Integrated Management System.
- Assessment of the emergency plan for BR1.

#### *c) BR2*

In 2016 the beryllium matrix of BR2 was replaced. According to the licence the matrix has to be inspected on regular intervals to follow cracking. Due to neutron irradiation, gases (helium and tritium) are formed in the beryllium. This causes swelling and the initial space between the beryllium blocks will be consumed and blocks will make contact with each other. The cracks are caused by deformation and mechanical stresses. The licence specifies that the beryllium matrix must be replaced if the inspection indicates that there is a risk of losing material. At the latest, the replacement must be done if the fluence reaches $6.4 \times 10^{22}$ fast neutrons per $cm^2$ for the most irradiated channel. The beryllium matrix was replaced in 2016 and is inspected according a scheme defined in the BR2 Safety Assessment Report. The actual matrix will reach its end of life in 2036. The exact date depends on the utilization (number of operation days and reactor power) of the reactor.

In case of replacement of the matrix, an inspection of the vessel, made of aluminium 5052-O, is also required by the licence. In fact, this is the only occasion when the vessel wall is accessible from inside. An inspection of the vessel was carried out in September 2015 using the same methodology and criteria as in 1996. Since the knowledge of irradiated aluminium is limited, the vessel assessment project is completed with the irradiation of samples taken from the shroud around the vessel. The samples are used to predict the mechanical properties (especially the fracture toughness) of the irradiation aluminium as a function of the neutron dose. The program shows that the mechanical properties of the vessel material could be sufficient to allow operation up to 2036. Over the next years, the follow up program about the properties of irradiated aluminium 5052-O will be continued. Together with the material follow up program new strength calculations are made to assess the influence of low cycle fatigue. Minimum required fracture toughness of the irradiated aluminium is calculated using recent fracture mechanics methodology

During the last years, several safety upgrades have been made. The most important is the replacement of the diesel generators. The new system is based on fly wheel generators for feeding the vital electrical grid. In normal operation the fly wheels are driven by the external grid. In case of loss of the grid, the fly wheels are powered by diesel generators. This system guarantees emergency power without any interruption in case of loss of the external grid. The electric grid has also been split into two separate trains.

A non-destructive inspection of the primary piping has been performed according to the principles of the ASME BPV Code, Section XI: In Service Inspection for Nuclear Power Plant Components. A first inspection period of 10 years is finished, and a second inspection period of 10 years has begun in 2022. This inspection makes use of the conclusions of the first round.

## II.K. Article 15. Radiation Protection

> Each Contracting Party shall take the appropriate steps to ensure that in all operational states the radiation exposure to the workers and the public caused by a nuclear installation shall be kept as low as reasonably achievable and that no individual shall be exposed to radiation doses which exceed prescribed national dose limits.

### II.K.1. Design

Chapter III "General Protection" of the GRR-1963 introduced from the very beginning in Belgian law the radiological protection principles.

Belgian nuclear power plants design was done according to that legislation and, furthermore, consistent with the US regulations and in particular 10 CFR50 Appendix I and the related Regulatory Guide 1.21. In fact, as demonstrated in the Safety Analysis Reports of Belgium's units, the objectives of the US regulations were amply met, considering that the doses to the population computed according to the US rules are smaller by a factor of at least 3 than the criteria prescribed by these rules.

The releases limits, in annual average or in instantaneous value, were presented in the Report to the European Commission (application of article 37 of the Euratom Treaty) and are discussed in the Safety Analysis Report (chapter 11).

### II.K.2.NPP Operation

#### *a) ALARA Policy*

Operational radiological protection programmes are inspired from chapter III of the GRR-2001 and from IAEA NS-G-2.7 (2002). Those programmes cover among others:

- Protective clothing and equipment;
- Training;
- Monitoring of individuals and workplace;
- Emergency plan;
- Health surveillance;

- Optimisation of protection;
- Etc.

The evolution has been taken into account, e.g. the introduction of the recommendations of the ICRP documents and the implementation of the Directive 96/29/EURATOM into the Belgian regulations.

To anticipate the implementation of these regulations ENGIE Electrabel has, on a voluntary basis, limited the individual worker dose at about the half of the dose limit which is 20 mSv for 12 consecutive months, in accordance with the GRR-2001.

Mid-2020, the Directive 2013/59/EURATOM has been fully transposed in the GRR-2001 (see section I.C.1). This led to some important changes with respect to operational radiological protection:

- Eye lens equivalent dose limit has been reduced from 150 mSv per 12 consecutive sliding months to 20 mSv for occupationally exposed persons, 15 mSv/y for students,
- Rules relative to "medical examination" have been revised and replaced by a new "Health surveillance", which is better aligned with the Code of Well-being at Work and ensures enhanced interactions between the certified medical doctors and the health physics experts,
- Information and training for workers, students and other persons liable to be exposed to ionizing radiation has been made applicable to external workers,
- External companies and operators (or head of the company) have been held responsible for the radiation protection and safety of the outside worker,
- The rules applicable to sealed sources have been strengthened,
- The use of the exposition register has been deployed to ensure adequate follow-up of all doses received by the workers throughout their career and new tasks for the health physics control have been defined with respect to the dosimetry surveillance programme,
- Etc.

Protection of the public is assured through limitation of the radioactive liquid and atmospheric releases. Those limits are presented in the Report for the European Commission (application of article 37 of the Euratom Treaty) and are discussed in the Safety Analysis Report (chapter 11), ensuring to limit the maximum dose to the individuals of the critical group well below 1 mSv per year. At the Belgian units the liquid effluents are released via one single pipe that groups the primary and secondary effluents and which is redundantly and automatically isolated in case an instantaneous limit is exceeded.

### *b) Implementation of radiation protection programmes*

(1) Dosimetric results

Various measures have been taken over the years to reduce the annual collective dose: the average value for the 7 Belgian units has been reduced by a factor of more than 4 during the 1990-2015 period.

Figure 12 represents the evolution of the outage collective doses of the Doel and Tihange sites since 1974.

The rise between 1974 and 1985 corresponds to the progressive start-up of the new units. The Tihange peak in 1986 is due to the extensive works linked to the first periodic safety review.

As the Tihange units operate along cycles up to 18 months, the number of refuelling outages varies from one year to the other, which introduces variations on the annual collective doses. Another factor of variation is the cumulated dose due to the replacement of steam generators at both Doel and Tihange. The introduction of an outage cycle of 18 months for Doel 4 in 2009 did not induce any significant variation in annual doses for the Doel NPP.

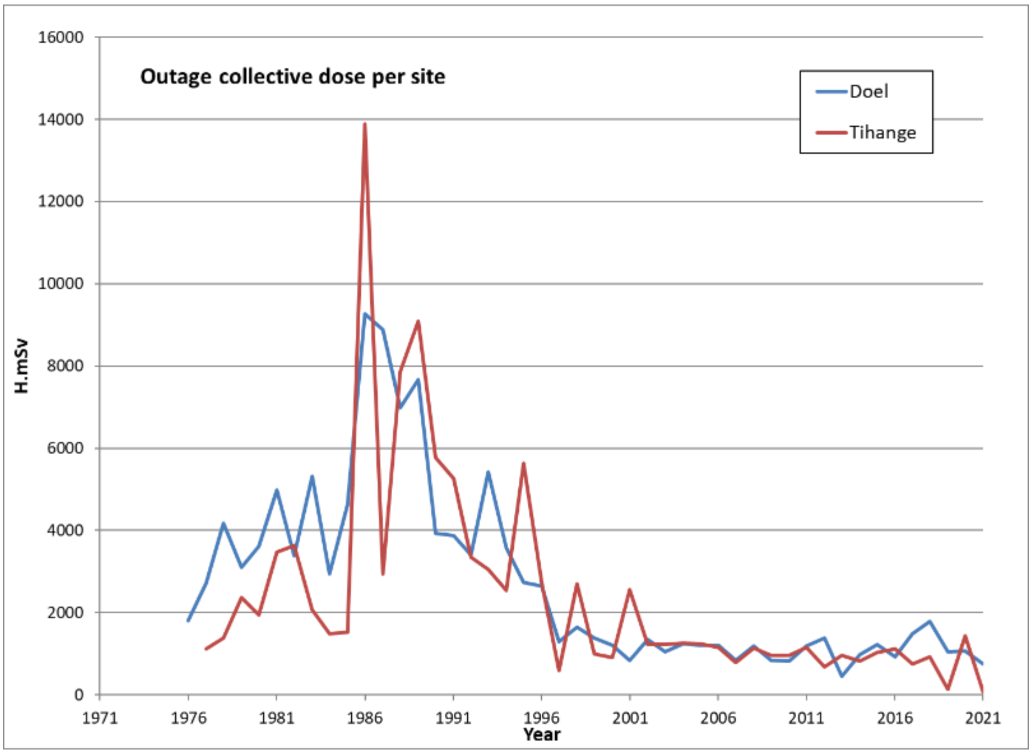


Figure 12 : Collective dose per outage

From 2017 onward, the radiological intensity of works during the outages at Tihange 1 and Doel 1&2 increased due to the projects executed in the framework of Long Term Operation (LTO). Examples include repairs on the reactor pressure vessel lid of Doel 1.

Actual individual exposure of workers amounts to an average of ~ 0.5 mSv per year. The dose constraint of 10 mSv per year, applied according to internal ENGIE Electrabel policies, had to be exceeded in 2018 for the first time since 2006, due to the specialized work that needed to be carry out in high radiation fields next to the reactor pressure vessel, for the repairs on the Upper Plenum Injection pipe at Doel 1 and 2. It should be noted that these works were thoroughly prepared beforehand, amongst others by placing lead shielding and training on a mock-up. No worker exceeded the legal limit of 20 mSv per year.

Good radiation protection performances are achieved through the optimisation of several parameters, whose main ones are briefly discussed below:

- The source term (dose rate and contamination);
- The monitoring of working places and individuals;
- The protective means (shielding and protective clothes);
- The time of exposure;
- The distance from the source term;
- The radiation protection culture.

(2) Reduction of the source term

The primary system chemical conditioning procedure applied in preparation of the core refuelling outages proved to be very effective to reduce the dose rates induced by the contaminated systems: a continuous decrease in mean dose rates has been recorded for the primary loops. This procedure was developed thanks to operational experience feedback from pressurised water reactors.

During the period 2007 – 2009, ENGIE Electrabel investigated the possibility to decrease the source term of plants characterized by higher figures than the average. Therefore, Doel NPP planned to initiate Zinc injection into the primary fluid of Doel 3 from 2010. Zinc injection is fully implemented since April 2011 and injection is still going on as of 2019. Over the years, the $^{60}$Co surface activity decreased, and there has been a higher decrease of the ex-core dose rates during the last cycles, which can be linked to the zinc injection.

In the period 2000 - 2007, statistics of fuel failures seemed to indicate a slight increasing trend. Therefore, ENGIE Electrabel put additional effort aimed at preserving the integrity of the 1st and 2nd barrier:

- Pay a special attention to the fuel assemblies' quality,
- Develop an intensive Foreign Material Exclusion (FME) programme,
- And develop an intensive programme of leakages tracking.

This effort proved to be efficient from 2009 onwards. During the past years, no new leaking fuel rods were detected.

Finally, since 2007, special effort is put on the improvement of the radiological cleanliness of the workplaces, connected to the associated monitoring (see below). The whole ENGIE Electrabel fleet can now display the following contamination performances:

- More than 97% of the Radiation Controlled Area (RCA) rooms are radiologically clean (i.e. surface contamination < 0,4 Bq/cm$^2$ beta/gamma);
- Residual individual contamination rate at the exit of RCA historically ranged between 0,5 and 1,5%. Between 2019-2021, an average of ~ 0.4% was obtained (averaged over the 7 reactors), thereby well respecting the internal objective of 0.7%.

(3) Monitoring of the working places and individuals

Systematic measurements of the surface contamination of the floors in representative locations during the outage are done daily. Immediate decontamination action is taken should a problem be detected. Effectiveness of the housekeeping activities inside the controlled area is pursued. Additional portable means for measuring the volumic activity (aerosols, iodine, and gases) are placed at the pool floor of the reactor building and at the access locks to the steam generators.

Since 2007, ENGIE Electrabel improves the monitoring of the radiological cleanliness, covering the monitoring of the radiological cleanliness of the (un)clean working areas, monitoring of the contaminated individuals at the exit of radiation controlled area (RCA) and the tracking and elimination of the cause of contamination.

Signalling of the hot points and the ambient dose rates informs the workers about the ambient radiological conditions in which they will carry out the work: access is denied to certain locations, without specific permission of the Radiological Protection Department. Specific radiation signalling indicates very low dose-rate areas ("green" area) which the workers may use as an identified falling-back station.

Personal dosimetry of the workers is achieved through the simultaneous wearing of a passive and an active (electronic) dosimeters. The latter one is set up in order to alert the worker in case excessive dose and dose rate, depending on the type of work. Throughout the outage period, the actual-versus-estimated dosimetry trends are monitored daily, and any significant deviation is analysed and may result in corrective actions.

On 1st Jan 2012, the Tihange NPP replaced the passive film dosimeters (which are becoming obsolete) by the more precise, state-of-the-art Optically Stimulated Luminescent (OSL) dosimeters.

From 2015 to 2017, the Doel NPP replaced the electronic personal dosimeters (EPD's). From 2018 onwards, the progressive replacement of the passive film dosimeters with OSL dosimeters is also carried out. At the moment, the intervention and BEST dosimeters are already replaced by OSL dosimeters.

(4) Protective means

Shielding is systematically installed at various locations during core refuelling outages: primary pump cell floor, between steam generator and primary pump, around pressure vessel-head on its stand, vessel-well decompression piping, corridor at the hot penetrations, places of passage and waiting (access locks to the steam generators...), hand-holes of the steam generators...

Specific shields are also installed when deemed necessary with regard to the size of the work: pressuriser dome, valves, detected hot points...

Protective clothing is foreseen for both regular entrance in radiologically controlled areas and for work requiring breath protection clothing.

(5) Reducing time of exposure

Reducing the time of exposure is achieved through appropriate:

- pre-job briefing;
- training on make-up facilities;
- experience feedback;
- etc.

For interventions in areas with high radiation fields, for example the inspections and repairs of the Upper Plenum Injection pipe next to the reactor pressure vessel at Doel 1 and 2 in 2018, operators first have to train beforehand on a mock-up before work authorisation. During the last years, additional effort was also set on the avoidance of "search dose", starting from the statement that a significant part of the workers exposure came from the initial step of just finding the equipment(s) on which one has to intervene.

(6) Distance from the source

Keeping distance from the radiation source considered in the work preparation and supported by the monitoring system and the related databases (e.g. see above about the "green area").

(7) Radiation protection culture

Internal and external workers are all committed to follow a base training "nuclear safety culture" encompassing radiation protection, prior to gaining access to the controlled zone of the Nuclear Power Plant. This base training includes sessions in a simulator area. A yearly refresher training is mandatory as well. Both the base and refresher training are used as opportunity to highlight the various parameters that intervene in order to reach good radiation protection results.

Late 2015, both sites of Doel and Tihange launched the project to enhance the representativeness of the simulation school, using pseudo radioactive contaminants and simulating the radiation fields, coupled to active electronic personal dosimeters.

### ***c) Radioactive Releases***

Discharges are defined as authorised and controlled releases into the environment, within limits set by the licence and regulations. In addition, there are operational release limits (limiting the release on time based assumptions), related with a scheme to notify the operators, the Health Physics Department, Bel V and the FANC.

The radiological impact of the authorized release limits to the most exposed individual of the public are given in the Table 5:

| | Gaseous releases | Liquid releases | **Total[6] maximum** |
|---|---|---|---|
| Tihange Site (3 units) | 190µSv | 80µSv | **210µSv** |
| Doel Site (4 units) | 180µSv | 230µSv | **370µSv** |

Table 5 : Impact of Release Limits

From 1 January 2011, the radioactive releases have to be reported to the Belgian Safety Authorities following a new method, inspired from the 2004/2/Euratom Recommendation and ISO 11929 standard. The impact of this new approach was significant, as the methodology implies a conservative declaration of isotopes below the detection level of the measurement devices, which automatically increases the release figures (see Table 6):

- **Iodine releases**: more than 10 % increase,
- **Aerosols releases**: more than 100 MBq/year in total for both sites, due to the fact that about 20 isotopes are below detection level and must be declared as a fixed amount.
- **Liquid releases**: about 2 times the previously declared values for both sites, due to the reason mentioned for aerosols.

[6] the total maximum is not the sum of the dose due to the gaseous release and the dose due to the liquid release because the most exposed individual by each type of release is in not in the same age category

- **Tritium releases**: no significant change.

The releases that take place effectively are only a few per cent of the limit values, except for tritium where the limit values had been chosen based on the operational experience of similar plants.

| | **Tihange** Nuclear Power Plant | | | | |
|---|---|---|---|---|---|
| | Gaseous releases | | | Liquid releases | |
| | Noble Gas GBq | Iodine MBq | Aerosols MBq | βγ GBq | Tritium GBq |
| Annual limit | 2 220 000 | 14 800 | 111 000 | 888 | 148 000 |
| 2008-2010 average | 15 433 | 23 | 3,4 | 13 | 47 367 |
| 2011-2015 average | 6054 | 14 | 250,2 | 10,7 | 40973 |
| 2016-2021 average | 4813 | 10 | 246,9 | 14,6 | 37269 |
| 2021 values | 4737 | 8,76 | 218,4 | 6,11 | 29878 |
| **2021 % of the limit** | **0,21** | **0,06** | **0,22** | **0,69** | **20,19** |

| | **Doel** Nuclear Power Plant | | | | |
|---|---|---|---|---|---|
| | Gaseous releases | | | Liquid releases | |
| | Noble Gas GBq | Iodine MBq | Aerosols MBq | βγ GBq | Tritium GBq |
| Annual limit | 2 960 000 | 14 800 | 148 000 | 1 480 | 103 600 |
| 2008-2010 average | 25 | 62 | 6,1 | 3,5 | 48 870 |
| 2011-2015 average | 37594 | 53 | 96,4 | 4,9 | 39293 |
| 2016-2021 average | 39653 | 20 | 44,7 | 3,8 | 39540 |
| 2021 values | 30788 | 20,1 | 28,2 | 4,5 | 47373 |
| **2021 % of the limit** | **1,04** | **0,14** | **0,02** | **0,31** | **45,73** |

Table 6 : Release to the environment of the NPP-sites

Radiation monitoring of the environment and assessment of public health impact is assured by a programme set up and managed by the FANC, as stipulated in Article 71 of the GRR-2001. However, a side surveillance program performed by the ENGIE Electrabel, in the vicinity of the plants, has been developed, as follows:

| Specific sample | Location and frequency | Measurement specifications |
|---|---|---|
| Terrestrial bio-indicator (lichen or mosses) | Annually on 2 locations in most prevalent wind direction and on 1 reference location | γ spectroscopy ($^{134,137}Cs$, $^{131}I$, $^{60}Co$), $^{3}H$, $^{14}C$ |
| Aquatic bio-indicator (algae, seaweed, mussels)[1] | Annually on 2 locations downstream and on 1 reference location upstream | γ spectroscopy ($^{134,137}Cs$, $^{131}I$, $^{60}Co$, $^{95}Nb$, $^{110m}Ag$), $^{3}H$, $^{14}C$ |
| Soil (pasture soil) | Annually on 2 locations in prevalent wind direction and on 1 reference location | γ spectroscopy ($^{134,137}Cs$, $^{131}I$, $^{60}Co$), $^{3}H$, $^{14}C$ |
| Grass (pasture) | Annually on 2 locations in prevalent wind direction and on 1 reference location (see soil sampling) | γ spectroscopy ($^{134,137}Cs$, $^{131}I$, $^{60}Co$), $^{3}H$, $^{14}C$ |
| Sediment | Annually in river Meuse or Scheldt, two sediment samples downstream in addition to the sediment sampling in the monitoring campaign of FANC/AFCN within 10 km from NPP and at 1 reference location upstream. | γ spectroscopy ($^{134,137}Cs$, $^{131}I$, $^{60}Co$, $^{95}Nb$, $^{110m}Ag$) |

Table 7 : Surveillance programme performed by ENGIE Electrabel

### II.K.3. Research reactors

The management of the SCK•CEN introduced 10 mSv per year as a dose constraint for the personnel. Beside this constraint the SCK•CEN has an active ALARA policy. Each task with a potential exposure is analysed before starting and dose optimisation is performed. Afterwards, the predicted doses are compared with the real measured dose, in order to learn from the experience such that predictions for future tasks can be improved. Due to this ALARA policy, the radiation dose for the personnel has been reduced. During the last years, the total collective dose per year is about 100 man.mSv, for about 800 persons. More important, the maximum individual dose during the last years always has been far below 10 mSv per year. A collective dose of about 70 man.mSv can be attributed to the operation of BR2 (Figure 13. This figure remains fairly constant during the last years. The higher value for 2015 (91 man.mSv) is caused by the unloading of the matrix and a large number of inspections during the shutdown. The collective dose for BR1 operation is about 3 man.mSv per year and remains stable during the last years. The main contribution to the dose is the handling of experiments, such as neutron activation analysis and reactor dosimetry.

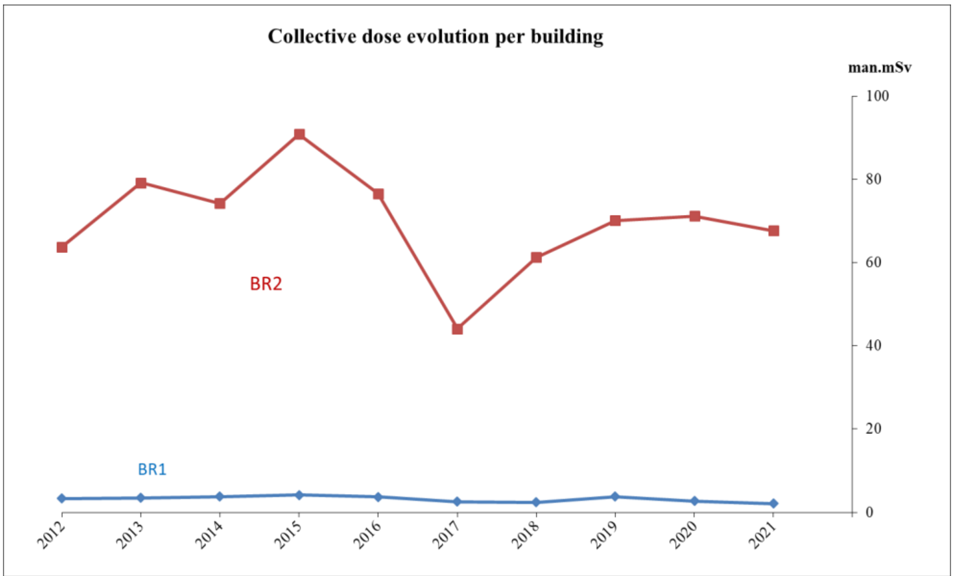


Figure 13 : Total Dose evolution per installation

### ***Gaseous releases***

The limits for radioactive gaseous releases were reviewed in 2002, following the implementation of the GRR-2001. The proposal was accepted by the FANC and the limits are integrated in the SCK CEN Safety Analysis Report. The limits for the releases are defined such that the most exposed person in the environment could receive an effective dose of 100 µSv per year due to the operation of the SCK CEN installations. 10 µSv per year is assigned to the operation of BR1 and 20 µSv per year to the operation of BR2.

The following gaseous releases are considered:

- For BR1: βγ activity of aerosols and I-131. Since BR1 is an air cooled reactor, it releases also Ar-41. The released activity is directly proportional to the reactor power and the releases of Ar-41 are calculated, not measured;
- For BR2: βγ activity of aerosols, a activity of aerosols, I-131, tritium and noble gases.

The releases of the last years are indicated in Figure 14. It is to be noted that BR2 stopped in February 2015 for replacement of the beryllium matrix and was restarted June 2017. The following comments could be made on the releases:

- The increased release during the years from BR1 of Iodine for the years 2017 and 2018 can be attributed to a higher number of operational per days year. Releases have since 2019 reduced to a previous back ground level;
- The release level of noble gases in BR2 is normally below detection level. However, there have been a number of air-cooled experiments. These caused the release of argon-41 as an activation product. Since 2018 this experimental loop has not been used, although it is still available;
- The main source for release of gaseous tritium is an old experimental device were helium-3 was used as a variable neutron screen. Irradiation with neutrons of helium-3 results in tritium. The installation is still present at the moment, but screens are no longer used with helium-3 and dismantling has begun. However, they still release some tritium;
- In the year 2019 two capsules containing irradiated Selenium broke during the treatment in the hot cell. This provoked a significant release of $^{75}$Se (half live about 120 days) to the environment through the chimney. The release was still measurable in 2020 and very limited in 2021. At this moment the release of $^{75}$Se is no longer significant. As separate graph of the total released quantity is given in the figure below. These releases are not taken into account the graph about the total quantity of βγ particles released in routine operation, as this would mask all other data. As a consequence of this incidents, the irradiation of Selenium is stopped for the moment.

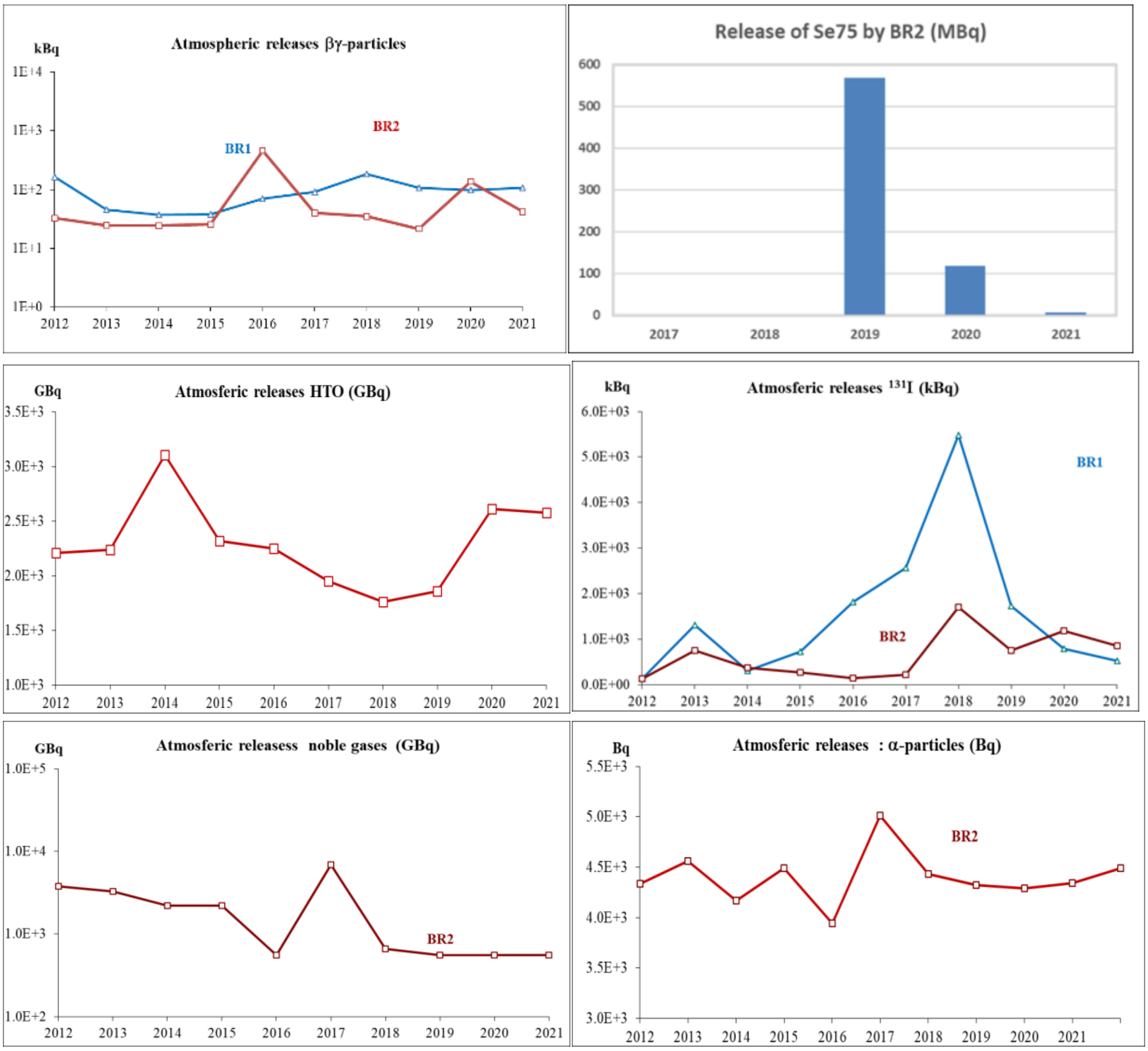


Figure 14 : Atmospheric Releases for SCK•CEN

### *Liquid releases*

The SCK CEN has no direct releases of liquid radioactive waste. All potentially contaminated water is sent to the waste treatment installation of Belgoprocess, where the water is treated before release to environment. Water contaminated with $^{75}Se$ required a special treatment, as this isotope is not expected in normal release and the waste water treatment is not designed to remove this isotope. A large quantity of $^{75}Se$ contaminated water was stored on site and only released when the $^{75}Se$ was sufficiently decayed.

### *Environmental control*

In addition to the direct stack measurements, 6 air measurement points are available around the site of the SCK CEN. The a- and β- activity of air samples is continuously measured. Air samples of one of these measurement points is analysed monthly by spectrometry, in order to have an absolute measurement of the air contamination.

Possible water contamination is checked in four different situations: surface water (running water and water from lakes), ground water and drinking water. In routine, the total a- and β- activity and the concentration of tritiated water is measured. On request other measurements are possible.

Regular samples of milk and grass of a neighbouring farm are taken and measured by spectrometry for potential radioactive contamination

The above-mentioned programme is managed by SCK CEN, and complemented with an automatic monitoring network for airborne radioactivity and a surveillance programme of the territory and the food-chain under initiative of the FANC.

## II.K.4. Regulatory activities

### *a) Radiological surveillance of the Belgian territory*

The TELERAD network is the automatic measurement and alarm network for radioactivity on Belgian territory. It consists of 250 measuring stations that continuously measure the radioactivity in the air and the water of the rivers and is discussed in more detail in section II.L.2.b).

In addition to this network there is a radiological monitoring program of the territory, which is currently based on more than 4660 annual samples, which are the subject of nearly 28 000 analyses of alpha, beta and gamma radiation.

The samples are taken by specialized teams on behalf of the FANC. They are then analysed in laboratories to accurately determine the nature and level of radioactivity that they contain. The FANC then centralises, analyses and interprets the results obtained.

### *b) International Exchanges*

The regulatory body and the Belgian operators participate actively since 1991 in the ISOE (Information System on Occupational Exposure) programme of OECD's Nuclear Energy Agency.

The Belgian NPPs operator is also participant in the working groups of the VGB (Germany).

## II.L. Article 16. Emergency Preparedness

1) Each Contracting Party shall take the appropriate steps to ensure that there are on-site and off-site emergency plans that are routinely tested for nuclear installations and cover the activities to be carried out in the event of an emergency. For any new nuclear installation, such plans shall be prepared and tested before it commences operation above a low power level agreed by the regulatory body.
2) Each Contracting Party shall take the appropriate steps to ensure that, insofar as they are likely to be affected by a radiological emergency, its own population and the competent authorities of the States in the vicinity of a nuclear installation are provided with appropriate information for emergency planning and response.
3) Contracting Parties which do not have a nuclear installation on their territory, insofar as they are likely to be affected in the event of a radiological emergency at a nuclear installation in the vicinity, shall take the appropriate steps for the preparation and testing of emergency plans for their territory that cover the activities to be carried out in the event of such an emergency.

## II.L.1. Legal and Regulatory Framework

- The GRR-2001 in its Article 72 requires an emergency plan for the regulated installations potentially presenting a serious radiological risk;
- Article 16 of the Royal Decree of 30 November 2011 requires each licensee of a Class I facility to set up an internal Emergency plan;
- The Royal Decree of 1$^{st}$ March 2018 defines a nuclear and radiological emergency plan for the Belgian territory.

## II.L.2. Implementation of Emergency Organisation in the Event of an Emergency

### *a) Classification of Emergency*

The Royal Decree of 1 March 2018 defines three levels for the notification of emergencies according to the classification systems of GSR-7, which are in ascending order of seriousness Facility Emergency, Site Area Emergency and General Emergency, which the operator must use when warning the National Crisis Centre (NCCN) which assembles under the authority of the Minister of Home Affairs. In addition, a fourth emergency class (General Emergency in 'reflex' mode) has been considered to cope with events with fast kinetics. In case an emergency situation is quickly developing (fast kinetics) and might lead within 4 hours to a radiation exposure of the population above an intervention reference level, immediate protective actions for the off-site population – without any assessment – are taken by the local authorities (Governor of the Province), waiting for the full activation of the emergency cells. The "automatic" protective actions taken under this "reflex"-phase are essentially limited to **warning**, **sheltering** and **keep listening** within a predefined **reflex zone**. Once the crisis cells and committees are installed and operational, the Emergency Director of the authorities will decide to cancel the reflex phase and to replace it by the proper emergency level. In such case the governor of the province hosting the nuclear site is immediately notified in parallel to the warning message to the National Crisis Centre. For each of these 4 emergency classes (Facility Emergency, Site Area Emergency, General Emergency and General Emergency in 'reflex' mode) the notification criteria are defined in the Royal Decree of 1 March 2018. In addition, for each nuclear installation concerned, a set of particular types of events is established for each of the emergency class. In the specific case of the General Emergency in 'reflex' mode emergency class, the activation criteria are based on predefined scenarios.

For example, the criterion associated with the Facility Emergency level is defined as follows: "Event which implies a potential or real degradation of the safety level of the installation and which could further degenerate with important radiological consequences for the environment of the site. Radioactive releases, if any, are still limited and there is no immediate off-site threat (no action requested to protect the population, the food chain or drinking water). Actions to protect workers and visitors on site might be necessary."

Each of these 4 emergency classes (Facility Emergency, Site Area Emergency, General Emergency and General Emergency in 'reflex' mode) activates the federal emergency plan. In addition to these four levels, a "Alert" level is defined for notifying the Authorities in case of a serious enough operational anomaly that request an evaluation by the regulatory body (concertation between FANC and Bel V) to decide whether or not it is worth activating the emergency plan. Other minor operational anomalies and situations that could raise public interest (such as any intervention of emergency services on site) must be communicated to the authorities, immediately or on the first next working day according to criteria for "Declaration" stated by the regulatory body.

All emergencies (Facility Emergency, Site Area Emergency, General Emergency and General Emergency in 'reflex' mode) have to be notified to the National Crisis Centre. This permanently manned centre alerts and mobilizes the cells involved in the crisis management at the federal level (Management Cell Federal Coordination Committee, Evaluation Cell, Measurement Cell, Information Cell) and houses these cells during the crisis situation as well.

In the case of General Emergency in 'reflex' mode, the Governor of the province hosting the nuclear site immediately takes the 'reflex' protective actions (warning, sheltering and keep listening) in a pre-defined 'reflex' zone around the affected site. As soon as all the National Crisis Centre's cells are in place and operational, the General Emergency in 'reflex' mode level will be later converted to an appropriate emergency level (Facility Emergency, Site Area Emergency or General Emergency) by the emergency director of the authority according to the evaluation of the situation and possible consequences. At that time the responsibility of the conduct of the operations returns to the Federal Minister of Home Affairs (or his representative).

#### *b) National Master Plan for Organisation in the Event of Emergencies*

The National Crisis Centre (NCCN in figure 13) is composed of the "Federal Co-ordination Committee" chaired by the Emergency Director of the Authorities, of the evaluation cell, of the measurement cell, and of the information cell, as indicated in Figure 15.

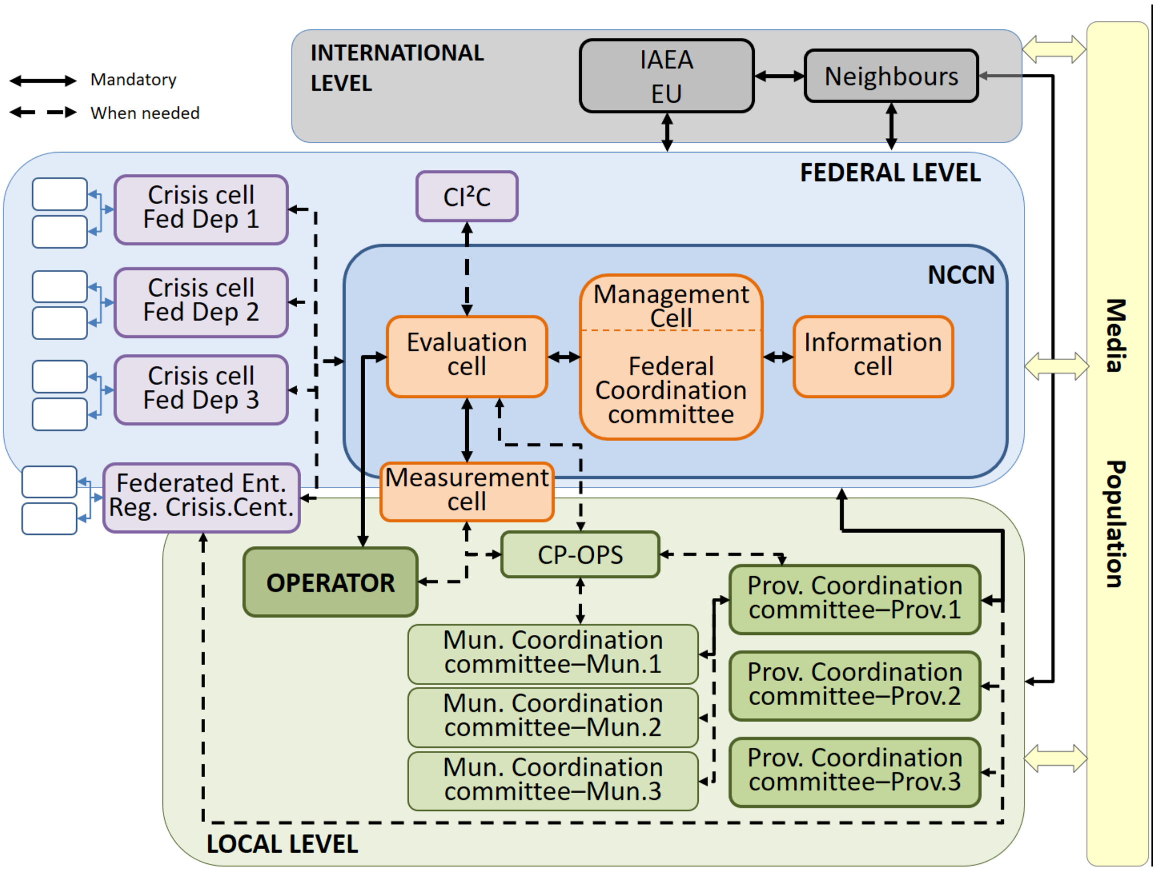

Figure 15 : EP&R organisation for Belgium

In case of an accident abroad, the National Crisis Centre, as National Warning Point (NWP), is informed by the Ministry of Foreign Affairs, the IAEA (through quick information exchange system USIE), the European Commission (through the European Commission Urgent Radiological Information Exchange system) or other reliable sources. The "Emergency Director" of the Authorities as National Competent Authority for accidents Abroad (NCA-A) could also be informed by the IAEA and/or the EC. This information channel provides possible redundancy. In case of an accident in a Belgian installation, the operator's "Emergency Director" informs the National Crisis Centre and supplies all the information that becomes known to him as the accident evolves.

The data received through Belgium's TELERAD network for automatic radiological monitoring can also be accessed by the National Crisis Centre and internationally through EURDEP and IRMIS. TELERAD is a network with the principal aim to measure routinely the radioactivity and to make measurements in case of an accident occurring in a Belgian nuclear site or abroad. The monitoring of the territory consists in a measurement network having a 20 km mesh (GM detectors), measurement stations in the vicinity of the Belgian nuclear installations and along the Belgian border in the vicinity of nuclear power plants in neighbouring countries. Around the Belgian nuclear sites, the network is arranged in two rings: the first ring (NaI scintillators) is on the site border and measures ambient radioactivity around the site, the second ring (GM detectors) covers the near residential zone, between 3 and 8 km from the site, depending on the direction. The monitoring network has 226 stations for the measurement of the ambient dose rate in air, 7 stations for the measurement of iodine and β/γ in aerosols and 11 stations for the measurement of radiation in river water; 13 stations are complemented with a meteorological mast.

Next to the fixed measuring station network, 24 mobile measuring devices (GM detectors) are available to be positioned where needed e.g. to fill up gaps between fixed stations.

Figure 16 depicts the TELERAD network:

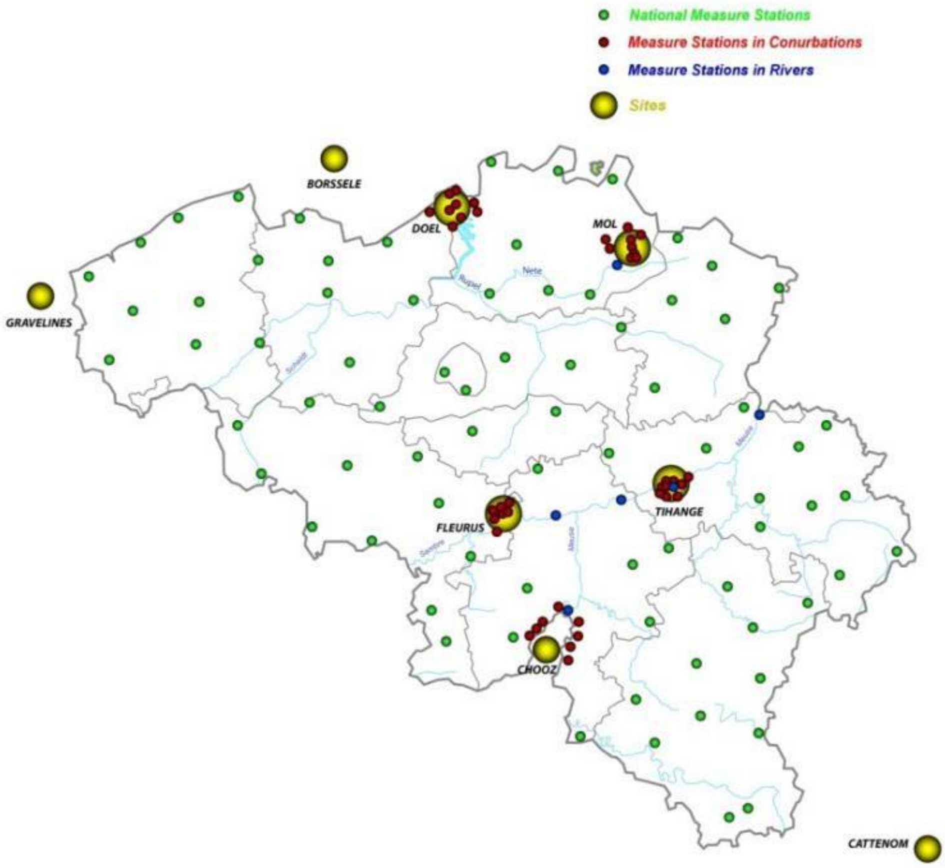


Figure 16 : TELERAD Network: location of the measuring stations

The Federal Management Cell, together with the Federal Coordination Committee, is the official leader of the conduct of the operation in case of an emergency. It defines the general strategy to deal with the emergency, takes the basic decisions (need and extent of direct protective actions for the population and/or for the food chain or the drinking water supply) and assumes the political responsibilities. The Management cell leans notably on the advices of the Evaluation cell on radiological aspects and on the relevant crisis cells of ministerial departments for the socio-economic aspects. The decisions taken are then transmitted for practical implementation and execution to the Provincial Crisis Centre, managing all the multidisciplinary intervention teams (fire brigades, civil protection, police, medical emergency services...).

The evaluation cell is composed of representatives of the relevant departments (in particular the FANC which chairs the cell), the Federal Public Service of Public Health, the Royal Institute of Meteorology, and of experts of the SCK CEN, the "Institut des Radioéléments", and of Bel V that supervises these installations, as well as of a representative of the operator of the facility. This cell gathers and evaluates all information received from the affected installation, the off-site radiological measurement results received from the Measurement Cell and information from institutions represented in the evaluation cell. It evaluates the installation status and its estimated time evolution in order to assess the real or potential impact of the event. Then, it advises the decision cell on protective actions for the protection of the population and the environment. This advice is elaborated on the basis of intervention criteria provided in the NEP. The evaluation cell is also responsible for the preparation of the relevant information to be communicated to neighbouring countries and to the international organisations (European Commission, IAEA) in accordance with the Convention on Early Notification of a nuclear Accident and the "Ecurie" convention.

The measurement cell co-ordinates all the activities related to the gathering of field radiological information (external radiation in the air and from the deposits, samples measurements, ...) transmitted either by the automatic radiological measurements network, TELERAD, or by the field teams. The measurement cell then transmits the collected and validated information to the evaluation cell.

The information cell is in charge of communications with the media and the population as well as with the neighbouring countries and specific target groups.

The relevant crisis cells of ministerial departments advise the Federal Coordination Committee on the feasibility and economic and social consequences of their decisions; it informs the Federal Coordination Committee about the follow-up and ensure the management of the post-accidental phase and an as prompt as possible return to normal life.

Depending on the scope, the cells which compose the National Crisis Centre (Emergency and Coordination Committee, Evaluation Cell, Measurement Cell and Information Cell) participate in exercises of the emergency plans at the relevant facilities.

The Royal Decree of 1 March 2018 defines the emergency planning zones relative to the direct actions to protect the population (evacuation, sheltering, and iodine thyroid blocking). The evacuation planning zones extend to a 10 km radius around the nuclear plants; the sheltering and ITB planning zones extend to 20 km around the nuclear plants.

The intervention criteria levels are set in the NEP. They are 5 mSv expected total effective dose integrated over 24 hours e.g. taking into account all direct exposure pathways (cloud shine, inhalation and ground shine) for sheltering, 50 mSv expected total effective dose integrated over 7 days (1 week), i.e. by taking into account all direct exposure pathways (cloud shine, inhalation and ground shine) for evacuation. For intake of stable iodine (ITB protective action), the intervention reference levels are 10 mSv thyroid equivalent dose for children less than 18 years and pregnant or breastfeeding women and 50 mSv for adults.

For off-site radiological calculations, focusing on the urgent protective actions, the licensee has to implement a radiological assessment model. For that purpose, a dose/dispersion model developed by the Belgian Nuclear Research Centre (SCK CEN) is used. The model is a segmented Gaussian plume model, based on the Belgian (also called Bultynck-Malet or SCK CEN) turbulence typing scheme and the associated dispersion ('sigma') parameters [7]. These parameters were obtained using extended tracer experiments on each site during the sixties/seventies. The calculation domain extends up to 50 km around the release point. For the Tihange site empirical correction factors were introduced to take the more complex topography into account. Calculations are done per time step of 10 minutes, extrapolations (projections) over time can be made as well. In addition to the dispersion model, a set of standard scenarios has been developed in order to perform quick assessments at early stages. In the latest version of the diffusion model [8], the parameters associated with the standard scenarios have been stored in a database allowing rapid projections for any of the pre-defined scenarios. In addition, simplified and user friendly tools and models are available to the evaluation cell and FANC-Bel V for cross-check validations and/or specific projections.

The exposure pathways considered for urgent protective actions are cloud shine dose, inhalation dose and ground shine dose (instantaneous and integrated up to one day and two weeks). Ingestion pathway would be covered by implementing measures on the food chain (food ban...).

Effective doses for adults and thyroid doses for adults and children are calculated. Deposition of iodine (limited to I-131) and caesium (limited to Cs-137) are also calculated. Related to forecasts, the total doses as well as the projected doses are calculated.

The National Emergency Plan is continuously evolving and is worked on a permanent basis. This effort incorporates lessons learned from emergency exercises and aims at a steady progress in the development of standardized working procedures and tools for diagnostic purposes, radiation monitoring strategy and decision making.

### *c) Internal and External Emergency Plans for Nuclear Installations, Training and Exercises, International Agreements*

The emergency plan of each Belgian unit is systematically described in its Safety Analysis Report (chapter 13, § II.I.3). In complement, an "internal emergency plan" details the instructions for all the actors.

---

[7] H. Bultynck and L.M. Malet, Evaluation of atmospheric dilution factors for effluents diffused from an elevated continuous point source, TELLUS Vol 24, N°5 (1972).

[8] A. Sohier, Expérience et évaluation des codes de calcul de doses actuels utilisés en temps de crise nucléaire, Annales de l'Association belge de Radioprotection, Vol 24, N° 4 (1999).

In case of accident the unit's "Centre Opérationnel de Tranche" (COT - Tihange) – "Bedrijfskamer" (Doel) (i.e. the On Site Technical Centre) is activated and manages all the technical problems to control the accident and mitigate its consequences. At site level, the "Centre Opérationnel de Site" (COS - Tihange) – "Noodplankamer" (NPK - Doel) (i.e. the Emergency Operations Facility) manages the environmental impact, liaises with the National Crisis Centre, and communicates with the Corporate crisis Organization.

The nuclear power plants conduct internal exercises several times a year, and the Civil Protection and of Crisis Centre Directorates of the Home Affairs Federal Public Service (FPS) organise one internal and one external exercise annually for each nuclear power plant and every two years for other sites.

Consistent with the intended objectives, the FPS involves the various disciplines (fire brigade, medical help, police force, civil protection, measurement teams, ...) in these exercises.

The operator is requested to draw up a scenario with which the objectives can be tested.

During the exercise, the information corresponding to the scenario is gradually forwarded to the various participants; the Training Centre full-scope simulator may in certain cases also be used on-line during exercise to provide information needed.

Information exchange at the international level is performed through the National Crisis Centre, which has contacts with the competent Authorities of the neighbouring countries, and which is the "national contact point" for Convention on Early Notification of a Nuclear Accident (IAEA) and for the similar European Union system (ECURIE).

Agreements also exist at local and provincial level. The protocol Agreement between the province of "Noord Brabant" (The Netherlands) and the province of Antwerp (Belgium) provides for a direct line between the alarm station of Roosendaal (The Netherlands) and that of Antwerp, informing it as soon as the emergency class Site Area Emergency is declared. This direct line is also used when certain accidents occur in the chemical industry (installations within the scope of the European post-Seveso Directive). A direct information exchange can also take place between the alarm station of Vlissingen (The Netherlands) and that of Ghent should an accident occur at the Borssele nuclear power plant. For the Chooz B and Tihange power stations, there are agreements between the Prefecture of the Ardennes department (France) and the province of Namur (Belgium).

In the frame of the agreement between the Government of the French Republic and the Government of the Kingdom of Belgium about the Chooz nuclear power plant and the exchange of information in case of incidents or accidents, a mutual alarm is foreseen between the two countries in case of an accident occurring in the nuclear plants in Tihange, Chooz or Gravelines. This alarm takes place between the National Crisis Centre on the Belgian side and the "COGIC", ("Centre opérationnel de gestion interministérielle des crises") on the French side.

During the exercises of Chooz and of Gravelines that transborder collaboration is regularly tested at the local and national levels. In addition, a direct exchange of technical and radiological information takes place between the organisations in charge of the expertise (IRSN on the French side, Bel V on the Belgian side) and in charge of the advice (Nuclear Safety Authority in France, Evaluation Cell of the National Crisis Centre in Belgium) and is quite successful. Based on these experiences, information exchanges have been developed as well as their implementation modalities between the French and Belgian parties involved with the view to be operational for further exercises and in case of incidents and accidents.

Regarding independent evaluation in the event of an emergency, Bel V sends a representative to the concerned affected site (in Belgium) and to the evaluation cell of the National Crisis Centre to contribute, based on the collected technical information and data, to the technical and radiological assessments used to support the issue of advices and recommendations of protective actions.

On April 28, 2004 an agreement was signed between Luxembourg and Belgium concerning the exchange of information in case of incidents or accidents with potential radiological consequences.

Table 8 gives an overview of some exercises (national and international) performed during the reporting period June 2019 – May 2022 (only for the installations within the scope of the CNS):

| Date | Site | Type | Objectives |
|---|---|---|---|
| 02/07/2019 | SCK CEN | National limited | Partial exercise, limited to the interaction and information exchange between the site emergency management team of the licensee and the federal evaluation cell CELEVAL. |
| 02/04/2019<br>02/09/2019<br>27/11/2019 | ECUREX | International | Test of notification and information exchange procedures. |
| 15/07/2019 | ConvEx 1b | International | Test of notification procedures (USIE).<br>Test of the coordination of national assistance capabilities by NCA(A). |
| 24/10/2019 | ConvEx 2d | International | Test whether National Competent Authorities can appropriately fill out reporting forms, drill the appropriate procedures for information exchange and practice the IAEA's assessment and prognosis process |
| 29/01/2020 | Chooz NPP | Cross-border | Workshop – TableTop exercise |
| 14/09/2020 | Doel NPP | National limited | Partial exercise, limited to the interaction and information exchange between the site emergency management team of the licensee and the federal evaluation cell CELEVAL. |
| 4/11/2020 | NPP Borssele (National) | Cross-border | CELEVAL's reaction, post-exercise with simulated advices |
| 24/11/2020 | Tihange NPP | National large-scale | *Delayed to 2021 due to COVID* |
| 12/05/2022 | ConvEx 2a | International | Test of the National competent authorities to fill the correct forms with respect to the delays |
| 15/10/2022 | ConvEx 1a | International | Test of notification procedures (USIE) |
| 25/05/2021 | Tihange NPP | Cross-border | TableTop exercise |
| 17/3/2021 &<br>29/06/2021<br>(Initially planned in 2020) | Tihange NPP | National large-scale | Phase 1: Global exercise directed by controllers, with the participation of some response organisations and deployment of field intervention teams.<br><br>Phase 2: Test of the transition phase of some response organisations. No participation of the operator |
| 19/10/2021 | Doel NPP | National limited | Partial exercise, limited to the interaction and information exchange between the site emergency management team of the licensee and the federal evaluation cell CELEVAL. |
| 26-27/10/2021 | EcurEx<br>ConvEx 3 | International | International Nuclear Emergency Exercise Held at Baraka Nuclear Power Plant in Abu Dhabi, UAE.<br>Full-scale exercises to assess the emergency response arrangements and resources during severe nuclear or radiological emergency for several days. |
| 16/11/2021 | ConvEx 1a | International | Test of notification procedures (USIE) |
| 17/5/2022 | Doel NPP | National limited | Partial exercise, limited to the interaction and information exchange between the site emergency management team of the licensee and the federal evaluation cell CELEVAL. |

Table 8 : Overview of EPP exercises during the period 2019-2022

### d) *Lessons Learned from Emergency Preparedness Exercises.*

Each year, an exercise with the participation of the authorities is carried out at each NPP site (i.e. Doel and Tihange). Once every four years, this annual exercise takes the form of a so-called "methodologically accompagnied exercise" in which all federal, provincial and local authorities participate. Such exercises were organised in 2021 respectively at the Tihange and Doel power plants.

The Tihange exercise in particular was originally planned for April 2020 but had to be postponed to March 2021 due to the Covid. The Steering Committee decided to divide it into two separate phases, with the aim, among other things, of testing the transition phase, a first in Belgium.

Phase I was, (as it was also for the Doel NPP exercise - 19 October 2021) a classical alert-mobilisation exercise of cells and committees to test the management of an emergency situation and the simulated implementation of protective actions on the ground. The mapping of radiological deposits ($^{137}Cs$ & $^{131}I$) after the releases will then serve as a basis for post-accident management (phase II).

Phase II of the exercise to test the transition phase was organised on 29 June 2021, and the important objectives were as follows:

- Ongoing work of CELEVAL (Evaluation cell) in the transition phase;
- Ongoing analysis of the radiological data;
- Testing of the food chain protective actions;
- Testing communication channels & tools between mobilized cells & committees

Both exercises were generally considered interesting with innovative scenarios, involving effective team shift/turnover. The overall assessment of the achievement of the objectives at the different levels (operator, CELEVAL, Federal Coordination Committee COFECO, Province) was globally very positive. Some examples of assessed objectives are:

- Test and sue of the Incident & Crisis Management System (ICMS) exchange platform;
- Test of the IAEA Reactor Assessment Tool to support and assist the technical assessment performed in CELEVAL
- Test of sending fictive BE-alert messages to the population.
- The use of Controllers network was also appreciated.

These exercises also allowed us to successfully test the hybrid mobilisation of the members of the evaluation unit, with some members participating remotely.

The general conclusions of the both exercises (Doel & Tihange NPP's) allowed many lessons to be drawn, which undoubtedly demonstrates the seriousness with which the exercises were prepared, conducted and evaluated. It also reaffirmed principles that are crucial to good nuclear crisis management, such as the need for an integrated response and the presence of the permanent representative of the FANC in COFECO.

The lessons learned from the cross-borders exercises did not offer very important conclusions to be drawn, in particular due to the use of scenarios with fast kinetics, which did not allow the experts to have sufficient time for the analysis and exchange of technical and radiological data to implement coordinated protection actions and a communication strategy.

## II.L.3. Information of the Public

The GRR-2001 specifies in its Article 72 all the obligations regarding training and information of the public.

During the accident itself, information is supplied to the media by the information cell of the National Crisis Centre. At local level the provincial emergency plan includes the ways to inform the population (sirens, police equipped with megaphones, radio and television) and to follow-up the instructions given to the population (iodine tablets, sheltering, evacuation …).

## II.L.4. SCK CEN (Research Reactors)

The general rules for emergency preparedness for the SCK CEN installations are the same as for the nuclear power plants. The SCK CEN has a central emergency control room, equipped with the necessary information and communication systems and is located in a building without major nuclear infrastructure. The SCK CEN has one vehicle fully equipped for radiation measurements in emergency situations. The measurement capacity can be increased using a second vehicle with manual measurement equipment. These measurement teams are available to the national crisis centre.

The organisation of the internal emergency plan is described in a general procedure. For each of the groups involved in the emergency plan a task description is available. Standard accident scenarios are developed for the major nuclear installation. These must allow recognizing and communicating the essential information and the potential consequences to the national crisis centre. According to the Belgian national nuclear emergency plan, these scenarios can lead to the various emergency classes described in section a). The level General Emergency in 'reflex' mode, corresponding to the risk of a fast significant release of fission products, can only occur for BR2 in case of severe damage to the fuel combined with containment bypass.

Exercises are held, in cooperation with the authorities and the other nuclear facilities in the neighbourhood. Every year, another company simulates the accident and takes the lead in the exercise. The measurement teams take also part in the exercises of the nuclear power plants.

Beside the internal emergency plan, the SCK CEN is also involved, as expert, in the Evaluation Cell of the National Crisis Centre Experts participate in different evaluation cells.

## II.M. Article 17. Siting

> Each Contracting Party shall take the appropriate steps to ensure that appropriate procedures are established and implemented:
>
> (i) for evaluating all relevant site-related factors likely to affect the safety of a nuclear installation for its projected lifetime;
>
> (ii) for evaluating the likely safety impact of a proposed nuclear installation on individuals, society and the environment;
>
> (iii) for re-evaluating as necessary all relevant factors referred to in sub-paragraphs (i) and (ii) so as to ensure the continued safety acceptability of the nuclear installation;
>
> (iv) for consulting Contracting Parties in the vicinity of a proposed nuclear installation, insofar as they are likely to be affected by that installation and, upon request providing the necessary information to such Contracting Parties, in order to enable them to evaluate and make their own assessment of the likely safety impact on their own territory of the nuclear installation

### II.M.1. NPPs

#### *a) Characteristics taken into Account in the Sites Selection*

The Doel and Tihange nuclear sites were originally evaluated according to the requirements set by the US rules (Chapter 2 of the Safety Analysis Report, Standard Review Plan, 10 CFR 100).

These requirements apply to the phenomena of natural origin (earthquakes, floods, extreme temperatures…) and to the phenomena of human origin (industrial environment, transport…).

With regard to the natural phenomena:

- The geological and seismic characteristics of the sites and their environment were specifically investigated so as to identify the soil characteristics and the earthquake spectrums in order to define the design bases to be considered when dimensioning the structures and systems;
- The hydrological characteristics of the rivers Meuse (Tihange) and Scheldt (Doel) were surveyed, not only to quantify the risk of floods and possible loss of the heat sink, but also in order to develop the river flow models in order to assess the dilution of released liquid effluent;
- Meteorological and climatic surveys allowed defining the atmospheric diffusion and dispersion models to be used when assessing the short-term and long-term environmental impacts of atmospheric releases taking into account the local characteristics. These studies were complemented with demographic surveys in the vicinity of these sites;

- Concerning the population density around the sites, no detailed criterion was imposed originally. But the design of the installations made allowance for the existing situation: the "low population zone" of the USNRC rules is in fact within the site. Consequently, the radiological consequences of incidents or accidents are calculated for the critical group living at the site border or in any other location outside the site where the calculated consequences are the largest;
- Due to the very high source terms imposed by the U.S. safety rules, the design of the Belgian units incorporates strict limits on the containment leak rate (double containment with a steel liner for the primary containment) and systems to prevent liquid or gaseous leaks through the containment penetrations.

With regard to the external events of human origin:

- Due to the population density in the vicinity of the sites, and also considering the impact that the local industrial activities may have on the power stations, specific requirements were adopted in 1975: protection against external accidents such as civil or military aircraft crash, gas explosion, toxic gas cloud, major fire;
- The Tihange 2 and 3 and Doel 3 and 4 units were equipped with ultimate emergency systems aimed at automatically tripping the reactor, keeping it in hot shutdown during three hours so that after that period of time it may be possible to bring the unit to cold shutdown and to remove residual heat, after a design basis external accident as referred to above, or during any loss of the normal control room or any of the systems that are controlled from it;
- These ultimate emergency systems are called "bunkered systems" as they are installed in specifically reinforced buildings. They comprise an autonomous protection and instrumentation system supplied with electric power from dedicated emergency diesel-generator sets, as well as primary make-up (water with boric acid to control the reactivity) and steam generator feedwater systems;
- Measures were also taken to guarantee the emergency heat sink in case of loss of ultimate heat sink (river). At the Tihange site, the preferred option was to bore wells from where groundwater can be pumped, whereas at Doel three artificial lakes were created;
- Following the 2001 September 11 events, ENGIE Electrabel and the Safety Authorities were brought to:
    - consider the eventuality of a voluntary aircraft crash on the Belgian Nuclear Power Plants;
    - identify which type of impact these plants would encounter;
    - determine the potential consequences of such impact;
    - consequently, adapt the in-depth defence strategy.
- From the studies performed on the potential consequences of an impact on each of the buildings of the plants of Doel and Tihange, it appears that:
    - the initial design of the last four units (Tihange 2 and 3 and Doel 3 and 4) is good: no perforation of the external containment even with a Boeing 767 at a speed of 150 m/s;
    - the initial design of the reactor buildings of Tihange 1 and Doel 1 & 2 is less resistant than those of the more recent units;
    - it is necessary to be able to fight a kerosene fire to avoid any damage to the structure of the building due to high temperature exposure. In consultation with the fire department and Bel V, new equipment was bought and is now operable (special firefighting truck with high pressure foam pumps) and are approved by the regulatory body.

#### *b) Periodic Reassessment of the Site Characteristics*

Reassessments are systematically performed during the periodic safety reviews of each unit.

During the 1st periodic safety review of Doel 1 & 2, as external accidents had not been considered in the initial design, additional emergency systems were installed in a reinforced building (the Bunker).

For the Tihange site, the safe shutdown earthquake originally considered (in the early seventies) for Tihange 1 was of 0.1 g acceleration. This value was increased to 0.17 g following the Tihange 2 safety analysis (end of the seventies). As a consequence, the latter value was adopted for the site as a whole;

it did not need to be modified when the Liège earthquake of 1983 was analysed. The seismic reassessment of Tihange 1 was performed during its 1st periodic safety review in 1985.

This resulted in a considerable number of reinforcements being made in certain buildings, and in the seismic qualification of the equipment being re-examined (using the methodology developed by the US Seismic Qualification Utility Group).

Also, a review of the protection of Tihange 1 against external accidents was performed: the probability that an aircraft crash would result in unacceptable radiological consequences was assessed; taking into account the specificities of the buildings, that probability was found sufficiently low.

During the periodic safety reviews of each of the units, studies are performed and, where necessary, measures are implemented to ensure that the residual risk following external accidents remains acceptable taking into account the environment of the site with respect to the risks resulting from transport (including by aircraft) and from industrial activities.

The protection against potential floods at Tihange NPP was reassessed in the framework of periodic safety reviews as well as the possible rise in temperature due to climate change. This led to the decision to build a peripheral protection of the site, this action being conducted as part of the "Stress Tests" action plan (see below) and ended in 2015.

The protection against extreme external temperatures (heat wave, extreme cold) is currently being reassessed by ENGIE Electrabel in the framework of the action plan of the most recent periodic safety review of each unit.

### c) *Stress Tests*

Following the Fukushima Daiichi accident, ENGIE Electrabel was asked to conduct Stress Tests. Safety evaluation reports for the Doel and Tihange sites have been established by ENGIE Electrabel and reviewed by the FANC and Bel V and external experts. Within the scope of the Stress Tests, an assessment of design bases, existing safety margins and cliff-edge effects was performed for the risks related to the Site Characteristics such as earthquake, flooding and bad weather conditions.

An action plan was performed as a result of the assessment, that leaded to:

- A probabilistic seismic hazard assessment for Doel and Tihange by ENGIE Electrabel (in collaboration with Royal Observatory of Belgium and external experts for peer review);
- A seismic safety margin assessment of the Structures, Systems and Components was performed;
- Reinforcements of Structures, Systems and Components to improve their resistance against beyond design earthquakes;
- A site peripheral protection for Tihange, in relation to an upgraded design basis flood;

Figure 17 : New peripheral protection of the site of Tihange

- Improvements of the protections against beyond-design-basis floods: in Doel, volumetric protections of sensitive buildings and adapted procedures; in Tihange, water supplies (involving pipes, pumps, additional electrical diesel generators, etc.) to the primary circuit, the steam generators and the spent-fuel pools, with adapted procedures and training;
- Improvements of the sewage systems for protecting the sites against rains with return periods much larger than considered in the design.

#### d) WENRA RL2014

A global reassessment of natural hazards for both sites, in particular for Design Extension Conditions, is currently ongoing in the framework of an action plan launched to identify and resolve potential gaps in the implementation of the WENRA RL2014 at the NPPs (see also section I.C.3.d).

### II.M.2. SCK•CEN (research reactors)

#### a) Characteristics taken into Account in the Sites Selection

The installations of the SCK CEN are located in the north-east of the province of Antwerp, which is one of the lesser populated regions of the northern part of Belgium. This was one of the major reasons for the choice of the location, together with the availability of sufficient free terrain.

The site has a low risk for the occurrence of natural phenomena.

- The site is located far from major rivers or from the sea, in a flat sandy area, such that the risk of flooding is very limited. However, very local flooding with a height up to 0.3 meter is possible in case of heavy rain combined with melting snow. Protection is available against this kind of flooding;
- The closest active seismic fault is located at a distance of about 80 km. At the occasion of the periodic safety review conducted in 1996, a seismic assessment of BR2 was made using a reference earthquake with a free field magnitude of 0.1g. This resulted in strengthening of a few components. With the periodic safety review of 2006, a similar analysis was made for BR1. For the safety review as a consequence of the Fukushima Daiichi accident, the reference acceleration was increased and the resistance of the reactors was studied. Although both reactors rely on natural convection cooling in emergency situation it was concluded that an improvement of the back-up electrical power system would be useful in case of a severely damaged installation. In 2019 new diesel generators for the BR2 including a new housing were installed. A number of other improvements are made, such as replacement of electrical cables and transformers. All electrical cabinets are modified according the most recent version of the Belgian regulation on electrical components. This includes improvement of the earthing system and modify the isolation, such the direct contact with live conductors is no longer possible.
- The site is also equipped with a fire extinguishing network with multiple water sources.

#### b) Stress Tests

Following the Fukushima Daiichi accident, all Belgian "Class 1" nuclear installations (including the power reactors and the research reactors), were asked to conduct Stress Tests. The safety evaluation report for SCK CEN has been established by the licensee and reviewed by the FANC and Bel V. No peer review was foreseen.

In the frame of the Stress Tests, an assessment of design bases, existing margins and cliff-edge effects was performed in relation to risks related to the site characteristics like earthquake, flooding and bad weather conditions. A graded approach was used.

The FANC National report was issued on April 16, 2013. The action plan for SCK CEN that consists of 42 actions was finalized and approved by July 2013. The actions have been implemented and the action plan is closed in 2021.

### II.M.3. International Agreements

The obligation to inform the neighbouring countries when planning a nuclear installation is stipulated in Article 37 of the Euratom Treaty, which is applicable in Belgium (cf. Article 6 of the GRR-2001). The reports drawn up to meet this requirement have been transmitted to the European Commission as provided for in the licensing procedures for the Belgian power plants. After consultation of the "Article 37" group of experts, the Commission issued a favourable advice for the sites of Doel and Tihange.

Direct information of the neighbouring countries which might undergo notable consequences on their territory was an obligation deriving from the Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment.

This European Directive has been superseded by the Directive 2011/92/UE on the assessment of the effects of certain public and private projects on the environment, which was amended by the Directive 2014/52/UE. This amendment was transposed in the Belgian legal framework by the Law of 6 December 2018 and by the Royal decree of May 29th 2020 (see section I.C.1) for the radiological part. The directive requires direct information and consultation of competent authorities of the neighbouring countries which might undergo notable consequences on their territory.

## II.N. Article 18. Design and Construction

> Each Contracting Party shall take the appropriate steps to ensure that:
>
> (i) the design and construction of a nuclear installation provides for several reliable levels and methods of protection (defence in depth) against the release of radioactive materials, with a view to preventing the occurrence of accidents and to mitigating their radiological consequences should they occur;
>
> (ii) the technologies incorporated in the design and construction of a nuclear installation are proven by experience or qualified by testing or analysis;
>
> (iii) the design of a nuclear installation allows for reliable, stable and easily manageable operation, with specific consideration of human factors and the man-machine interface.

### II.N.1. NPPs

The design, as well as the major modifications following the successive periodic safety reviews of the Belgian nuclear power plants is described in III to the present Report.

#### *a) Rules followed during design and construction*

The "Commission Spéciale des Radiations Ionisantes" (i.e. the Belgian nuclear Special Commission, now replaced by the Scientific Council of the FANC) decided in 1975 that the USNRC rules should be followed for the construction of the next four units (Doel 3 and 4, Tihange 2 and 3) and that some accidents of external origin should be considered in the design.

Accordingly, the design and safety analysis of these units have been done following the US NRC rules and all the associated documentation (regulatory guides, standard review plans, ASME Code, IEEE standards, ANSI, ANS, etc.) in order to ensure a consistent approach. 10 CFR 20 on radioprotection was not followed, as the corresponding topics were covered by the Euratom Directive on the Basic Safety Standards. Compliance with the withheld US NRC rules is documented in the Safety analysis Report, deviations are identified and justified. For non-mandatory rules, the Safety Analysis Report documents how they have been implemented, in compliance with the safety objectives.

For safety-related pressure vessels, a specific derogation to the Belgian pressure vessel regulations ("Règlement général pour la protection du travail") was elaborated, in order to allow the use of the US rule based ASME Code sections III and XI. A few components not covered by the ASME specifications but covered by the Belgian regulations had still to comply with the Belgian regulations. A transposition of the ASME Code has been written to cover organisational aspects like the definition of an inspector, of the Authorised Inspection Agency (AIA), etc …That transposition of the ASME Code clarifies also the conditions under which other construction or in service inspection codes (like French or German codes) can be used. Their equivalence must be justified, justification which must be agreed by the AIA and by Bel V.

As mentioned above, the Special Commission also required that accidents of external origin be considered (i.e. aircraft crash, gas explosion, toxic gases, large fire).

The protection against explosions was based on German rules. For the aircraft crash the bunkered structures were designed to resist the impact of a large civil airplane. It was also checked that the probability to go beyond the design criteria of the bunkered structures was smaller than $10^{-7}$ per reactor year. Toxic and explosive gas (external explosion) have also been considered and integrated in the design.

It has been shown that the probability to exceed the design criteria was, for each family of external accidents, smaller than $10^{-7}$ per reactor year and $10^{-6}$ per reactor year for all external accidents together. The residual risk that an external event leads to unacceptable radiological consequences for the public is a fortiori even smaller, as exceeding the design criteria for an external hazard does not necessarily lead to unacceptable radiological consequences in all cases.

### b) Application of the defence in depth concept

The defence in depth concept is an integral part of the Framatome or Westinghouse nuclear power plants designs and is also found in the US safety rules.

Accordingly, this concept has been systematically applied in all Belgian nuclear power plants.

Furthermore, the design of all the additional systems to address external accidents adhered to the same principles, and in particular the single-failure criterion was applied. Compared to a conventional-design pressurised water reactor nuclear power plant, the additional systems installed to mitigate the consequences of an external accident in fact strengthen considerably the third level of the defence in depth approach, as they can help during certain internal accidents which might develop unfavourably.

In the framework of periodic safety reviews, for all units, a global evaluation of the safety during low-power and shutdown states is performed.

### c) Periodic safety reviews

The first periodic safety reviews took place in 1985 for the Doel 1 & 2 and Tihange 1 units. At the time of design of these units, i.e. in the early 1970s, the safety rules were less numerous and less detailed than they were for the later Belgian units that were started between 1980 and 1985. For instance, physical separation was less strictly applied, seismic and post-accidental qualification were less developed, the notion of high-energy line break did not apply to all systems, external accidents were not systematically considered.

The different subjects examined during these periodic safety reviews are detailed in VII.

These 1st periodic safety reviews were conducted very comprehensively and were an in-depth review of the safety of the nuclear power plants. This made it possible to identify coherent solutions and, at times, to simultaneously solve several problems (an example is the emergency building, i.e., the bunker, of Doel 1 & 2). It also demonstrated that it is even possible to improve strongly design- and lay-out dependent systems of the nuclear power plant: taking into account a higher-intensity earthquake, protection against external accidents, a new reactor protection system, ...

For instance, at Tihange 1, considering a design earthquake of 0.17 g acceleration (value of the Safe Shutdown Earthquake defined in the safety analysis of Tihange 2 and 3) instead of the original value of 0.1 g used in the design of unit 1, resulted in recalculating with much more elaborate methods the seismic behaviour of all the buildings, and strengthening a number of structures. Also, the resistance to earthquake of many equipment and components had to be reviewed, based on feedback from experience with equipment which had undergone a real earthquake. Similarly, external accidents due to human activity were considered. Other fields included protection against high-energy line breaks, protection against primary system overpressure, improvement of fire protection, improvements of the reliability of systems, more effective training of operators (training centres with several simulators), improvements to the man-machine interface, systematic utilisation of both national and international feedback of operating experience.

Similar steps were followed for Doel 1 & 2. In the design and during the construction of Doel 1 & 2, earthquakes had not been considered as a factor influencing the design requirements, due to the weak seismic activity of the region. For Doel 3 and 4, applying the USNRC rules has imposed a minimum of 0.1 g for the Safe Shutdown Earthquake (SSE). For Doel 1 & 2, the same methodology for defining the SSE has been followed, except the requirement of a minimum value of 0.1 g. The resulting SSE retained for the design has an acceleration of 0.056 g.

As for Tihange 1, this led to a check of the resistance of buildings and equipment. Moreover, to cope with accidents of external origin, a bunkered and seismically resistant building has been erected, containing so-called emergency safeguard systems, which allow maintaining primary water inventory, ensuring reactor sub-criticality and residual heat removal and coping with accidents like a fire in the electrical auxiliaries building (including the loss of the main control room), the total loss of electric power (external grid and the safety Diesels), the SSE, a high-energy line break.

In this way the safety level of these units was raised towards a level closer to that of the most modern units. All the analyses were conducted according to deterministic safety rules and complemented with reliability analysis of the various systems.

The 1st periodic safety review of the most recent units (Doel 3 and 4, Tihange 2 and 3) and the 2nd periodic safety review of Doel 1 & 2 and Tihange 1 did not require reviewing the design bases, since post-TMI actions had already been taken into account and there had been no major evolution in the regulations during that period.

During these safety reviews, national and international feedback were examined; the results of probabilistic safety studies made for power operation or for shut down states were taken into account, the severe accident consequences were analysed in order to infer prevention and mitigation measures, structural and equipment ageing were evaluated, as well as qualification problems, and the field of accidents that are considered as design-basis accidents was broadened. The PSAs and the analyses of severe accidents resulted in the installation of (autocatalytic) hydrogen recombiners inside the reactor containment for all units.

The second periodic safety reviews of the most recent units (Doel 3 and 4, Tihange 2 and 3), and the third periodic safety review of the oldest ones (Doel 1 & 2, and Tihange 1) include two sets of topics: the first one is made of topics common to all units ("fleet approach"), the second one addresses aspects specific to one unit.

All these periodic safety reviews included two parts: one part "studies", another part "implementation" of the results of the studies, which led to a large number of modifications on the first Belgian units.

The third periodic safety reviews of the most recent units (Doel 3 and 4, Tihange 2 and 3), and the fourth periodic safety review of the oldest ones (Doel 1 & 2, and Tihange 1) were performed according to IAEA Guide NSG-2.10. As far as Doel 1 & 2 and Tihange 1 are concerned, they included an LTO-approach. Due to the evolving context (e.g. post-Fukushima action plans), almost no hardware modifications resulted directly from those periodic safety reviews, which are more focused on the evaluation of the processes to manage safety and its results.

### *d) Accident prevention and mitigation of consequences*

Accident prevention and mitigation of consequences are basic principles adhered to in the design of Belgian nuclear power plants.

In case of disturbance in the operation parameters of the plant, the control system will respond in order to bring the plant back to its nominal operation point.

In case of risk of reaching the safety limits, the reactor protection system will shut down the plant.

The engineered safety systems are activated to address the design basis accidents and achieve the safe shut down of the plant.

Consistent with the standard format of the Safety Analysis Report, all the instrumentation and control systems are described in chapter 7, and incident and accident analyses are discussed in chapter 15.

The four more recent Belgian units (Doel 3 and 4, Tihange 2 and 3) are three-loop 1 000 MWe units that are designed with three independent safety trains (instead of two interconnected trains in a traditional design).

Apart from the Doel 1 & 2 units, in which the primary containment is a metal sphere, the primary containment of all other units is a prestressed concrete structure with on the inside a steel liner. The secondary containment is in reinforced concrete at all units. The annular space between the two containments is put at negative pressure, so as to collect possible leaks after an accident. There is an internal recirculation and filtration system in the annular space and the air is filtered again prior to release via the stack.

During the 90's, probabilistic safety studies were carried out for all the Belgian units. These studies were either level 1 with analyses of scenarios that could present a risk to the containment integrity, or level 2 studies (in this case with no source term calculation). PSA studies are now required by article 29 of the SRNI-2011.

These studies considered reactor operation at power as well as in shut down states.

The results showed, among other, the value of having protection systems against external accidents. Indeed, these systems can act also in the event of failure of the traditional engineered safety systems;

this considerably reduces the probability that certain initiating events could develop to the point of contributing to a core melt.

The update of all PSAs led to full Level 2 analyses for all representative plants, for power and shutdown states. A level 1 Fire and Flooding PSA has been performed for all units and a level 2 Fire and Flooding PSA for a representative unit. The most recent and the ongoing developments in the field of PSA are discussed in section 2.A.1.g

Apart from PSA studies, severe accident management guidelines have been introduced at all Belgian plants in order to strengthen the 4th level of defence-in-depth. They are subjected to periodic reviews. All Belgian plants dispose of adequate emergency operating facilities, in order to cope with major accidents, according to the principles of Defence-In-Depth. "Stress tests" also led to plant modifications, increasing the robustness of the plant with regard to extreme natural phenomena

### e) Application of proven or qualified technologies

The safety-related structures, systems and components are subject to qualification programmes to the environment in which they are situated and operated (normal, test, incident, accident). The same is applied regarding seismic qualification. The programmes are described in the sections 3.10 and 3.11 of the Safety Analysis Report and are consistent with the relevant US rules. Significant efforts have been made in this field, with tests in large qualification loops or on high-capacity seismic tables.

The results of all these tests are included in the "Manufacturing Records" of the qualified equipment and are summarised in synthetic reports for later use.

For the design codes used by vendors or architect-engineers, audits are conducted by Bel V to verify the qualification file and to examine the experimental bases on which the models and correlations of the code are founded.

Particular attention is given to verify and validate the design code itself and the quality assurance programme applied to the use of the code

### f) Requirements of reliable, stable and easily controllable operation, taking into account human factors and the man-machine Interface

In order to make the operation of their power units easier and to increase their availability, the Belgian licensee frequently applies the redundancy principle even to the normal control functions, so as to avoid spurious signals in the event of a failure. Similarly, they install additional components in standby that can be quickly started or connected, so as not to have to shut down the power station in the event of significant unavailability of the first components.

In the control room, operators are informed through display and alarm windows as soon as possible of any operational anomaly of the power station. The alarm windows have been colour-coded according to their importance. Normal operation and safeguard system panels are separated as much as possible.

A process computer is available for the operator, with dedicated pre-formatted screens to follow up particular system variables, or with alarm logs. Alarm sheets are available in the control room for each alarm, indicating to the operator the significance of the alarm, its origin (and possible causes), the automatic actions possibly initiated and the manual response, if any, that is required from the operator.

As a post-TMI action, following NUREG 0737, the control room and its ergonomics were reassessed. The instrumentation used for post-accidental operation was identified more clearly, and the notion of SPDS (Safety Parameter Display System) was implemented in the control room (or in a room adjacent to it).

In case of unavailability of the main control room (for example inacceptable habitability) a Remote Safety Panel, located in the bunker control room for the last four units or in an appropriate building for the older ones, is fitted with all the controls of the main systems necessary for bringing the reactor to cold shutdown. A specific set of procedures for the remote panel is present in the bunker control room (or equivalent location).

Moreover, the bunker control room and the bunker specific equipment have the capability to bring the reactor to a safe state (fallback state) and to go safely to cold shutdown, in case of an accident of external origin (aircraft crash, explosion and/or large fire). Procedures covering these cases are also available in the bunker control room (or equivalent location).

In the probabilistic safety studies, the tasks expected from the operators are detailed and modelled during the accident as well as during the post-accidental phase when the safe status of the unit is being restored. Following this critical review, the existing procedures can be amended to increase their efficiency and ease of use, or new procedures can be written (for instance for the non-power states).

### II.N.2. Research Reactors

The reactors BR1 and BR2 were designed and constructed between 1952 and 1962, before a dedicated nuclear regulation existed in Belgium. The reactors were licensed according the regulations on industrial installations. This licence was amended several times, with specific requirements for nuclear installations. In 1986 the existing licence was replaced by a new one, a Royal Decree based on the actual nuclear safety regulations.

The design of the BR1 is based on the reactors X-10 of ORNL, USA and BEPO of UKAEA, Harwell. The reactor was designed for a thermal power of 4 MWth. Since 1965, the maximum thermal power has not exceeded 1 MWth and since a few years, the power is limited by licence to 1 MWth. This allows working with the auxiliary ventilation only and avoids the accumulation of Wigner energy in the graphite. During the lifetime of the reactor no major modifications were made.

The design of BR2 is rather unique. The reactor is designed to produce a high neutron flux (thermal and fast), without being a fast sodium cooled reactor. The design has never been repeated. A reactor that is comparable is the ATR reactor of Idaho National Laboratory, USA. The original design thermal power of BR2 was 50 MW. In 1973 the primary heat exchangers were replaced in order to allow a thermal power of more than 100 MW. However, this thermal power is not the limiting factor as long as the heat can be evacuated without a too high temperature on the fuel plates. The power of the reactor is limited by the fact that the maximum heat flux on the fuel plates must be lower than 470 W/cm² in routine operation and 600 W/cm² for special experimental conditions.

Both reactors were included in the complementary safety analysis after the Fukushima Daiichi accident. As a conclusion of the analysis, a number of design upgrades were installed.

## II.O. Article 19. Operation

Each Contracting Party shall take the appropriate steps to ensure that:

- (i) the initial authorisation to operate a nuclear installation is based upon an appropriate safety analysis and a commissioning programme demonstrating that the installation, as constructed, is consistent with design and safety requirements;
- (ii) operational limits and conditions derived from the safety analysis, tests and operational experience are defined and revised as necessary for identifying safe boundaries for operation;
- (iii) operation, maintenance, inspection and testing of a nuclear installation are conducted in accordance with approved procedures;
- (iv) procedures are established for responding to anticipated operational occurrences and to accidents;
- (v) necessary engineering and technical support in all safety-related fields is available throughout the lifetime of a nuclear installation;
- (vi) incidents significant to safety are reported in a timely manner by the holder of the relevant licence to the regulatory body;
- (vii) programmes to collect and analyse operating experience are established, the results obtained and the conclusions drawn are acted upon and that existing mechanisms are used to share important experience with international bodies and with other operating organisations and regulatory bodies;
- (viii) the generation of radioactive waste resulting from the operation of a nuclear installation is kept to the minimum practicable for the process concerned, both in activity and in volume, and any necessary treatment and storage of spent fuel and waste directly related to the operation and on the same site as that of the nuclear installation take into consideration conditioning and disposal.

### II.O.1. NPPs

#### *a) Initial authorisation and commissioning*

For the 7 operating NPPs, the Royal Decree of Authorisation was signed by the King after it has been examined in detail by an Authorised Inspection Organisation (AVN), the "Commission Spéciale Radiations Ionisantes" (now replaced by the Scientific Council of the FANC) and the Safety Authorities (now the FANC).

The commissioning test programme was discussed and approved by the AIO (AVN), which followed the tests, evaluated the test results, verified the conformity to the design and issued the successive permits that allowed proceeding with the next step of the test programme.

This process was complete when the AIO (AVN) authorised the operation of the unit at full power.

#### *b) Operational limits and conditions*

As described before, the Technical Specifications are approved in the frame of licensing (chapter 16 of the Safety Analysis Report). They specify the operational limits and conditions, the availability requirements of the systems, the tests and inspections, and the actions to be taken if the acceptance criteria are not met. This applies to any state of the nuclear power plant. Extensive backgrounds of the Technical Specifications exist and are available to the personnel.

There are procedures related to compliance with the Technical Specifications for maintenance activities during plant outage and plant operation. Technical Specifications requirements and limitations are explicitly addressed in the maintenance procedures. Independent checks of the strict compliance with Technical Specifications during outages are carried out, both in the preparatory outage activities (work planning) as well as during the outage itself. These checks relate to equipment as well as to safety-related functions, like the integrity of the containment during refuelling, verification of the redundancy of the heat removal systems during RHR operation, …

Modifications of the installations with a potential impact on nuclear safety must be approved by the Health Physics department and Bel V before it can be implemented, as explained in Article 14, section II.J.1.c). In this respect, changes of procedures, of the Technical Specifications and of the Safety Analysis Report are identified and discussed.

#### *c) Procedures for operation, maintenance, inspection and testing*

A general description of the operation procedures is given in section 13.5 of the Safety Analysis Report.

The completeness (in format and contents) of the procedures has been examined based on Regulatory Guide 1.33 which lists the subjects for which procedures must be established. This examination was conducted in the scope of licensing and acceptance of the installations by AVN.

During the commissioning tests, the relevant procedures that were used by the operators were verified for adequacy.

Document management is based on ENGIE Electrabel guidelines and on the Internal Code for Nuclear Safety. Documents are classified into the following categories: policy-related procedures, operational procedures, instructions, supporting documents, help documents and witness documents. For policy-related procedures, operational procedures and instructions, more strict handling requirements have been established.

#### *d) Incident and accident procedures*

A full set of incident and accident management procedures has been developed by ENGIE Electrabel, with the help of the Architect Engineer and the designer of the Nuclear Steam Supply System. These procedures cover both power operations and shutdown modes.

These procedures are validated on a simulator and are used for operator training. Procedures are periodically reviewed and relevant experience feedback is integrated. Procedures backgrounds have been developed for some normal and incident procedures.

The Belgian NPPs, except Tihange 1, have implemented the Emergency Response Guidelines (ERG) approach developed by the Westinghouse Owners Group (WOG). These standard procedures have been adapted to the plant-specific elements and systems, especially the systems for protection against external events.

The ERG procedures are composed of 3 major elements: (1) the optimal recovery procedures (ORG: optimal recovery guidelines) which are event-based, (2) the critical safety function status trees and (3) the function restoration procedures (FRG: function restoration guidelines) which are both symptom-based, i.e. independent of the event scenario.

The ORG procedures, based on event scenarios with a probability of occurrence greater than $10^{-8}$/y, have as main objective to recover the plant and to bring it back to a known safe state (in general the cold shutdown with the RHR system connected). ORG procedures are characterized by a response directly connected to event scenarios, by a preliminary diagnostic and by a constant diagnostic within each specific procedure in order to allow possible reorientation.

The critical safety function status trees explicitly identify the status of the safety functions independent of the event scenario. The trees prioritize challenges to these functions and identify the appropriate FRG procedure to be used to respond to these challenges. The 6 defined critical safety functions are: subcriticality, core cooling, heat sink, integrity of the primary system, containment and primary water inventory.

The FRG procedures are used to restore any challenged critical safety function.

The ORG on one hand and the status trees and the FRG on the other hand are applied in parallel during an event: the first procedures are used by the operator’s crew (event-based approach) whereas the second ones are applied independently by a Shift Technical Adviser (symptom-based approach).

In conclusion, event-based and symptom-based procedures are used in parallel in Belgium by the NPP staff. The combination of a redundant approach (ORG <> FRG) associated with a human redundancy (operators crew <> shift technical adviser) allows to cover a larger scope of events, ensuring an optimized response for simple event scenarios.

Specific procedures have been written to give guidance to the operators after an earthquake that could occur during normal operation or in shutdown state.

Severe accident management procedures, inspired by the “Severe Accident Management Guidelines” developed by the Westinghouse Owners’ Group, were implemented, adapted to the specificities of each unit. The training programme of the control room operators was developed in parallel.

For Tihange 1, the Framatome approach has been followed. The accident management procedures combine event-based and symptom-based approaches, using the surveillance of key safety functions or parameters.

Severe accident management procedures were developed like in the other units, on the basis of the Westinghouse Owner’s Group Guidelines.

#### *e) Engineering and technological support*

The organisation and know-how of the operator, described in chapter 13 of the Safety Analysis Report, must be maintained throughout the useful life of the power station, and even after its definitive shutdown as long as this new status is not covered by a new licence.

The Engineering Department has the overall responsibility for the Technical Support Process. However, technical support activities are decentralized into several surveillance programmes, each programme being under the leadership of the department having the most comprehensive knowledge of the particular process. The allocation of technical support functions between the different site departments and external organizations is clearly established. The Engineering Department also acts as design authority.

The divisions of the Engineering Department at the corporate level also provide technical support to the sites. These corporate divisions are, amongst others, in charge of the management of the periodic safety review, of large-scale projects common to Doel and Tihange and their coordination, of the monitoring of the ageing projects and of specific safety projects.

Some technical support activities are carried out in partnership with Tractebel ENGIE. A new and reinforced partnership agreement was signed in 2019. This agreement defines an exclusive and systematic collaboration for all services needed by ENGIE Electrabel in the identified areas of collaboration. Examples of these identified areas are safety and licensing studies, fuel and core management, FSAR update management, QA supplier qualification, plant life management studies, expertise in nuclear construction and inspection codes. If certain activities in these identified areas are to be performed by other companies, this will be a joint decision between ENGIE Electrabel and Tractebel ENGIE.

Tractebel ENGIE has been in charge of the studies and their implementation during the periodic safety reviews, which take place on a periodic basis, of the steam generators replacement projects, power increase projects and of a large part of minor modifications projects, which allowed to maintain competence and knowledge of the installations. Tractebel ENGIE has also been participating in an integrated way to large programs like the Stress Tests (analysis and realization), the Long Term Operation project for the oldest plants, and the conformity with the WENRA Reference Levels. Tractebel ENGIE is also in charge of the follow-up of the provisioning of fuel reloads and of core management. Through its R&D projects, training actions and technological surveys, Tractebel ENGIE maintains a high competency in conformity with the state of the art. In order to reach these goals, Tractebel ENGIE participates in international research projects and is a member of various networks (or competency centres).

The design bases of the plants, i.e. the knowledge of the design of the plants and the reasons of the choices made in this design are an important part of the knowledge.

#### *f) Notification of significant events*

A technical regulation of the FANC of 5 July 2019 determines the criteria and modalities for notification of events and the use of INES.

This technical regulation stipulates in which circumstances and how INES is to be used. As explained in section I.C.6, the licensee has to perform an INES-analysis according the latest INES manual, and this level has to be approved by Bel V and by the FANC. Depending on the INES-level, a specific notice is issued.

The same section also specifies the cases where incident reports must be supplied to Bel V, and within which time period. In function of the significance of the events, the time period ranges from immediately to a month.

IRS (Incident Reporting System) reports are established by Bel V for the incidents it considers interesting for the international community.

Near misses are handled through the operational experience feedback process.

#### *g) Operational Experience Feedback*

At ENGIE Electrabel, Operating Experience is supported in all activities and at all levels of the organization. Operating Experience is part of the ENGIE Electrabel's continuous improvement programme.

A policy for operating experience has been established at ENGIE Electrabel. Comprehensive programmes have been set up for detecting, processing and communicating operating issues in order to optimize the use of international, national and local experiences in operating nuclear power plants.

The Operating Experience (OE) process can be initiated by different input triggers:

- An event inside or outside the operating organization. An event is defined as any unwanted, undesirable change in the state of plant structures, systems, or components or in human/organizational conditions (health, behaviour, administrative controls, environment…) that exceeds established significance criteria;
- Findings from audits and self-assessments;
- Findings from the task observation programme;
- Findings from post job debriefings;
- Ideas, insights with a potential to significantly improve plant performance.

The OE programme results in:

- Immediate corrective actions;
- Medium and long-term corrective actions and/or improvements.

The OE feedback programme interacts on different levels of issues, events and ideas throughout the organization:

- Events and near misses: these are events and issues that require a stringent, formal approach by means of event reports;
- Low level events: these are events, issues and good practices that are revealed during the task observation programme and post job debriefings. These inputs are used for immediate actions as well as for annual self-assessments.

In parallel, different learning cycles exist to ensure learning from internal and external faults and strengths. Operating experience input coming from different sources is bundled in order to reveal relationships that lead to identifying and eliminating error precursors and flawed defences and their underlying organizational weaknesses. The main goal of this exercise is not merely counting events but pattern recognition. This OE feedback occurs in five loops and findings of lower loops are used as input for higher loops:

- Loop 1: immediate feedback, corrective actions, direct solutions and coaching;
- Loop 2: tri-monthly feedback of the performed observations (number, spread, quality) to different teams and services;
- Loop 3: annual self-assessments by the operational and maintenance teams. This bottom-up approach, supported by the immediate management, aims to define the next year's focus on different domains (technical, training, human performance, …);
- Loop 4: annual self-assessments and management reviews on intermediate level (within departments and/or services) aim to identify improvement areas on a (sub)process or organizational level and to identify weak points by systematically comparing real process outputs with management expectations, requirements of the regulator and authorities, and expectations from the nuclear sector. Per department a more hierarchical or transversal, horizontal approach is chosen;
- Loop 5: annual management reviews on fleet level of each process.

The information related to operating experience is accessible to all plant personnel, both on the intranet and in the document management system. The use of the available operating experience information is integrated into the different department processes and methods, in order to evaluate their own performance, to identify hidden weaknesses and to pro-actively avoid events

## II.O.2. Research Reactors

### *a) Operational Limits and Conditions*

The operational limits and conditions are described in the respective safety analysis report. A number of basic OLCs are defined in the licence.

The OLCs for the BR1 are:

- The maximum temperature of the cladding of the fuel;
- The maximum temperature of the graphite;
- The maximum burn up of the fuel;
- The maximum death time of the control rods.

The Wigner energy stored in the graphite moderator is measured on regular basis and serves to define the maximum temperature in the graphite.

The OLCs for the BR2 are:

- the tightness of the containment building;
- the maximum allowed fluence of the control rod guide tubes;
- the maximum allowed heat flux on the fuel plates;
- the maximum allowed fluence of the beryllium matrix.

Further OLCs are detailed in the safety analysis report of the reactors. There is a significant difference between these two types of OLCs. Those mentioned in the licence cannot be changed without a licence amendment. This requires a Royal Decree. An OLC formulated in the safety analysis report can be changed according to the designated procedures for modifications.

### *b) Modifications*

The categorization and the treatment of modifications are similar to those for NPPs. The SCK CEN developed a procedure for the practical treatment of modifications. This procedure is valid for all the installations, including the reactors BR1 and BR2.

The number of modifications for the BR1 is very limited. The general SCK CEN procedure for modifications is used. An important modification must be submitted to the internal SCK CEN advisory committee for the safety of installations. For modifications of the BR2, there is a dedicated procedure. All requests are submitted to an internal committee for approval. During the meeting, the decision whether the modification is significant or not is also taken.

Experiments are not considered as modifications and a dedicated approval procedure exists. For the BR1, new experiments are approved by the health physics department, in some cases following an advice of the SCK CEN committee on the safety of installations. All information is transmitted to Bel V. The experiments for the BR2 have to follow a specific three stage approval (principle, design and construction). A fourth stage is also foreseen to integrate experience feedback including any problems that occurred.

#### *c) Notification of events*

The criteria and modalities for notification of events and the use of INES are determined in a technical regulation of the FANC (Technical Regulation of 5 July 2019). A number of criteria about the delay time for communicating events are defined. Belgium is also member of the Incident Reporting System for Research Reactors. A number of events regarding the BR1 and the BR2 are reported in the IRSRR. At BR2, a non-conformity report (NCR) is issued and stored in a database for all deviations from normal operation. Every person working at the installation has the authorization to establish such a report. It is discussed in the daily operators meeting and a decision is taken for follow up. All NCRs are reported to Bel V and discussed in the monthly meeting.

#### *d) Documentation*

The design and construction of both the BR1 and the BR2 date from more than 50 year ago. All persons having knowledge about the original design of the reactors have gone. For BR2 a Plant Asset Management Program (PAM) was started. One of the objectives of the PAM is to collect all information (design specification, drawings, commissioning tests, periodical test, repairs) about the listed assets. and to define an inspection, repair and replacement strategy for future operation. In case original components are no longer available, potential replacement components are defined that have an equivalent functionality. The program is defined is such way that the highest priority is given to components which are important to nuclear safety. An equivalent program for BR1 is under development.

#### *e) Maintenance*

For the BR1, a yearly maintenance plan is foreseen. This maintenance is mainly focused on the control rod mechanisms and the ventilation system, including the air filters. Beside this maintenance a two monthly inspection plan is executed. For BR2, the maintenance is done during the longer shutdowns. For every shutdown a detailed task plan is made. The list of tasks comprises repairs, preventive regular maintenance and modernization of components which were approved as modification. During the shutdown for replacement of the beryllium matrix major maintenance works were done.

### II.O.3. Generation of Radioactive Waste

See the last Belgian national report issued in the frame of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (October 2020): https://afcn.fgov.be/fr/system/files/jc-rapport-be-2020-public.pdf

### II.O.4. Temporary Storage of Used Fuel

See Appendix III.H and III.J, and also the Belgian national report issued in the frame of the Joint Convention (October 2020).

A significant recent development is the upcoming extension of on-site spent fuel storage capacities at both Doel and Tihange sites, with the construction of new installations called "SF²" (Spent Fuel Facility for interim on-site storage).

The current national policy for the management of spent fuel from commercial nuclear power plants is the safe interim storage of spent fuel followed by reprocessing or final disposal. This policy is consistent with the resolution adopted by the Belgian Parliament in December 1993, which asked electricity producers to ensure a safe temporary storage of spent fuel. Taking the expected operation time of the nuclear units into account, the interim storage capacity has to be extended making it possible to empty the pools of the nuclear units before the start of the decommissioning activities. The SF² facilities are new interim spent fuel storage facilities on the nuclear sites (1 facility at Doel and 1 at Tihange). Together with the current interim spent fuel storage building on site (dry storage building SCG at Doel and wet storage building DE at Tihange), the additional storage facilities will allow the storage of the spent fuel elements from the nuclear units (4 units in Doel and 3 units in Tihange) after their definitive shutdown. These new facilities (SF² Doel and SF² Tihange) are designed for an operating lifetime of 80 years. The choice is made for a dry storage at both sites in the framework of this project. The internal experience feedback with the building SCG in Doel and the international feedback from other operators of interim dry storage facilities for spent fuel elements were satisfying. In addition, the dry storage of spent fuel elements offers more flexibility and is a passive installation compared to the wet storage.

In 2018 the license application was introduced by ENGIE Electrabel to construct and operate a new spent fuel storage facility ($SF^2$ ) at the NPP site in Tihange. The licensing process took place in 2019. The review of the application showed, amongst others, that the concept meets the most recent expectations related to the safety demonstration by the Belgian nuclear authority which were developed in response to the European directive 2014/87/EURATOM, in particular the avoidance of large and early releases. The license was granted by a Royal Decree in January 2020. The construction activities for Tihange were started early May 2020 with the objective to have the building operational by 2023. For the storage building at Doel the licensing application (at federal level for nuclear aspects) and the permit application (at regional, Flemish level, for urbanistic and non-nuclear environmental aspects) were also obtained. Construction has started with the objective to have the storage building operational by 2025.

Detailed information can be found in the last Belgian national report issued in the frame of the Joint Convention.

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

# III. Appendix 1 - Description of the Nuclear Installations: Power Plants

## III.A. Introduction

This appendix aims at providing a general overview of all the nuclear generating facilities in Belgium, including the related nuclear installations, situated at the Doel and Tihange sites.

Each nuclear power plant is described as it was designed. The descriptions of the power plants of similar design have nevertheless been regrouped and their differences highlighted. The description covers the main characteristics and lay-out of the installations, the main operational parameters, the reactor characteristics, protection against accidents, instrumentation and control designs, power supplies, ultimate heat sink and, finally, a description is given of the fresh and spent fuel storage facilities and the radioactive effluent and waste treatment installations. Also, a list is included of the main modifications brought to the nuclear units since their construction.

## III.B. The Sites

### III.B.1. Location of the Sites

The nuclear generating units in Belgium are spread over two sites, one in the south of the country (Tihange) and the other in the northern part of Belgium (Doel).

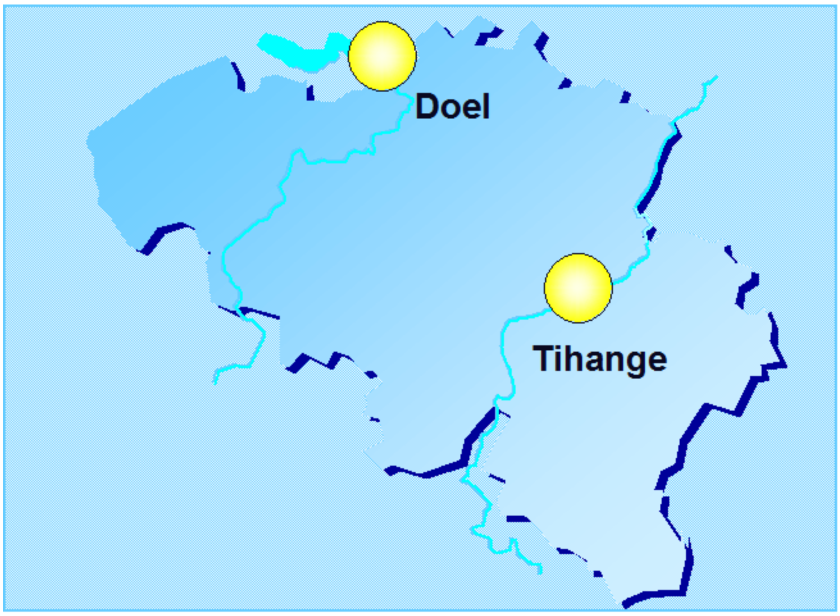


Figure 18 : NPP sites in Belgium

### III.B.2. Doel Site

The Doel site (Figure 19 and Figure 20), situated some 15 km from Antwerp, comprises the following installations :

- the twin nuclear generating units Doel 1 & 2 (A);
- the nuclear generating unit Doel 3 (B);
- the nuclear generating unit Doel 4 (C);
- the centralised installations for radioactive effluent and waste treatment (D);
- the dry storage building for spent fuel (storage in containers);
- the storage building for the replaced steam generators;
- the training centre, located near the Doel site (at Kallo, a few kilometres distant).


Figure 19 : Doel Site

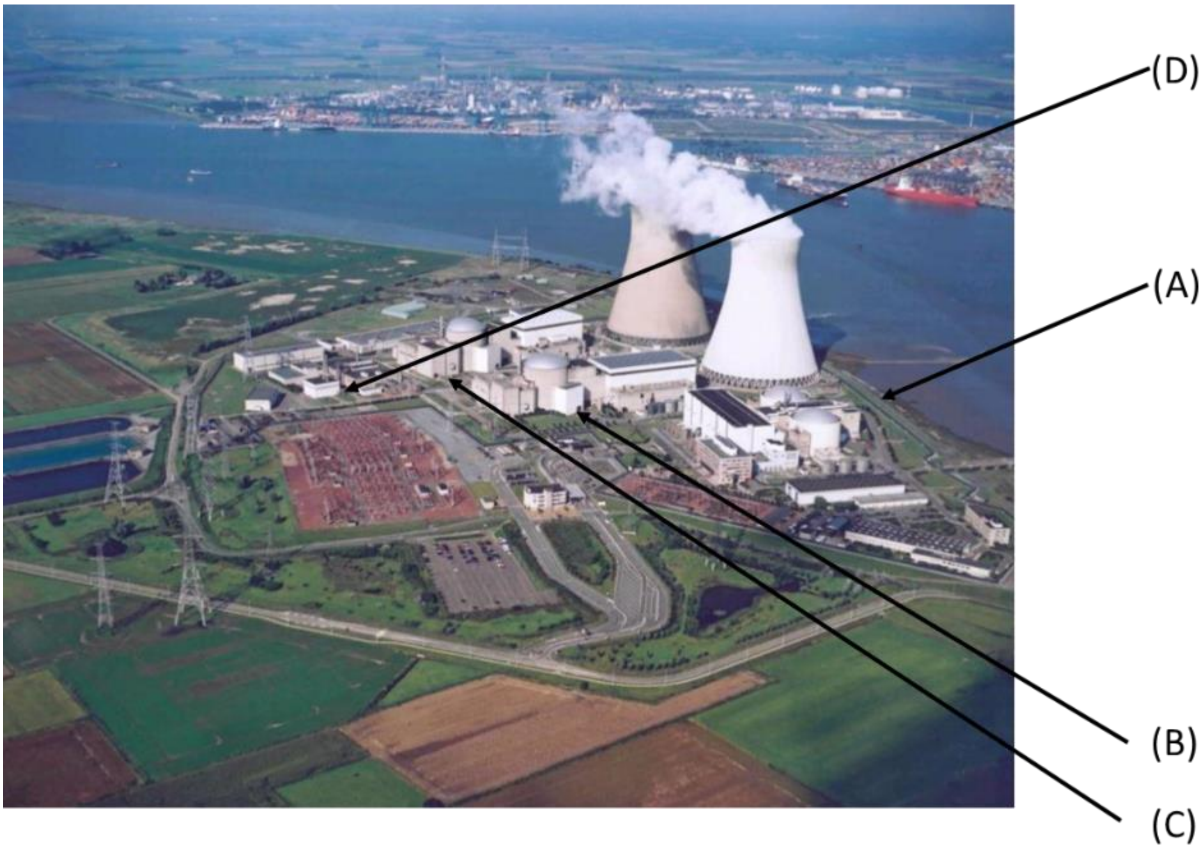


Figure 20 : Major buildings of the Doel Site

### III.B.3. Tihange Site

The Tihange site, situated not far from Huy along the river Meuse 30 km upstream of Liège regroups the following installations:

- the nuclear generating unit Tihange 1 (A);
- the nuclear generating unit Tihange 2 (B);
- the nuclear generating unit Tihange 3 (C);
- the wet storage building for spent fuel (storage in pools);
- the storage building for the replaced steam generators;
- the training centre.

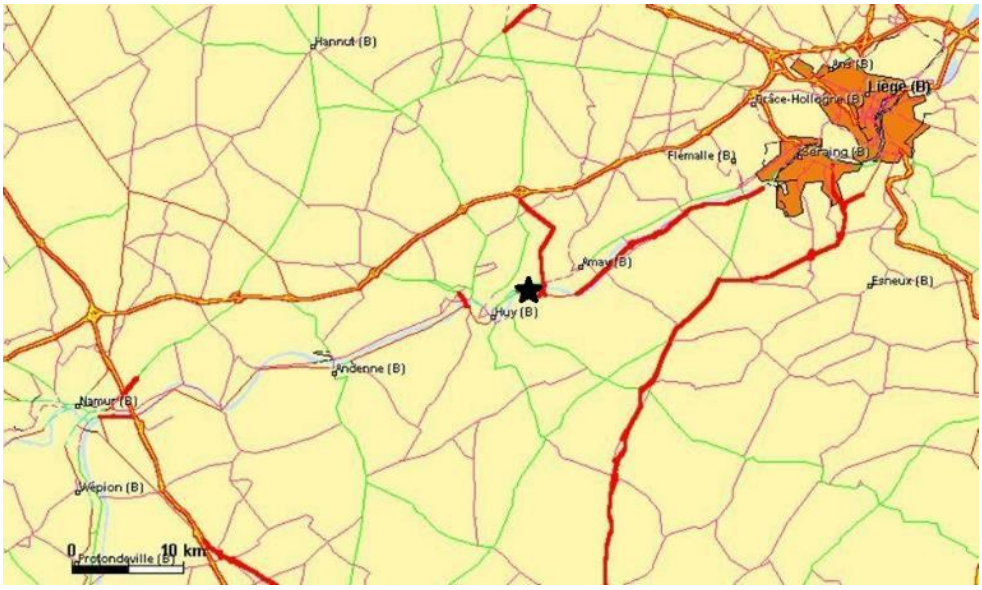


Figure 21 : Tihange Site


Figure 22 : Major buildings of the Tihange Site

## III.C. Doel 1 & 2

### III.C.1. General

#### *a) Introduction*

Doel 1 & 2 are twin units for nuclear generation of electricity, each of the two nuclear reactors having a thermal power of 1312 MW[9]. They are of the pressurised water reactor (PWR) type, of WESTINGHOUSE design.

Each nuclear steam supply system is composed of a reactor vessel and two cooling loops, which form the primary system. Each of these primary loops comprises a centrifugal pump and a steam generator with inverted vertical U-tubes. On one of the two hot legs the pressuriser is installed.

The reactor containment building houses the reactor, the primary system (including the steam generators and the pressurizer) and nuclear auxiliaries. This containment is double: the inner one is a steel sphere, and the cylindrical outer envelope is reinforced concrete. The annular space between these two containments is permanently kept at a pressure less than the outside atmospheric pressure. The containment is designed to withstand a LOCA (loss of coolant accident) and a SLB (steam line break).

#### *b) Power (Design Data) and Key Dates*

| **Power** | **Doel 1** | **Doel 2** |
|---|---|---|
| Nominal thermal power delivered to the steam generators | 1312 MW[9] | 1 312 MW[9] |
| Net electrical power of the power plant | 440 MW[9] | 440 MW[9] |
| **Key Dates** | | |
| Start of construction | 1969 | 1969 |
| First criticality | 1974 | 1975 |
| First connection to the grid | 1974 | 1975 |
| 1st safety review | 1984 | 1984 |
| 2nd safety review | 1995 | 1995 |
| Steam Generator Replacement + Power Increase | 2009 | 2004 |
| 3rd safety review | 2005 | 2005 |
| 4th safety review (+ LTO) | 2015 | 2015 |

Table 9 : Power and key data for Doel 1 & 2

### III.C.2. General Description of the Installations

#### *a) The Nuclear Island*

- **RGB**: each **reactor building** houses the reactor and the primary system, the accumulators of the safety injection system, the spray nozzle rings of the containment spray system and the containment's internal ventilation system. The reactor buildings are symmetrically set on either side of the common nuclear auxiliary building (the GNH);
- The annular space ;
- **GNH: the common nuclear auxiliary building** houses most of the nuclear auxiliaries of the two units (safety injection system, containment spray system, component cooling system, reactor shutdown cooling system, volume and chemical control system, …), the external refuelling water storage, as well as the spent fuel pools and the liquid and gaseous waste storage tanks.

#### *b) Safety-Related Buildings outside the Nuclear Island*

- **DGG**: **the building diesel generators** which houses the five diesel generators;
- **GEH**: **the electrical auxiliary building** mainly accommodates the control room and the electrical rooms. There is only one control room shared by the two units. It comprises the signalling panels and control desks specific to each unit and those shared between the two units;

[9] After Steam Generator Replacement and Power Increase

- **GMH**: **the mechanical auxiliary building**, which houses the instrument air compressors and the safety related generators;
- **BAR**: **the water-steam building** houses the isolation valves of the steam generator feedwater systems, of the steam lines, the safety valves, the steam relief valves to the atmosphere and the feedwater systems;
- **GNS**: **the emergency systems building (2nd level of protection).** This building was added during the 1st safety review (par. III.C.4. a). The building accommodates the following systems : an emergency feedwater system, an emergency injection system for the primary pump seals, an emergency control room and a number of support systems (compressed air, ventilation, equipment cooling, pools cooling, power supply from own diesel generator set and batteries, I & C equipment);
- **HUK**: **the forced-draft cooling towers** to cool the component cooling system.

### *c) Buildings without Safety-related Function*

- **MAZ** : **the machine room** housing mainly the turbine-generator sets;
- the changing rooms, the workshops, the warehouse (**MAG**), the auxiliary boilers, the laboratories, the office buildings (**CGA**);
- **WVA**: **the river water pumping station, the related intake tunnel and the raw water discharge channel** (the raw river water is the cold source for cooling the water station's intermediate cooling system and the condenser);
- **NBK** : basements for the neutralisation tank and related pumps.

## III.C.3. Detailed Description

### *a) Reactor*

The fuel is sintered uranium oxide ($UO_2$) presented in the form of pellets stacked in zirconium alloy tube sleeves that confine the fission products. The so formed rods are assembled and maintained in a 14 x 14 lattice. The core comprises in all 121 fuel assemblies, each containing 179 fuel rods. The active height of the fuel is 2 438 mm. The fuel cycle is 12 months.

Reactivity control is achieved through neutron-absorbing control rods and through the boron present in the form of a boric acid solution in the cooling water. There are two categories of control rods :

- the control rods (21 assemblies in all) for quick-response reactivity control;
- the shutdown control rods (12 assemblies in all) which in combination with the control rods provide a sufficient antireactivity margin in the event of an automatic trip.

The control rods are moved by the Control Rods Drive Mechanisms. In case of emergency shutdown, the de-energising of these mechanisms causes these rods to drop in the core simply by gravity.

### *b) Main Operational Parameters Doel 1 & 2 (100% of rated power -5% of SG tubes plugged)*

The operation point specified below was established in the framework of the Steam Generator Replacement and Power Increase (100% power – 5% tube plugging).

| Primary System | |
|---|---|
| nominal operation pressure (at pressuriser) | 155.1 bara |
| core/vessel inlet temperature | 282.3 °C |
| vessel outlet temperature | 316.9 °C |
| core outlet temperature (taking into account a core bypass flow of 4.5 %) | 318.4 °C |
| loops mean temperature | 299.6 °C |
| mean per-unit-length power of the core | 244 W/cm |
| flow per loop (Thermal Design Flow) | 16 350 $m^3$/h |
| **Secondary System** | |
| SG steam pressure (5% of SG tubes plugged) | 60 bara |
| feedwater temperature | 229 °C |
| steam flow per SG | 1 316.2 t/h |

Table 10 : Main Operational Parameters for Doel 1 & 2

#### *c) Protection against Accidents*

As regards protection against the possible effects of accidents, two types of systems have been provided:

- **safety systems** provide protection against the majority of internal incidents and accidents (except for a fire in the electrical auxiliary building or in the machine room, and total loss of the main control room); these systems are housed mainly in the water-steam building (BAR), the electrical auxiliary building, the mechanical auxiliary building, the nuclear auxiliary building and the reactor building; these systems start automatically if needed;
- **emergency systems** intended to shut down the reactor during certain external accident situations – that were not considered at the time the plant was initially designed - arising during power operation or during a hot shutdown. These systems have been added in the scope of the 1st safety review and have been significantly improved in the framework of the LTO action plan.

#### *d) Safety Systems*

(1) Safety injection system

The main purpose of the safety injection system is primary system inventory restoration, core cooling and, through primary system water boration, avoiding the return to criticality during accidents. For this, each unit has a 1 000 $m^3$ borated water storage tank (the reactor pool filling tank) which is able to feed the low-pressure and high-pressure safety injection pumps.

The high-pressure safety injection system, which is common for both units, comprises four high-pressure safety injection pumps, each 50 % of the capacity required under the most adverse circumstances, that deliver to the primary system cold legs and directly to the reactor vessel, through the so-called upper plenum injection UPI.

The low-pressure safety injection system, specific to each unit, is composed of two exchangers fed from a set of three low-pressure safety injection pumps (3x100% of the required capacity), delivering via two injection lines directly to the reactor vessel (2x100% of the required capacity). The same pumps and exchangers are also part of the residual heat removal system operated when the reactor is shut down.

Each unit has two accumulators that deliver to the cold legs of the primary system.

Once the refuelling water storage tank is empty, the water collected in the sumps is recirculated by the low-pressure pumps and re-injected (at low pressure) into the primary system through the heat exchangers of the residual heat removal system. Systems alignment during changeover to the recirculation phase is manually controlled.

(2) Containment spray system

The containment spray system is intended for post-accident lowering of the containment pressure and temperature. It sprays in the containment the borated water coming from the refuelling water storage tank.

This system, which is shared by both units, has four identical pumps, each 50 % of the required capacity, that can draw water from either of the refuelling water storage tanks. In each unit the pumps can deliver to two manifolds leading to the spray-nozzle rings.

(3) Reactor building ventilation system

The reactor building ventilation system, which comprises four fans and cooling batteries, each 50 % of the required capacity, is intended to remove the thermal energy released in the containment during a LOCA or SLB. This function is also taken care of in a diversified way by the containment spray system.

(4) Component cooling system

The component cooling system also ensures the cooling of the Safety systems equipment.

(5) Containment annular space depressurising and filtering system, and ventilation system for the nuclear auxiliary building

The containment annular space depressurising and filtering system filters the contents of this space in a closed circuit, collects the potential containment leaks, filters them and after complementary filtration evacuates them to the auxiliary building stack. Furthermore, the air exhausted from the nuclear auxiliary building is released via the same stack.

(6) Containment isolation

The containment isolation system ensures redundant isolation of containment penetrations to prevent leakage of radioactive material from the containment to the environment.

(7) Control room habitability

Control room habitability is ensured through a ventilation and air-conditioning system equipped with HEPA filters and charcoal filters. Should a toxic gas be detected, the ventilation is isolated, the operators are warned by an alarm and are required to wear the masks permanently provided in the control room.

(8) Post-accident containment hydrogen control system

This system measures the containment hydrogen concentration and can fill the containment with air. There are autocatalytic recombiners installed in the containment and which can passively maintain the hydrogen concentration in the containment below 5 %.

(9) Auxiliary feedwater system

The auxiliary feedwater system supplies feedwater to the steam generators to ensure residual heat removal from the reactor in case of main feedwater system unavailability.

***e) Emergency Systems***

(1) Primary pump seal injection systems

In addition to the normal chemical and volume control system, a system for water injection to the primary pump seals is installed at each unit. For each unit the system is composed of a 7000 ppm boric acid storage tank and 2 injection pumps (the redundant pump installed in the framework of the LTO design upgrade) that ensures the required injection flow to the No 1 seals of the primary pumps, as well as the pressuriser spray flow so as to allow primary system depressurising.

(2) Emergency feedwater systems

An emergency feedwater system is installed at each unit. The systems are interconnected so that they can back-up each other. The system is intended to supply feedwater to the steam generators in the event of a loss of both the main feedwater and the auxiliary feedwater systems, to be able to remove the residual heat from the reactor. In the framework of the LTO design upgrade, an automatic start and supply of emergency feedwater was foreseen.

(3) GNS-building ventilation system

This is aimed at controlling the temperature in the rooms of the GNS building, as well as at extracting smoke from them. The system is composed of a forced supply part and an extraction part for the mechanical and electrical rooms, and of an extraction part only for the emergency diesel generators rooms.

(4) Emergency compressed air system

An emergency compressed air system is installed at each unit, and the two systems are interconnected. The compressor feeds compressed air to several safety-related valves and is active only if the main compressed air system is unavailable.

(5) Emergency diesel generators

The emergency diesel generators supply power to all the emergency systems.

(6) Emergency cooling system

This system, which is shared by the two units, is equipped with two cooling towers mounted on the roof of the GNS building. It ensures the long-term cooling of the residual heat removal system in the event of a loss of the normal and safety related heat sinks.

(7) Spent fuel pools emergency cooling system

The emergency cooling system for the spent fuel pools consists mainly of a cooling tower for cooling these pools in the event of unavailability of the component or raw water cooling systems.

(8) Emergency control room

From the emergency control room, all the equipment needed to shut down the plant and to maintain it in hot shutdown can be controlled. The reactor can then later be brought to cold shutdown.

### f) Instrumentation and Control Systems, Electrical Systems

(1) Instrumentation and Control Systems

In addition to maintaining the balance between the power of the primary and secondary systems, the first-level instrumentation & control system is designed to ensure automatic reactor protection and automatic actuation of the safety systems and their auxiliary systems in case of necessity. Conventional electromagnetic relaying is used for this first level of protection.

- Reactor automatic trip : for each unit, several measurement chains generate via two trains the logic protection signals which open the automatic trip breakers that cause the control rods to drop. Two sets of two breakers are installed in parallel. This arrangement makes it possible to achieve a 1/2 automatic trip logic.
- Actuation of safety systems : for each unit the automatic control signals for the safety systems are also generated through two independent logic systems.

(2) Electrical Systems

The voltage supplied by the generator is stepped-up by the main transformer prior to being fed to the 380 kV network. A second external supply is arranged from a 150 kV link independent from the 380 kV network.

In normal operation, the auxiliaries of the two units are fed from each of the unit's auxiliary transformers directly supplied by the main alternator.

The two units share four 6 kV first-level safety busses and their related panels, each one can be fed from an associated diesel generator.

### g) Energy Transformation System

For each unit, the steam generated by the two steam generators feeds a turbine-generator that has one high-pressure body and two low-pressure bodies.

### h) Cooling Systems

The component cooling system provides for cooling of the nuclear system equipment by means of a closed-circuit chromated demineralised water system. This system comprises four pumps, each feeding one exchanger, aligned in two closed loops. In turn, this water is cooled by :

- either, the normal cooling of the raw water in an open system, comprising two pumps per unit that draw water from the river Scheldt, a common collector for the two units which is used for cooling the exchangers of the component cooling system, and a discharge canal to the river Scheldt;

- or, the closed-circuit safety cooling system which comprises four loops for the two units, each cooled via a forced-draft cooling tower. In the framework of the LTO action plan, new submergible pumps were foreseen to supply water from the river Scheldt to these cooling towers.

Changeover from normal to safety cooling is automatic.

#### *i) Fuel handling and Storage System*

Before being transferred to the dry storage the spent fuel assemblies are stored for several years in the spent fuel storage pool in the nuclear auxiliary building, the water of which is purified and cooled.

Dry storage is provided for the fresh fuel assemblies.

#### *j) Radioactive Effluents and Waste Treatment System*

(1) Liquid waste

Liquid waste is selectively collected within the unit (recyclable and non-recyclable). Waste treatment for all the waste of all the nuclear units of the Doel site takes place in a common installation inside a specific building. Liquid waste is batch-transferred from the nuclear auxiliary building to the waste treatment building through underground galleries.

(2) Gaseous waste

Gaseous waste is collected and stored inside the unit for radioactive decay, after which it is released to the atmosphere.

(3) Solid Waste

Solid waste is collected within the unit. Treatment of all the waste of the units of the Doel site takes place in a common installation installed in a specific building.

### III.C.4. Major Modifications

#### *a) SG Replacement at Doel 1 & 2*

Replacement of the steam generators of Doel 2 was executed in the summer of 2004 and of Doel 1 in the winter 2009. The steam generators were replaced in 2004 and 2009 given the significant number of tubes that had to be plugged due to corrosion on the primary and secondary sides. For the new steam generators, Inconel 690 tube materials was specified instead of Inconel 600; they have 4 820 tubes of ¾ inch outside diameter, instead of 3 260 tubes of 7/8 inch outside diameter. These differences have an impact on both normal operation and operation in accidental conditions (e.g. increase of the exchange surface).

Figure 23 : SG Replacement at Doel 1

#### *b) Power Increase at Doel 1 & 2*

The replacement of the steam generators made possible to redefine an operating point following the increased thermal performance of the new steam generators. ENGIE Electrabel was granted the licence to increase the power of the unit. The increased exchange area of the new steam generators improved the heat exchange between the primary and the secondary systems. A 10 % power increase of the unit was justified as a result of the higher exchange area of the SGs.

#### *c) Fuel Cycle Extension*

None.

#### *d) MOX Fuel*

None.

#### *e) Protection in Case of Severe Accident*

ENGIE Electrabel installed autocatalytic hydrogen recombiners. These consist of a high number of passive recombiners installed in the various compartments of the reactor building of each of the two units.

Passive cavity flooding devices have been installed to allow molten core cooling in order to mitigate containment base-mat melt through.

#### *f) New safety diesel generators.*

The four existing generators have been replaced with by five new generators, the fifth one being a swing generator able to be lined in case of planned unavailability of any of the 4 other ones, in a new safety diesel generator building (DGG).

Figure 24 : Installation of new safety diesel generators in the DGG of units Doel 1 & 2

The commissioning of the building and the new safety diesel generators was completed in September 2012.

#### *g) LTO action plan:*

See Appendix VII.E, including CFVS containment filtered venting system.

## III.D. Tihange 1

### III.D.1. General

#### *a) Introduction*

Tihange 1 is an electric power generating unit with a nuclear reactor having at present a thermal power of 2875 MW. It is a pressurised water reactor (PWR), of FRAMATOME design. Electrical energy generation is done by two independent turbine-generator sets, each with a nominal power of 518 MW.

The nuclear steam supply system is composed of a reactor vessel and three cooling loops, which form the primary system. Each of these primary loops comprises a centrifugal pump and a steam generator with vertical inverted U-tubes. The pressurizer is installed on one of these three hot legs.

The reactor containment houses the reactor, the primary system (including the steam generators and the pressurizer), and part of the nuclear auxiliaries. This containment is double : the inner one is in pre-stressed concrete, lined on the inside for leak-tightness with a steel liner, and the outer one is in reinforced concrete. The annular space between these two envelopes is permanently kept at a pressure below the outside atmospheric pressure. The containment is designed to withstand a LOCA (loss of coolant accident) and a SLB (steam line break).

All the safety-related systems are composed of two independent trains that can each handle the full (100 %) function.

***b)* *Power (design data) and Key Dates***

| **Power** | | |
|---|---|---|
| Nominal thermal power delivered to the steam generators | 2652 MW | 2 875 MW (after PI/SGR) |
| Net electrical power of the power plant | 870 MW | 962 MW (after PI/SGR) |
| **Key Dates** | | |
| Start of construction | 1970 | |
| First criticality | 1975 | |
| First connection to the grid | 1975 | |
| 1st safety review | 1986 | |
| 2nd safety review | 1995 | |
| PI/SGR | 1995 | |
| Vessel Head Replacement | 1999 | |
| 3rd safety review | 2005 | |
| 4th safety review (+ LTO) | 2015 | |

Table 11 : Power and key data for Tihange 1

## III.D.2. General Description of the Installations

From the safety point of view, the installations can be considered situated in three types of premises : the first one comprises the premises that contain materials or fluids that present a potential radiological risk to the population and the environment (the nuclear island); in the second group are the premises other than those above, that contain the safety-related systems; finally, the third group consists of the premises that house the installations that are simply necessary for normal operation.

***a)* *The Nuclear Island***

- **Building R** (BR) : **the reactor building** houses the reactor and the primary system (including the steam generators and the pressuriser), the reactor shut down cooling system, the safety injection system accumulators, the spray nozzle rings of the containment spray system and the recirculation spray pumps, as well as the heat exchangers of the recirculation and back-up containment spray systems;
- **Building N** (BAN) : **the nuclear auxiliary building** houses most of the nuclear auxiliaries and a large number of the safety systems (direct containment spray systems, intermediate cooling system, volume and chemical control system) that may handle a contaminated fluid;
- **Building D** : **the deactivation pool building** houses the (spent fuel) deactivation pool and the dry storage racks for fresh fuel;
- The **ISBP pit** : premises forming an extension of the annular space and which house the low-pressure safety injection pumps and the back-up spray system pumps ; the electric motors of the pumps are located in the Building N;
- **Building L** : the analysis laboratories ;
- **Building Y** : the liquid waste storage tanks prior to treatment, and gaseous waste tanks;

***b)* *Safety-related Premises outside the Nuclear Island***

- **Building E** : **the electrical auxiliary building** houses the control room, offices and the electrical rooms;
- **Building S** : the building of the two safety diesel generators ;
- **Building K** : the building housing the auxiliary feedwater pumps and the small feedwater tank;
- **Building W** : the building housing the isolating valves of the feedwater lines to the steam generators, the isolating valves of the steam lines, the safety valves of the steam lines, the steam discharge valves to the atmosphere, and the compressed air system compressors.

- **Building UR** : this building houses the emergency turbine generator set and the emergency compressors ;
- **Building BUR-E** : this building (installed in the framework of the LTO) houses the emergency control room and the emergency electrical systems (power, instrumentation and control);
- **Building BUR-D** : this building (installed in the framework of the LTO) houses the two emergency diesel generator sets, the emergency motor-driven feedwater pump and the big feedwater tank.
- **Building P : the West part of the river water pumping station** comprising the raw water system and pumps (the raw water is the heat sink for the intermediate cooling system) and the fire water system pumps.
- Groundwater catchments' wells;
- Liquid waste storage tanks before discharge.
- **Building of the diesel generators** being part of the ultimate additional means installed after the Stress Tests.

#### *c) Buildings without Safety-related Function*

- **Building M** : **the machine room,** housing mainly the turbine-generator sets;
- the East portion of the river water pumping station (Building P), the related underground galleries and the discharge canal of the circulating water (the circulating water is the heat sink for condenser cooling);
- Building J : the **cooling tower**;
- Building F : the building housing the **demineralisation plant**;

### III.D.3. Detailed Description

#### *a) Reactor*

The fuel is sintered uranium oxide ($UO_2$) presented in the form of pellets stacked in zirconium-alloy tube sleeves that confine the fission products. The so formed rods are assembled and maintained in a 15 x 15 lattice. The core comprises in all 157 fuel assemblies, each containing 204 fuel rods. The active height of the fuel is 3 650 mm. The fuel cycle is 18 months.

Reactivity control is achieved through neutron-absorbing control rods and through the boron present in the form of a boric acid solution in the cooling water. There are two categories of control rods :

- the control rods (32 assemblies in all) for quick-response reactivity control;
- the shutdown control rods (16 assemblies in all) which in combination with the control rods provide a sufficient antireactivity margin in the event of an automatic trip.

The control rods are moved by the Control Rods Drive Mechanisms. In case of emergency shutdown, the de-energising of these mechanisms causes these rods to drop in the core simply by gravity.

#### *b) Main Operational Parameters at 100 % Nominal Power (after PI/SGR) with 5% of SG tubes plugged*

| **Primary System** | |
|---|---|
| nominal operation pressure (at pressuriser) | 155 bara |
| core/vessel inlet temperature | 283.4 °C |
| vessel outlet temperature | 321.9 °C |
| core outlet temperature (taking into account a core bypass flow of 4.5 %) | 323.5 °C |
| loops mean temperature | 302.7 °C |
| mean per-unit-length power of the core | 239 W/cm |
| flow per loop (Thermal Design Flow) | 21 122 $m^3$/h |
| **Secondary System** | |
| SG steam pressure (5% of SG tubes plugged) | 59.92 bara |
| feedwater temperature | 235.5°C |
| steam flow per SG | 1 896 t/h |

Table 12 : Main Operational Parameters for Tihange 1

### *c) Protection against Accidents*

As regards protection against accidents, two types of systems have been provided :

- **safety systems** are activated in the event of an accident of internal origin; these systems are mainly located in the nuclear auxiliary building, the reactor building, the electrical building, the diesel generators building and the auxiliary feedwater building;
- **emergency systems** were installed during the first safety review and are improved significantly in the framework of the LTO action plan. They can manually address certain external accidents that had not been taken into account when the unit was first designed, such as, for instance, a total loss of (external and internal) electric power supply and the unavailability of the electrical auxiliary building (instrumentation and control systems, main control room, and power supplies) following a fire. These systems are able to bring and maintain the unit to a safe cold shutdown.

### *d) Safety Systems*

(1) Safety injection system

- The main purpose of the safety injection system is primary system inventory restoration, core cooling so as to maintain the integrity of the fuel elements and, through primary system water boration, ensure the return to sub-criticality during accidents (e.g. loss of primary coolant, secondary system line break, steam generator tube rupture, control rod cluster ejection).
- The high-pressure safety injection system comprises three pumps, each 100 % of required injection capacity (one of these is in stand-by and is not operational); these pumps are also the pumps used for the volume and chemical control system. Three (each 50% of required capacity) accumulators installed inside the containment constitute the medium-pressure safety injection system. The low-pressure safety injection system comprises two pumps, each sized for 100% of required capacity. The water injected into the primary system in case of a line break comes from the refuelling water storage tank (1 650 $m^3$).
- Once the refuelling water storage tank is empty, the water collected in the sumps of the reactor building is recirculated through the heat exchangers of the containment spray system and reinjected in the primary system. Systems alignment during changeover to recirculation is manually controlled for the containment spray system and automatic for safety injection.

(2) Containment spray system

This system comprises six pumps (each 50% of required capacity), two of these for direct spraying, two for recirculation spraying and two as back-up for either direct or recirculation spraying. The recirculation spray pumps are located in the reactor building.

The containment spray system is intended for removing the heat released in the containment (and therefore limiting and afterwards reducing the pressure in the containment so as to maintain containment integrity). It sprays in the containment via the nozzle rings the borated water coming from the refuelling water storage tank (common to the safety injection system), with the possibility to add a chemical reagent (caustic soda) aimed at iodine reduction and pH control.

After the refuelling water storage tank has been emptied, the water collected in the sumps of the containment is re-injected in the containment after having been cooled through the heat exchangers. The four exchangers (two for the recirculation spray pumps and two for the back-up spray pumps) are located in the reactor building. The heat sink for these exchangers is the raw water system.

(3) Intermediate cooling system

This closed system provides the function of intermediate coolant between the fluids circulating in the nuclear auxiliaries and the raw water used for cooling these auxiliaries.

(4) Ventilation systems

- Ventilation and depressurising of the rooms inside the nuclear auxiliary building (BAN) and the spent fuel deactivation pool are provided through redundant fans that release the air via the plant stack. Prior to release the air can be filtered through HEPA and activated-carbon filters.

- Annular space underpressure is normally provided by the BAN ventilation system. In accidental situations, annular space depressurising is performed by a specific system with filtered recirculation and release of the filtered exhausted air to the plant stack.
- The control room and some rooms of the electrical auxiliary building are permanently maintained in overpressure in order to ensure their habitability. In case of radioactive contamination of the outside air, the inlet air is purified by a filtration system.

(5) Containment isolation

The containment isolation system ensures redundant isolation of containment penetrations to prevent radioactive material leakage from the containment to the environment.

(6) Post-accident containment hydrogen control system

Autocatalytic hydrogen recombiners are installed in the containment as a means to passively maintaining the containment hydrogen content to values less than 5%.

(7) Auxiliary feedwater system

The auxiliary feedwater system supplies feedwater to the steam generators to ensure residual heat removal from the reactor in case of loss of the main feedwater system. This system comprises two 50 % motor driven pumps and one 100 % turbine driven pump supplied by two (connected) seismic-designed tanks.

### *e) Emergency System*

This system allows to address events that were not taken into account in the initial design of the unit These emergency systems are improved significantly in the framework of the LTO action plan. For each of the scenarios covered by the improved "SUR-étendu" emergency systems, these systems are able to bring and maintain the unit to cold shutdown and to guarantee the following safety functions: maintain the reactor subcritical, evacuate residual heat from reactor and spent fuel pools, control the primary system inventory and pressure. The scenarios include:

- total loss of external and internal safety power supply;
- unavailability of the main control room;
- loss of the normal and safety control systems in the BAE building, e.g. due to fire.

Following the LTO action plan, the emergency system has the following dedicated equipment:

- two emergency diesel generator sets, redundancy provided in LTO framework;
- an emergency turbine generator;
- one motor-driven emergency steam generator feedwater pump;
- power supply for the pumps needed to bring the plant to cold shutdown (shutdown cooling pumps, intermediate cooling pumps and raw water pumps);
- the well pumps ;
- emergency control panels ;
- an emergency compressed air system : the task of this system is to feed compressed air to the valves that are essential to maintaining the hot shutdown or to cooling the reactor during accidental conditions.
- two emergency injection pumps providing for 7000ppm water injection to the seals of the primary pumps, redundancy provided in LTO framework;
- ventilation, heating and smoke extraction systems for the emergency buildings.

### *f) Instrumentation and Control Systems, Electrical Systems*

(1) Instrumentation and Control Systems

The control systems allow to achieve and maintain the power balance between the primary and secondary systems during steady operation of the unit (reactor and primary temperature control, pressuriser level and pressure control, turbine steam bypass, and water level control in the steam generators).

Furthermore, the instrumentation and control systems are designed to ensure automatic protection of the reactor and automatic actuation of the safety systems and their auxiliary systems :

- Reactor automatic trip : the automatic reactor trip signals open six emergency breakers by acting on the shunt trip coil and on the undervoltage trip coil of each of these breakers. Breaker opening cuts off the electrical supply to the control rod drive mechanisms, resulting in the control rods dropping in the core by gravity.

- Actuation of the safety systems : the instrumentation and control systems start the safety systems and the auxiliary systems necessary to ensure actuation of the other safety equipment (safety diesel generators, intermediate cooling, raw water, ventilation, etc.).
- Protection system against automatic trip failure during a transient : in case of Anticipated Transient without Scram (ATWS), an additional remedial system is available independently from the already existing protection system. The signals of this remedial system act mainly:
    - in parallel, on the two trains of the safety system that ensure reactor emergency cooling via the steam generators (auxiliary feedwater injection into the SGs, and opening the condenser by-pass valves),
    - to trip the two turbine-generator sets,
    - by cutting off the electrical supply of the converters that supply power to the control rod mechanisms (causing their drop),
    - on the shunt coils and undervoltage coils of the six automatic trip breakers.

(2) Electrical Systems

The voltage supplied by the generators is stepped up by step-up transformers prior to being fed to the 380 kV network. A second link between the high-voltage grid and the unit is provided by a 150 kV link independent of the 380 kV network.

The unit's safety auxiliaries are fed from two 6 kV busses and their associated panels. The unit has two safety diesel generator sets. An additional diesel generator set common to all the Tihange units can replace any of the two safety diesel generator sets of the unit.

The equipment that has an emergency function is supplied with power from 2 emergency diesel generators and an emergency turbine generator.

***g) Energy Transformation System***

The steam generated by the three steam generators feeds two turbine-generator sets. Each of the turbines has a high-pressure body and two low-pressure bodies.

***h) Cooling Water***

An intermediate cooling system ensures closed-circuit cooling of the nuclear systems with phosphated demineralized water. This system comprises three pumps, each dimensioned for 100% the required capacity (one of these pumps is in stand-by), which deliver to a common manifold. This system is itself cooled by an open raw water system comprising a pumping station equipped with three motor operated pumps, each 100 % of the required capacity (one of the pumps being in non-immediate stand-by), which deliver river water.

In case of unavailability of the raw water pumping station, groundwater is used. The groundwater system has four pumps, each 50% of the required capacity, which are installed two by two in each of the two wells.

***i) Fuel handling and Storage System***

The spent fuel assemblies are stored in a spent fuel deactivation pool, the water of which is cooled and purified, prior to being transferred and stored in a dedicated storage building at the Tihange site.

Dry storage is provided for the fresh fuel assemblies delivered to the site.

***j) Radioactive Effluents and Waste Treatment System***

(1) Liquid waste

The primary liquid waste can be recycled, i.e. after treatment at the Tihange 2 unit, to be used as deaerated demineralized water and as a concentrated boric acid solution. The non-reusable effluents are either released to the river or first treated and/or stored in external control tanks prior to discharge. The Tihange 1 single discharge collector is equipped with permanent monitoring of the effluent activity and with redundant isolation valves which are automatically activated when a pre-set activity-threshold is exceeded.

(2) Gaseous waste

The gaseous waste is collected and stored within the unit for radioactive decay, after which it is released to atmosphere. The system is split into two independent subsystems:

- hydrogen holding effluent : storage for decay monitoring and checking, controlled release; possible reuse after decay if the residual activity permits;
- aerated effluent : controlled release

(3) Solid Waste

The solid waste produced by Tihange 1 is transferred to:

- Tihange 2 for encapsulation of filters and concentrates, and for treatment of various waste;
- Tihange 3 for encapsulation of active resins.

## III.D.4. Major Modifications

### *a) SG Replacement*

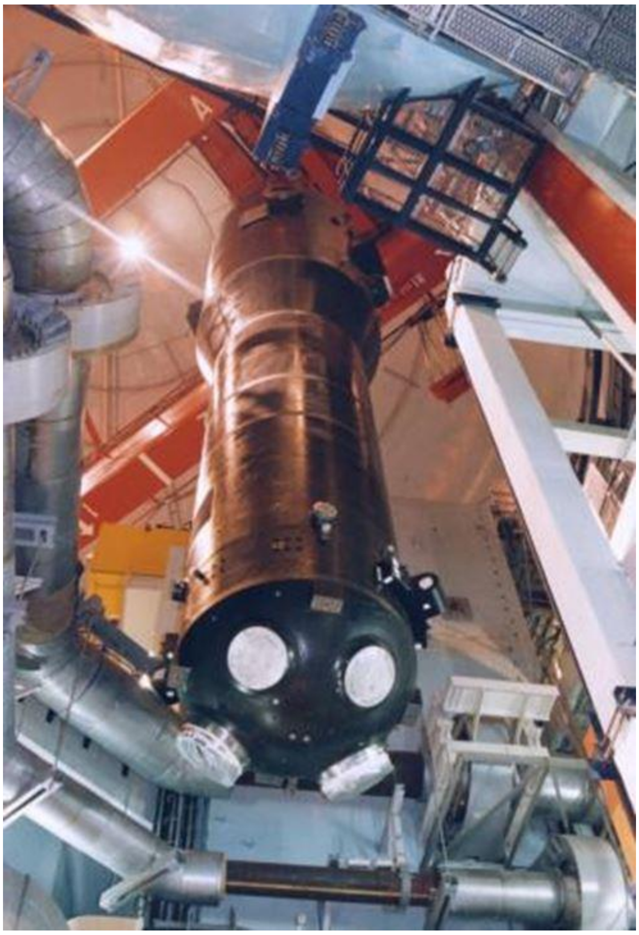

Figure 25 : Replacement of the SGs of Tihange 1

The steam generators were replaced in 1995 given the significant number of tubes that had to be plugged due to corrosion on the primary and secondary sides. For the new steam generators, Inconel 690 tube materials were specified instead of Inconel 600; they have 5 330 tubes of ¾ inch outside diameter, instead of 3 388 tubes of 7/8 inch outside diameter. These differences have an impact on both normal operation and operation in accidental conditions (e.g. increase of the exchange surface).

### *b) Power Increase*

In 1995, the operator was granted the licence to increase the power of the unit. The increased exchange area of the new steam generators improved the heat exchange between the primary and the secondary systems. An 8 % power increase of the unit was justified; the power increase is achieved as a result of the higher exchange area of the SGs and replacement of the turbine rotors.

### *c) Fuel Cycle Extension*

In 1986 (restart after the 1st safety review) the operator obtained permission to extend the fuel cycle to 18 months, which implied an increase in fuel enrichment to 4.3%.

#### *d) MOX Fuel*

None.

#### *e) Vessel Head Replacement*

In September 1999, following cracks that appeared on a number of adapters, the reactor vessel head was replaced.

#### *f) Renovation of the External Nuclear Instrumentation System (SIN) and of the Process Instrumentation System (SIP).*

In March 2001, the SIN which forms one of the instrumentation and control systems of Tihange 1 was renewed with a programmable logic control system. Its ageing necessitated the replacement of four electronic cabinets.

In March 2004, the SIP was renewed with a programmable logic control system. Its ageing necessitated the replacement of all electronic cabinets.

#### *g) Protection in case of Serious Accident.*

The operator installed autocatalytic hydrogen recombiners. These consist of passive recombiners installed in the various compartments of the reactor building.

#### *h) LTO action plan:*

See Appendix VII.E, including CFVS containment filtered venting system.

## 3.E. Doel 3 - Tihange 2

### III.E.1. General

#### *a) Introduction*

Doel 3 and Tihange 2 are electric power generating units with a nuclear reactor having a thermal power of 2 785 MW[10]. They are pressurised water reactors of FRAMATOME design.

The nuclear steam supply system is composed of a reactor vessel and three cooling loops, which form the primary system. Each of these primary loops comprises a centrifugal pump and a steam generator with vertical inverted U-tubes. The pressuriser is installed on one of the three hot legs of the primary loops.

The reactor containment houses the reactor, the primary system (including the steam generators and the pressuriser), and part of the nuclear auxiliaries. This containment is double: the inner one is in prestressed concrete, with a steel liner on the inside for leak-tightness, the outer one is in reinforced concrete. The space between the two containments is called the annular space. The containment is designed to withstand a LOCA (loss of coolant accident), a SLB (steam line break), and an aircraft crash.

#### *b) Power and key dates*

| **Power** | **Doel 3** | **Tihange 2** |
|---|---|---|
| Nominal thermal power delivered to the steam generators | 2 785 MW[10] | 2 785 MW[11] |
| Net electrical power of the power plant | 900 MW | 900 MW[8] |
| **Key Dates** | | |
| Start of construction | 1975 | 1975 |
| First criticality | 1982 | 1982 |
| First connection to the grid | 1982 | 1983 |
| 1st safety review | 1992 | 1993 |
| Steam Generator Replacement + Power Increase | 1993 | 2001 |
| 2nd safety review | 2002 | 2003 |
| 3rd safety review | 2012 | 2012 |

Table 13 : Power and key data for Doel 3 and Tihange 2

[10] Original design data

[11] After Steam Generator Replacement and Power Increase

### III.E.2. General Description of the Installations

The installations are organised in three groups : those in the nuclear island, those in the safety-related equipment group and those in the group where the installations have no safety-related function.

***a) The Nuclear Island – Doel 3***

- **RGB** : **the reactor building** houses the reactor and the primary system (including the pressuriser and the steam generators), the reactor shutdown cooling system, the safety injection system accumulators, the spray nozzle rings of the containment spray system and the fans for post-accident containment cooling;
- The annular space ;
- **GNH: the nuclear auxiliary building** houses most of the nuclear auxiliaries, the safety systems (safety injection systems and containment spray systems), the volume and chemical control system, the storage tanks for the residual drains, chemical effluent, primary effluent and the refuelling water storage tanks;
- **SPG : the deactivation pools building** houses the spent fuel deactivation pools and the fresh fuel storage facility.

***b) The Nuclear Island Tihange 2***

- **Building R** (BR) : **the reactor building** houses the reactor and the primary system (including the pressuriser and the steam generators), the reactor shutdown cooling system, the safety injection system accumulators, the spray nozzle rings of the containment spray system and the ventilation of the BR ;
- The annular space (Z);
- **Building N** (BAN) : **the nuclear auxiliary building** houses most of the nuclear auxiliaries, the safety systems (safety injection system and containment spray system), the volume and chemical control system, the storage tanks for the residual drains, chemical effluent, primary effluent and the refuelling water storage tanks;
- **Building D** : **the deactivation pool building** houses the spent fuel deactivation pool, the fresh fuel storage facility, the gaseous effluent storage tanks, the containment hydrogen recombiner and part of the nuclear auxiliaries ;
- Building Φ : the nuclear waste treatment building

***c) Safety-related Buildings outside the Nuclear Island – Doel 3***

- **GEH : the electrical auxiliary building** houses, amongst other things, the control room and the electrical rooms;
- GMH : the mechanical auxiliary building, housing the safety diesel generator sets (and the stand-by diesel generator set) as well as the fuel storage facility;
- GVD (partly): the premises housing the auxiliary feedwater pumps and tanks ;
- **The bunkered annexe** housing the isolating valves of the steam generator feedwater lines and of the steam lines as well as the safety valves and relief valves to atmosphere;
- **BKR : the emergency building** housing the second-level protective systems (emergency feedwater system, emergency cooling system, the fuel tanks of the emergency diesel generator sets, an emergency control room and a number of support systems: compressed air, BKR building ventilation, equipment cooling, power supply by dedicated diesel generator and batteries, instrumentation and control) ;
- **HUK : the cooling towers** for cooling the intermediate cooling system ;
- **The emergency ponds** (one pond specific for Doel 3 and one pond in stand-by which can be used for Doel 3 as well as for Doel 4).

***d) Safety-related Buildings outside the Nuclear Island – Tihange 2***

- **Building E** : **the electrical auxiliary building**, housing amongst other things the control room and the electrical rooms;
- Building S : the building of the safety diesel generator sets (and the stand-by diesel generator set);
- **Building B** : **the fuel storage building** for the safety diesel generator sets;
- **Building K** : **the building housing the auxiliary feedwater pumps** as well as the external tanks and the instrument air system compressors**;**

- **Building W** (BEV): **the steam-water building** housing the isolating valves of the steam generator feedwater lines and of the steam lines, as well as the safety valves and relief valves to atmosphere;
- **Building W** (BUS) : **the emergency building** housing the second-level protection systems (emergency feedwater system, emergency cooling system, , an emergency control room and a number of support systems: compressed air, W building ventilation, equipment cooling, power supply by dedicated diesel generators and batteries, instrumentation and control) ;
- **Building O** : basement housing the fuel tank of the emergency diesel generator sets ;
- **Building P** : **the pumping station**, partially, for the part accommodating the raw water pumps (raw water is the heat sink for cooling the intermediate cooling system water) and the emergency well-water pumps (groundwater being the second-level heat sink);
- The wells for the second-level cooling system.
- **Building of the diesel generators** being part of the ultimate additional means installed after the Belgian Stress Tests.

***e) Buildings without Safety-related Function – Doel 3***

- **MAZ** : **the machine hall,** which houses mainly the turbine-generator set;
- River water pumping station (WVP) common to Doel 3 and Doel 4, the cooling tower (KTR) and the discharge canal for raw water and circulating water (the circulating water is the heat sink for condenser cooling);
- GVD : the demineralisation building and the auxiliary feedwater in the part near the bunker;

***f) Buildings without Safety-related Function – Tihange 2***

- **Building M** (SdM) : **the machine room,** housing mainly the turbine-generator;
- River water pumping station (for the non-safety-related part) (Building P), the associated underground galleries, the cooling tower (J) and the discharge canal for the raw water (Q) and the circulating water (the circulating water is the heat sink for condenser cooling);
- **Building F**: **the old demineralization building** complement of the new demineralization building;
- **New demineralization building (in front of building F)** in which is produced the demineralised water for both the nuclear and the non-nuclear users;

## III.E.3. Detailed Description

### *a) Reactor*

The fuel is sintered uranium oxide ($UO_2$) or MOX ($UO_2$-$PuO_2$) presented in the form of pellets stacked in zirconium-alloy tube sleeves that confine the fission products. The so formed rods are assembled and maintained in a 17 x 17 lattice. The core comprises in all 157 fuel assemblies, each containing 264 fuel rods. The active height of the fuel is 3 657 mm. The fuel cycle is comprised between 12 months (Doel) and 18 months (Tihange).

Reactor reactivity control is achieved through control rods and through the boron present in the form of a boric acid solution in the cooling water. There are two categories of control rods:

- the control rods (32 assemblies in all) for quick-response reactivity control;
- the shutdown control rods (16 assemblies in all) which in combination with the control rods provide a sufficient antireactivity margin in the event of an automatic trip.

The control rods are moved by the Control Rods Drive Mechanisms. In case of emergency shutdown, the de-energising of these mechanisms causes these rods to drop in the core simply by gravity.

| **Primary System** | **Doel 3** | **Tihange 2** |
|---|---|---|
| nominal operation pressure (at pressuriser) | 155 bara | 155 bara |
| core/vessel inlet temperature | 282.35 °C | 283.5 °C |
| vessel outlet temperature | 324.05 °C | 322.9 °C |
| loops mean temperature | 303.2 °C | 303.2 °C |

| | | |
|---|---|---|
| mean per-unit-length power of the core | 196 W/cm | 196.2 W/cm |
| flow per loop (Thermal Design Flow) | 20 667 $m^3$/h | 21 922 $m^3$/h |
| **Secondary System** | | |
| SG steam pressure (5% of SG tubes plugged) | 59.2 bara | 60.8 bara |
| feedwater temperature | 222.5 °C | 224 °C |
| steam flow per SG | 2029 t/h | 2 018 t/h |

Table 14 : Main Operational Parameters for Doel 3 and Tihange 2

### *b) Protection against Accidents*

As regards protection against the possible effects of accidents, two types of systems have been provided :

- **the safety systems (first-level protection)** which operate in the event of an internal accident; these systems are mainly housed in the nuclear auxiliary building and in the reactor building;
- **the emergency systems (second-level protection)** are designed to perform in combination with certain first-level protections the emergency functions aimed at mitigating the consequences of an external accident (aircraft crash, gas cloud explosion, major fire) affecting the installations.

The systems of this second level of protection are either installed in a reinforced structure (Bunker) or are physically separated so that the probability of their simultaneous destruction in the case of an external accident is extremely low. All the emergency systems are monitored and controlled from premises within the Bunker, in the initial phase automatically (i.e. during the first three hours after the event has arisen) and manually after this first automatic phase.

The basic principle adopted is the principle of independence between the first-level protection systems and the emergency systems. However, certain first-level protection systems that are also capable of performing emergency functions have not been duplicated when they are installed inside reinforced structures that can resist external accidents. These systems are fitted with extra control systems which are independent from the main control systems but which can override the main controls when an external accident occurs.

### *c) Safety Systems*

(1) <u>Safety injection system</u>

The main purpose of the safety injection system is primary system water inventory restoration, core cooling so as to preserve fuel element integrity, and ensuring of primary system water boration during accidents (loss of primary coolant, secondary system line break, steam generator tube rupture, control rod ejection).

The safety injection system comprises three separate and independent 100% capacity trains, each having a high-pressure safety injection pump and a low-pressure safety injection pump. The water injected into the primary system is drawn from the refuelling water storage tanks (one per train). The pumps and the refuelling water storage tanks are located in the nuclear auxiliary building. Three accumulators (3x50% of the required capacity) are located inside the containment and compose the medium-pressure injection system.

Once the reactor water storage tanks are empty, the water collected in the sumps in the event of a primary system line break is sucked-up by the low-pressure pumps and re-injected into the primary system through the heat exchangers of the reactor shutdown cooling system. Systems alignment during changeover to recirculation is controlled automatically.

(2) <u>Containment spray system</u>

The containment spray system is composed of 3 identical trains, each 50 % of required capacity (accounting for the single-failure criterion of one of the trains), which are separate and independent and which each have a spray pump, a heat exchanger (Tihange 2), a soda tank and containment spray nozzle rings. Each train draws its water from its respective refuelling water storage tank of the safety injection system.

The containment spray system is intended for removing the heat released in the containment (and thus mitigating and then reducing the containment pressure so as to maintain containment integrity) following a primary or secondary system line break, by spraying in the containment the borated water coming from the reactor water storage tanks, with the possibility to add a chemical reagent (soda) aimed at reducing and trapping the iodine released in the containment, and pH control.

In the recirculation phase, after the refuelling water storage tanks have been emptied, the water collected in the sumps of the containment is re-sprayed in the containment and cooled through heat exchangers (Tihange 2). At Doel 3 the spray water is not cooled, but the containment is cooled by a ventilation system (cf. point 4) below).

(3) Intermediate cooling system

This closed system provides the function of intermediate coolant for cooling the nuclear auxiliaries and uses the raw water system as heat sink.

(4) Reactor building ventilation system (Doel 3)

The reactor building ventilation system, which comprises six fans and cooling batteries, each 50 % of required capacity, is intended to remove the thermal energy released in the containment during a primary or secondary system pipe break. This function is also taken care of by the containment spray system, as the spray reduces the containment temperature.

(5) Depressurising and filtering system, for the containment annular space and for some of the nuclear auxiliary buildings

The containment annular space depressurising and filtering system collects the containment leaks, filters them and evacuates them to the plant vent. Inside the annular space the air is filtered in recirculation. Furthermore, the air exhausted from the nuclear auxiliary building is also filtered prior to be released via the plant vent.

(6) Containment isolation

The containment isolation system ensures redundant isolation of containment penetrations to prevent radioactive material leakage from the containment to the environment.

In order to prevent any leakage from within the containment to the outside via the containment isolation valves, some of these are fitted with a system that pressurises the space between these valves to a pressure higher than the pressure due to the accident.

(7) Control room habitability

The control room is permanently pressurised in order to ensure its habitability. In case of radioactive contamination of the outside air, the air taken in is purified through a filtering system.

(8) Post-accident containment hydrogen control system

This system measures the hydrogen concentration in the containment. Autocatalytic hydrogen recombiners have been installed in the containment as a means to passively maintaining the containment hydrogen concentration to values less than 5%.

(9) Auxiliary feedwater system

The auxiliary feedwater system supplies the feedwater required by the steam generators to remove the reactor residual heat following a loss of the main feedwater system. This auxiliary system comprises two motor-pump sets and one turbine pump that draw water from a tank (2 tanks at Doel 3).

***d) Emergency Systems***

(1) Reactor emergency protection system

This system has instrumentation and logic control systems fully separated from the first-level reactor protection system; however, the six reactor trip breakers are common to the two systems;

(2) Emergency electricity supply systems

This system comprises three emergency diesel generator sets, with their associated auxiliary circuits and distribution panels.

(3) Emergency boration system

This system borates and makes up the primary system boration in order to offset leaks and the contraction of the primary system inventory during cooling. It also controls the primary pressure by pressuriser spraying. The system comprises three trains, each 100 % of the required capacity. The trains can be interconnected. The same system can also be used for emergency injection to the seals of the primary pumps at Tihange 2.

(4) Emergency feedwater system for the steam generators

This system, which consists of three identical separate independent trains, ensures water supply to the steam generators. Each train comprises a pump that draws water from a tank (at Tihange 2 it shares this tank with the emergency cooling system). Water is supplied to this tank from ponds at Doel 3; at Tihange 2 the tank is supplied with groundwater or river water.

(5) Emergency cooling system

Tihange 2 : this system provides the emergency heat sink. The circulation pumps draw water from a tank whose level is maintained with groundwater or river water and return the water to the river. Doel 3: cooling is secured through an artificial pond.

This water can cool, among other, the primary pump thermal barriers, the heat exchangers and pump packings of the reactor shutdown cooling system, the emergency boration system pumps, the emergency feedwater pumps and the exchangers of the spent fuel deactivation pool cooling system.

(6) Emergency injection system in the seals of the primary pumps (Doel 3)

This system, provided with two pumps, ensures from a common manifold the cooling and protection of the primary pump seals by injecting pressurised water in them in case of loss of the normal water injection.

(7) Emergency water supply system

Three physically separated well pumps draw groundwater for cooling the emergency diesel generator sets and the ventilation of the emergency building, and for filling the tanks from which are pumped the water for steam generator feedwater and for the emergency cooling system pumps. Three additional pumps installed in the river water pumping station also perform these functions (back-up for the groundwater pumps). This function is ensured at Doel 3 by the pond.

(8) On each steam generator, two emergency steam relief valves to atmosphere (one of these having also a safety function)

(9) An air supply to the emergency diesel generator sets

At Tihange 2, this air supply system consists of three physically separated buried air-intakes and underground intake tunnels. At Doel 3, the air is supplied via the linking tunnels to the ponds;

(10) Valves have been added to the non-nuclear circuits so as to ensure redundant isolation of the circuits after an external accident.

### *e) Safety Systems capable of performing Emergency Functions*

The systems which have not been duplicated in the emergency systems, but which can receive second-level protection orders, are :

- the six reactor trip breakers;
- the reactor shutdown cooling system;
- the portion of the intermediate cooling system situated inside the containment and in the spent fuel deactivation pools building;
- the three pressuriser relief valves;
- the sets of pressuriser heaters;
- certain containment isolation valves.
- the steam relief valves to atmosphere (one per steam generator)
- the isolation valves of the steam lines and feedwater lines
- the primary pump breakers

### *f) Instrumentation and Control System, Electrical Systems*

(1) Instrumentation and Control Systems

The control systems allow to achieve and maintain the power balance between the primary and secondary systems during steady operation of the unit (reactor control, primary temperature control, pressuriser pressure and level control, turbine steam bypass, and water level control in the steam generators).

The reactor protection systems are designed to ensure automatic tripping of the reactor and automatic actuation of the safety systems and their auxiliaries :

- Reactor automatic trip

The logic signals issued from the threshold triggers are used by three redundant and independent logic channels (B,R,G) which generate the signals that open the automatic trip breakers, thus causing dropping of the control and shutdown rod assemblies in the core. Three sets of two parallel-mounted breakers have been installed in series. The signal issued from the B (R,G) logic channels orders a breaker to open, whereas the breaker in parallel to that breaker receives an order from the R channel signal or from a G channel signal (B or G, B or R). This arrangement makes it possible to very reliably achieve a 2/3 automatic trip logic and still retain unit availability. It also makes it possible to test one of the three logic channels and retain a 1 /2 redundancy between the two remaining logic channels.

- Actuation of the safety systems

The instrumentation and control systems start the safety systems and also start the auxiliary feedwater system and the auxiliary systems necessary to secure performance of the safety functions (safety diesel generator sets, intermediate cooling, raw water, ventilation, containment isolation, isolation of feedwater lines and steam lines, etc.).

- Actuation of the emergency systems

The instrument and control systems of the emergency systems actuate these manually or automatically, depending on which emergency systems are involved; the functions of these systems are detailed in §III.E.3 d).

(2) Electrical Systems

The voltage supplied by the generator is stepped up by the step-up transformer prior to being fed to the 380 kV network. A second link between the high-voltage grid and the unit is provided by a 150 kV link independent of the 380 kV network.

The unit's auxiliaries are fed from three 6.6 kV safety busses and their associated switchboards, and from three 6.6 kV emergency busses and their associated switchboards.

The units have three first-level protection diesel generator sets and three second-level protection diesel generator sets. An additional diesel generator set is also available at the site and can be connected should one of the first-level diesel sets fail.

### *g) Energy Transformation System*

The steam generated by the three steam generators feeds a turbine-generator set of which the turbine has a high-pressure body and three low-pressure bodies.

### *h) Cooling Water*

An intermediate cooling system ensures closed-circuit cooling of the nuclear systems equipment with demineralised water with corrosion inhibitors. Closed-circuit use of this treated water enables the physical separation to be achieved between a fluid that could possibly be contaminated and the cooling system that is open to the outside. The system comprises three trains, to feed the equipment of the safety trains in case of an accident, and a common part to feed non-essential equipment during normal operation of the unit.

This water is cooled:

- for the Tihange unit, by the raw water system comprising a pumping station equipped with three identical motor-pump sets that draw water from the river, a three-train water distribution system with a common part, and a discharge canal to the river;
- for the Doel unit, by a system comprising one pump per train which sends the water cooled by two forced draft cooling towers to the heat exchanger of the intermediate cooling system.

### *i) Fuel handling and Storage System*

The spent fuel assemblies are stored several years in a spent fuel pool, the water of which is cooled and purified, prior to being transferred and stored in a dedicated storage building at the site.

Dry storage is provided for the fresh fuel assemblies (except the fresh MOX assemblies, which are stored in the spent fuel pools).

#### *j) Radioactive Waste and Waste Treatment System*

(1) Liquid Waste

- Tihange 2 : The liquid waste is selectively collected, stored and treated within the unit. After treatment the effluents are stored in tanks prior to disposal or re-use.
- Doel 3 : Effluent treatment for all the units of the Doel nuclear plant site is performed in a common installation housed in a dedicated building. Liquid waste is batch-transferred from the nuclear auxiliary building to that waste treatment installation via pipes running in the connection galleries.

(2) Gaseous Waste

The gaseous waste is stored within the unit in several decay tanks. The hydrogen concentration is measured and can possibly be reduced with the recombiners (Doel 3). After decay the gaseous effluents are either released via the plant vent or re-used in the units.

(3) Solid Waste

The solid waste to be treated comprises used resins, evaporation concentrates, flocculates, fouled filter cartridges, residue of magnetic filtration, …

- Tihange 2 *:* The installations provide for on-site encapsulation in concrete and drumming of waste, encapsulation of resins and concentrates by means of a mobile encapsulation unit, and removal from the site of the concentrates by means of road containers. The waste treatment installations are entirely remote controlled.
- Doel 3 *:* The solid waste is collected within the unit. Treatment of it is performed in a dedicated treatment building at the Doel site which is the common treatment facility for solid waste originating from all the Doel units (cf. the WAB).

### III.E.4. Major Modifications

#### *a) Power Increase*

(1) Doel 3

In 1993 the operator was authorised to increase the power of the unit and to replace the steam generators. The increased exchange surface of the new steam generators allowed to improve the heat exchange between the primary and the secondary systems. A 10 % power increase of the unit was justified (thermal power of the core : 3 054 MW, net electrical power : 1 006 MW).

(2) Tihange 2

In 1996 the operator was authorised to increase the power of the Tihange 2 unit by 4.3%, resulting in 2 895 MW thermal power of the core and 967 MW net electrical power. Furthermore, the limit on the percentage of steam generator tubes permitted to be plugged was raised to 5 %, and fuel cycles were allowed to be more flexible (refuelling of quarter core, increase of the maximum fuel enrichment to 4.5 %).

The replacement of the steam generators, in 2001, made it possible to redefine an operating point according to the increased thermal performance of the new SGs. Indeed, the larger exchange surface of the new steam generators will improve the heat exchange between the primary and secondary systems. A power increase of the unit by 5.5 % was justified, raising the thermal power of the core to 3 054 MW.

***b) SG Replacement***

(1) a. Doel 3

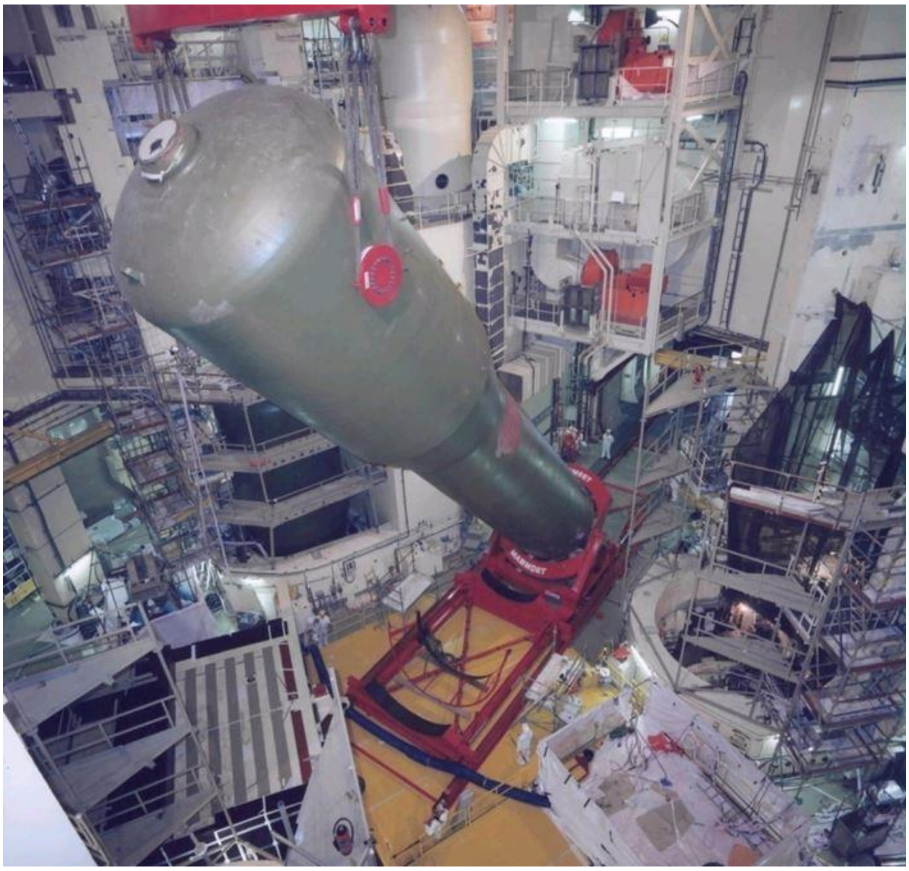

Figure 26 : SG Replacement at Doel 3

The steam generators were replaced in 1993 given the significant number of tubes that had already been plugged due to corrosion on the primary and secondary sides. For the new steam generators, Incoloy 800 tube materials were specified instead of Inconel 600; they have 5 130 tubes of ¾ inch outside diameter, instead of 3 361 tubes of 7/8 inch outside diameter. These differences have an impact on both normal operation and operation in accidental conditions (e.g. increase of the exchange surface). This required a safety review of the installation.

(2) Tihange 2

The steam generators were replaced in 2001. For the new steam generators, Inconel 690 tube materials were specified instead of Inconel 600 ; they have 5372 tubes of ¾ inch outside diameter, instead of 3361 tubes of 7/8 inch outside diameter. These differences have an impact on both normal operation and operation in accidental conditions (e.g. increase of the exchange surface). This required a safety review of the installation.

***c) Fuel Cycle Extension***

In 1988, authorisation was obtained to extend the fuel cycle to a maximum of 18 months at Tihange 2, and in Doel 3 the fuel burn-up has been limited to 55 000 MWd/t on average per assembly.

***d) MOX Fuel***

In 1994, the operator obtained the authorisation to recycle the plutonium produced through reprocessing and use MOX in the reactors of Tihange 2 and Doel 3. MOX fuel is composed of uranium oxide ($UO_2$) and plutonium oxide ($PuO_2$) with an average total plutonium content of 7.7 % by weight.

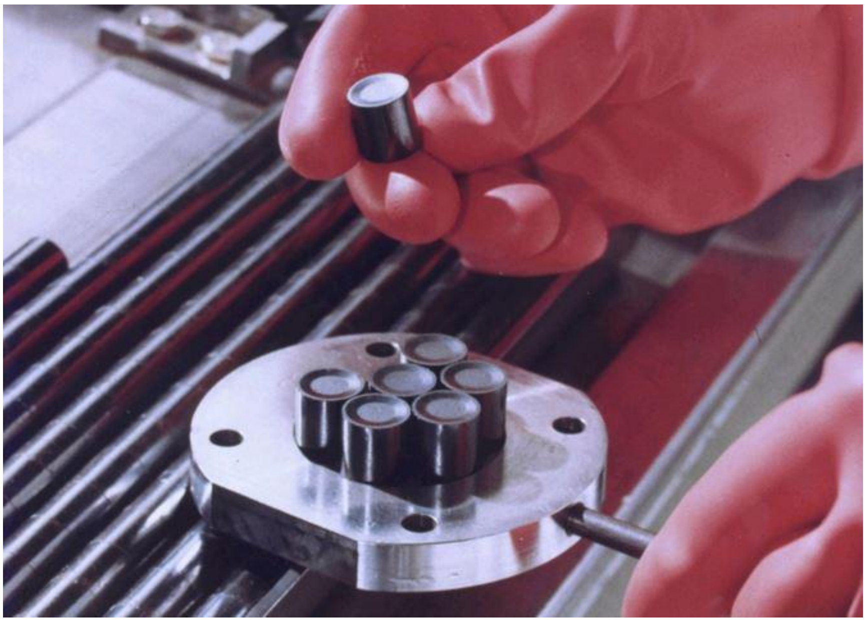

Figure 27 : MOX Fuel

### *e) Protection in case of a Severe Accident*

The operator installed autocatalytic hydrogen recombiners in all the units. These consist of passive recombiners installed in various compartments of the reactor building.

A passive cavity flooding device has been installed at Doel 3 to allow molten core cooling in order to mitigate containment base-mat melt through.

### *f) CFVS containment filtered venting system*

In the framework of the BEST action plan, both Doel 3 as Tihange 2 have been equipped with containment filtered venting systems.

## III.F. Doel 4 - Tihange 3

## III.F.1. General

### *a) Introduction*

Doel 4 and Tihange 3 are electric power generating units with a nuclear reactor having a thermal capacity of 3000 MW. They are pressurised water reactors of WESTINGHOUSE design.

The nuclear steam supply system is composed of a reactor vessel and three cooling loops, which form the primary system. Each of these primary loops comprises a centrifugal pump and a steam generator with vertical inverted U-tubes. On one of three hot legs of these loops the pressuriser is installed.

The reactor containment houses the reactor and the primary system (including the steam generators and the pressuriser), as well as part of the nuclear auxiliaries. This containment is double: the inner one is in prestressed concrete, lined on the inside for leak-tightness with a steel liner, the outer one is in reinforced concrete. The space between the two containments is called the annular space. The containment is designed to withstand a LOCA (loss of coolant accident), a SLB (steam line break), and an aircraft crash.

***b) Power and key dates***

| Power (Design data) | Doel 4 | Tihange 3 |
|---|---|---|
| Nominal thermal power delivered to the steam generators | 3 000 MW | 3 000 MW |
| Net electrical power of the power plant | 1 003 MW | 1 006 MW |
| **Key Dates** | | |
| Start of construction | 1977 | 1977 |
| First criticality | 1985 | 1985 |
| First connection to the grid | 1985 | 1985 |
| First safety review | 1995 | 1995 |
| Replacement of the steam generators | 1997 | 1998 |
| Second safety review | 2005 | 2005 |
| Third safety review | 2015 | 2015 |
| Reactor vessel head replacement | 2015 | 2015 |

Table 15 : Main Operational Parameters for Doel 3 and Tihange 2

## III.F.2. General Description of the Installations

The installations are organised in three groups: those in the nuclear island, those in the safety-related equipment group, and those in the group where the installations have no safety-related function.

***a) The Nuclear Island – Doel 4***

- **RGB** : **the reactor building** houses the reactor and the primary system (including the steam generators and the pressuriser), the reactor shutdown cooling system, the safety injection system accumulators, the spray nozzle rings of the containment spray system and the fans for post-accident containment cooling;
- the annular space ;
- **GNH : the nuclear auxiliary building** houses most of the nuclear auxiliaries;
- **SPG** : **the spent fuel pools building** houses the spent fuel deactivation pools and the fresh fuel storage premises.

***b) The Nuclear Island – Tihange 3***

- **Building R** (BR) : **the reactor building** houses the reactor and the primary system (including the steam generators and the pressuriser), the reactor shutdown cooling system, the safety injection system accumulators, the spray nozzle rings of the containment spray system and the reactor building ventilation system;
- the annular space (Z);
- **Building N** (BAN) : **the nuclear auxiliary building** houses most of the nuclear auxiliaries, the safeguard systems (safety injection system and containment spray system) and the water storage tanks for filling the BR pool;
- **Building D** : **the deactivation pool building** houses the spent fuel deactivation pool, the fresh fuel storage facility, the gaseous waste storage tanks, the hydrogen recombiner and part of the nuclear auxiliaries (volume and chemical control system, pool water treatment system).
- **Building YL** : **the effluent storage building** houses the storage tanks for the liquid waste (residual drains, primary waste, service waste, chemical waste,…) and various solid waste, the primary and secondary sampling systems, the laboratories.

***c) Safety-related Premises outside the Nuclear Island – Doel 4***

- **GEH : the electrical auxiliary building** houses, amongst other things, the control room and the electrical rooms;
- GMH : the mechanical auxiliary building, housing the safety diesel generator sets;
- GVD (partly): the premises housing the auxiliary feedwater pumps and tanks;
- **The bunkered annexe** housing the isolating valves of the steam generator feedwater lines and of the steam lines as well as the safety valves and relief valves to atmosphere;

- **BKR : the emergency building** housing the second-level protective systems (emergency feedwater system, emergency cooling system, the fuel tanks of the emergency diesel generator sets, an emergency control room and a number of support systems: compressed air, BKR building ventilation, equipment cooling, pools cooling, power supply by dedicated diesel generator and batteries, instrumentation and control) ;
- **HUK : the cooling towers** for cooling the intermediate cooling system ;
- **The emergency ponds** (one pond specific for Doel 4 and one pond in reserve which can be used for Doel 3 as well as for Doel 4

#### *d) Safety-related Premises outside the Nuclear Island – Tihange 3*

- **Building E** : **the electrical auxiliary building**, housing amongst other things the control room and the electrical rooms;
- Building S : the building of the safety diesel generator sets;
- **Building B** : **the fuel storage building** for the safety diesel generator sets;
- **Building I** : the building of the RCC assembly control units
- Building K : the building housing the auxiliary feedwater pumps as well as the external tank;
- **Building W** (BEV) : **the steam-water building** housing the isolating valves of the steam generator feedwater lines and of the steam lines, as well as the safety valves and relief valves to atmosphere;
- **Building W** (BUS) : **the emergency building** housing the second-level protective systems (emergency feedwater system, emergency cooling system, the primary pump seal injection system, an emergency control room and a number of support systems: compressed air, W building ventilation, equipment cooling, pools cooling, power supply by dedicated diesel generator and batteries, instrumentation and control) ;
- **Building O** : basement housing the fuel tank of the emergency diesel generator sets ;
- **Building P** : **the pumping station**, partially, for the part accommodating the raw water pumps (raw water is the heat sink for cooling the intermediate cooling system water) and the emergency well-water pumps (groundwater being the second-level heat sink);
- The wells for the second-level cooling system

#### *e) Buildings without Safety-related Function – Doel 4*

- **MAZ** : **the machine hall,** which houses mainly the turbine-generator set;
- **the river water pumping station (WVP)** common to Doel 3 and Doel 4, **the cooling tower (KTR) and the discharge canal** for raw water and circulation water (the circulating water is the heat sink for condenser cooling);
- GVD : the demineralization building and the auxiliary feedwater in the part near the bunker ;

#### *f) Buildings without Safety-related Function – Tihange 3*

- **Building M** (SdM) : **the machine room,** housing mainly the turbine-generator;
- the river water pumping station (for the non-safety-related part) (Building P), the associated underground galleries, the cooling tower (J) and the discharge canal for the raw water and the circulating water (Q) (the circulating water is the heat sink for condenser cooling);
- Building F : the demineralization building;

### III.F.3. Detailed Description

#### *a) Reactor*

The fuel is sintered uranium oxide ($UO_2$) presented in the form of pellets stacked in Zirconium-alloy tube sleeves that confine the fission products. The so formed rods are assembled and maintained in a 17 x 17 lattice. The core comprises in all 157 fuel assemblies, each containing 264 fuel rods. The active height of the fuel is 4 267 mm. The fuel cycle is comprised between 12 months (Doel) and 18 months (Tihange).

Reactivity control is achieved through control rods and through the boron present in the form of a boric acid solution in the cooling water. There are two categories of control rods :

- the control rods (28 assemblies in all) for quick-response reactivity control;

- the shutdown control rods (24 assemblies in all) which in combination with the control rods provide a sufficient antireactivity margin in the event of an automatic trip.

The control rods are moved by the Control Rods Drive Mechanisms. In case of emergency shutdown, the de-energising of these mechanisms causes these rods to drop in the core simply by gravity.

### *b) Main Operational Parameters at 100 % Nominal Load, after Steam Generator Replacement, with 5% of the SG tubes plugged*

| **Primary System** | **Doel 4** | **Tihange 3** |
|---|---|---|
| nominal operation pressure (at pressuriser) | 155 bara | 155 bara |
| core/vessel inlet temperature | 294.1 °C | 294.1 °C |
| vessel outlet temperature | 329.9 °C | 329.9 °C |
| temperature at core outlet (taking into account a 4.5% core by-pass flow) | 331.9 °C | 331.9 °C |
| loops mean temperature | 312 °C | 312 °C |
| mean per-unit-length power of the core | 164.7 W/cm | 164.7 W/cm |
| flow per loop (Thermal Design Flow) | 23 050 $m^3/h$ | 23 050 $m^3/h$ |
| **Secondary System** | | |
| SG steam pressure (5% of SG tubes plugged) | 72.5 bara | 72.5 bara |
| feedwater temperature | 224 °C | 220 °C |
| steam flow per SG | 1992 t/h | 1972 t/h |

Table 16 : Main Operational Parameters for Doel 3 and Tihange 2

### *c) Protection against Accidents*

As regards protection against the possible effects of accidents, two types of systems have been provided :

- **the safety systems (first-level protection)** which operate in the event of an internal accident; these systems are mainly housed in the nuclear auxiliary building and in the reactor building;
- **the emergency systems (second-level protection)** are designed to perform in combination with certain first-level protections the emergency functions aimed at mitigating the consequences of an external accident (aircraft crash, gas cloud explosion, major fire) affecting the installations.

The systems of this second level are either installed in a reinforced structure (Bunker) or are physically separated so that the probability of their simultaneous destruction in the case of an external accident is extremely low. All the emergency systems are monitored and controlled from premises within the Bunker, in the initial phase automatically (i.e. during the first three hours after the event has arisen) and manually after this first automatic phase.

The basic principle adopted is that of independence between the first-level protection systems and the emergency systems. However, certain first-level protection systems are not duplicated: they perform emergency functions and are installed inside reinforced structures that can resist external accidents. These systems are fitted with extra control systems which are independent from the main control systems but which can override the main controls when an external accident occurs.

### *d) Safety Systems*

(1) <u>Safety injection system</u>

The main purpose of the safety injection system is primary system water inventory restoration, core cooling so as to preserve fuel element integrity, and ensuring of primary system water boration during accidents (loss of primary coolant, secondary system line break, steam generator tube rupture, control rod ejection).

The safety injection system comprises three separate and independent 100 % of required capacity trains, each having a high-pressure safety injection pump and a low-pressure safety injection pump, an accumulator and a refuelling water storage tank. The water injected into the primary system is drawn from the refuelling water storage tank. The pumps and the refuelling water storage tank are located outside the containment, the accumulators inside the containment.

Once the refuelling water storage tank is empty, the water collected in the sumps in the event of a primary system line break is sucked-up by the low-pressure pumps and re-injected into the primary system through the heat exchangers of the reactor shutdown cooling system. Systems alignment during changeover to recirculation is controlled automatically.

(2) Containment spray system

The containment spray system is composed of 3 identical trains, each 50 % of required capacity, which are separate and independent and which each have a spray pump, a heat exchanger (Tihange 3), a soda tank and containment spray nozzle rings. Each train draws its water from the reactor water storage tank of the respective safety injection system.

The containment spray system is intended for removing the heat released in the containment (and thus mitigating and then reducing the containment pressure so as to maintain containment integrity) following a primary or secondary system line break, by spraying in the containment the borated water coming from the refuelling water storage tanks, with the possibility to add a chemical reagent (soda) aimed at better reducing and trapping the iodine released in the containment.

In the recirculation phase, after the refuelling water storage tanks have been emptied, the water collected in the sumps of the containment is re-sprayed in the containment by the containment spray system after having been cooled through heat exchangers. At Doel 4 the water sprayed in the containment is not cooled, but containment cooling is provided by a ventilation system (cf. point 4) below).

(3) Intermediate cooling system

This closed system provides the function of intermediate coolant for cooling the nuclear auxiliaries and uses the raw water system as heat sink.

(4) Reactor building ventilation system (Doel 4)

The reactor building ventilation system, which comprises six fans and cooling batteries, each 50 % of required capacity, is intended to remove the thermal energy released in the containment during a primary or secondary system pipe break. This function is also taken care of by the containment spray system, as the spray reduces the containment temperature.

(5) Depressurising and filtering system, for the containment annular space and for some of the nuclear auxiliary buildings

The containment annular space depressurising and filtering system collects the containment leaks, filters them and evacuates them to the plant vent. Inside the annular space the air is filtered in recirculation. Furthermore, the air exhausted from the nuclear auxiliary building is also filtered prior to be released via the plant vent.

(6) Containment isolation

The containment isolation system ensures redundant isolation of containment penetrations to prevent radioactive product leakage from the containment to the environment.

In order to prevent any leakage from within the containment to the outside via the containment isolation valves, some of these are fitted with a system that pressurises the space between these valves to a pressure higher than the pressure due to the accident.

(7) Control room habitability

The control room is permanently pressurised in order to ensure its habitability. In case of radioactive contamination of the outside air, the air taken in is purified through a filtering system.

(8) Post-accident containment hydrogen control system

This system measures the containment hydrogen concentration. Autocatalytic hydrogen recombiners have been installed in the containment as a means to passively maintaining the containment hydrogen concentration to values less than 5 %.

(9) Auxiliary feedwater system

The auxiliary feedwater system supplies the feedwater required by the steam generators to remove the reactor residual heat following a loss of the main feedwater system. This auxiliary system comprises two motor-pump sets and one turbine pump that draw water from a tank (Tihange 3) / from 2 tanks (Doel 4).

### *e) Emergency Systems*

(1) Reactor emergency protection system

This system has instrumentation and logic control systems fully separate from the first-level reactor protection logic and instrumentation system; however, the six reactor trip breakers are common to both systems;

(2) Emergency electricity supply systems

This system comprises three emergency diesel generator sets, with their associated auxiliary circuits and distribution panels.

(3) Emergency boration system

This system borates and makes up the primary system boration in order to offset leaks and the contraction of the primary system inventory during cooling. It also controls the primary pressure by pressuriser spraying. The system comprises two trains, each 100 % of the required capacity. A Tihange 3 a third train comprises only on tank and the piping necessary to connect the system's reserve pump.

(4) Emergency feedwater system for the steam generators

This system, which consists of three identical separate independent trains, ensures feedwater supplies to the steam generators. Each train comprises a pump that draws water from a tank (at Tihange 3 it shares this tank with the emergency cooling system). Water is supplied to this tank from ponds at Doel 4; at Tihange 3 the tank is supplied with groundwater or river water.

(5) Emergency cooling system

This system provides the emergency heat sink. The circulation pumps draw water from a tank whose level is maintained with groundwater or river water and return the water to the river (Tihange 3). At Doel 4, cooling is secured through an artificial pond.

This system can cool, among other, the primary pump thermal barriers, the heat exchangers and the pump packings of the reactor shutdown cooling system, the emergency injection system pumps, the emergency feedwater system pumps, as well as the exchangers of the spent fuel deactivation pools cooling system.

(6) Emergency injection system in the seals of the primary pumps

This system ensures the cooling and protection of the primary pump seals by injecting pressurised water in them in case of loss of the normal water injection.

(7) Emergency water supply system (Tihange 3)

Three physically separated well pumps draw groundwater for cooling the emergency diesel generator sets and for filling the tanks from which are pumped the water for steam generator feedwater and for the emergency cooling system pumps. Three additional pumps installed in the river water pumping station also perform these functions (back-up for the groundwater pumps). This function is ensured at Doel 4 by the pond.

### *f) Safety Systems capable of performing Emergency Functions*

The systems of which the function has not been duplicated in the emergency systems, but which can receive second-level protection orders, are:

- the six reactor trip breakers;
- the reactor shutdown cooling system;
- the portion of the intermediate cooling system situated inside the containment and in the spent fuel deactivation pools building;
- the three pressuriser relief valves;
- sets of pressuriser heaters;
- the isolation valves of steam lines and feedwater lines;
- the steam relief valves to atmosphere (one per steam generator);
- certain containment isolation valves;
- the primary pump breakers.

### *g) Instrumentation and Control Systems, Electrical Systems*

(1) Instrumentation and Control Systems

The control systems allow to achieve and maintain the power balance between the primary and secondary systems during steady operation of the unit (reactor control, primary temperature control, pressuriser pressure and level control, turbine steam bypass, and water level control in the steam generators).

The reactor protection systems are designed to ensure automatic tripping of the reactor and automatic actuation of the safeguard systems and their auxiliary systems:

- Reactor automatic trip

The logic signals issued from the threshold triggers are used by three redundant and independent logic channels (B,R,G) which generate the signals that open the automatic trip breakers, thus causing dropping of the control and shutdown rod assemblies in the core. Three sets of two parallel-mounted breakers have been installed in series. The signal issued from the B (R,G) logic channel orders a breaker to open, whereas the breaker in parallel to that breaker receives an order from the R channel signal or from a G channel signal (B or G, B or R). This arrangement allows to achieve very reliably a 2/3 automatic trip logic and still retain unit availability. It also makes it possible to test one of the three logic chains and retain a 1 /2 redundancy between the two remaining logic chains.

- Actuation of the safeguard systems

The instrumentation and control systems start the safeguard systems and also start the auxiliary feedwater system and the auxiliary systems necessary to secure performance of the safety functions (safety diesel generator sets, intermediate cooling, raw water, ventilation, containment isolation, isolation of feedwater lines and steam lines, etc.).

- Actuation of the emergency systems

The instrument and control systems of the emergency systems actuate these manually or automatically, depending on which emergency systems are involved; the functions of these systems are detailed in §III.F.2 e).

(2) Electrical Systems

The voltage supplied by the generator is stepped up by the step-up transformer prior to being fed to the 380 kV network. A second link between the high-voltage grid and the unit is provided by a 150 kV link independent of the 380 kV network.

The unit’s auxiliaries are fed from three 6.6 kV safety busses and their associated switchboards, and from three 6.6 kV emergency busses and their associated switchboards.

The units have three first-level protection diesel generator sets and three second-level protection diesel generator sets. An additional diesel generator set is also available at the site of Doel, dedicated solely to Doel 3-4, and can be connected should one of the first-level protection diesel sets fail.

### *h) Energy Transformation System*

The steam generated by the three steam generators feeds a turbine-generator set of which the turbine has a high-pressure body and two low-pressure bodies.

### *i) Cooling Water*

An intermediate cooling system ensures closed-circuit cooling of the nuclear systems equipment with demineralised water with corrosion inhibitors. Closed-circuit use of this treated water enables the physical separation to be achieved between a fluid that could possibly be contaminated and the cooling system that is open to the outside. The system comprises three trains to feed the equipment of the safety trains in case of an accident, and a common part to feed non-essential equipment during normal operation of the unit.

This water is cooled:

- for the Tihange unit, by the raw water system comprising a pumping station equipped with three identical motor-pump sets that draw water from the river, a three-train water distribution system with a common part and a discharge canal to the river;
- for the Doel unit, by a system comprising one pump per train which sends the water cooled by two forced draft cooling towers to the heat exchanger of the intermediate cooling system.

### j) Fuel handling and Storage System

The spent fuel assemblies are stored several years in a spent fuel pool, the water of which is cooled and purified, prior to being transferred and stored in a dedicated storage building at the site.

Dry storage is provided for the fresh fuel assemblies.

### k) Radioactive Effluent and Waste Treatment System

(1) Liquid waste

- Tihange 3 : the liquid waste is collected in the tanks of Tihange 3 and treated in the installations of Tihange 2. After treatment the waste can be stored in the large storage tanks situated in the units 2 and 3 prior to re-use or discharge to the river.
- Doel 4 : waste treatment for all the units of the Doel nuclear plant site is performed in a common installation housed in a dedicated building. Liquid waste is batch-transferred from the nuclear auxiliary building to that waste treatment installation via pipes running in the connection galleries.

(2) Gaseous waste

The gaseous waste is stored within the unit in several decay tanks. The hydrogen concentration is measured and can possibly be reduced with the recombiners (Doel 4). After decay the gaseous waste is either released via the plant vent or re-used in the units.

(3) Solid Waste

The solid waste to be treated comprises used resins, evaporation concentrates, flocculates, fouled filter cartridges, residue of magnetic filtration, …

- Tihange 3 : The collected waste is transferred to the Tihange 2 unit for encapsulation of filters and concentrates and for conditioning of various waste. The active resins are treated on-site by means of a mobile encapsulation unit.
- Doel 4 : The solid waste is collected within the unit. Treatment of it is performed in a dedicated treatment building at the Doel site which is the common treatment facility for solid waste originating from all the Doel units.

## III.F.4. Major Modifications

### a) Power Increase

None.

### b) Steam Generator Replacement

(1) Doel 4

The steam generators were replaced in 1997 given the significant number of tubes that had already been plugged (close to 20%) due to corrosion on the primary and secondary sides. The new SGs have dimensional characteristics quite similar to replaced SGs, from which they differ chiefly with respect to the tube material, which is Inconel 690 instead of Inconel 600, suppression of the preheater, and number of tubes which is 6 019 tubes of 3/4 inch outside diameter instead of 4 864 tubes of the same outside diameter. In the old SGs, the feedwater supply was arranged via the top for the low flow and via the bottom for the high flow, whereas in the new ones all feedwater is fed via the top. These differences have an impact on both normal operation and operation in accidental conditions (e.g. increase of the exchange surface). This required a safety review of the installation).

(2) Tihange 3

Replacement of the SGs took place in the Summer of 1998. The new steam generators have characteristics similar to those of the new steam generators installed at Doel 4. This implied a modification of the feedwater supply to the SGs following the suppression of the preheater : in the old SGs, the feedwater supply was arranged via the top for the low flow and via the bottom for the high flow, whereas in the new ones, all feedwater is fed via the top.

Figure 28 : Replacement of SGs of Tihange 3

### c) *Fuel Cycle Extension*

(1) Doel 4

In 1988, the operator obtained the authorisation to extend the fuel cycle to a maximum burn-up limited to 55 000 MWd/t on average per assembly and to increase fuel enrichment to 4.35 %.

(2) Tihange 3

In 1988, the operator obtained the authorisation to extend the fuel cycle to 18 months (maximum 17 months at full power).

### d) *MOX Fuel*

None.

### e) *Protection in case of a Severe Accident*

The operator installed autocatalytic hydrogen recombiners in all the units. These consist of a large number of passive recombiners installed in various compartments of the reactor building.

A passive cavity flooding device has been installed at Doel 4 to allow molten core cooling in order to mitigate containment base-mat melt through.

### f) *Reactor vessel head replacement*

According to worldwide experience, hot vessel heads with Alloy 600 are susceptible to Primary Water Stress Corrosion Cracking (PWSCC). The vessel heads of Doel 4/Tihange 3 were among the last hot vessel heads in the world with Alloy 600 until the decision to replace them in 2015.

### g) *CFVS containment filtered venting system*

In the framework of the BEST action plan, both Doel 4 as Tihange 3 have been equipped with containment filtered venting systems.

## III.G. The Waste Treatment Building at the Doel Site

### III.G.1. General

In the WAB building the liquid and solid waste originating from the various units of the Doel site are treated. The gaseous waste is not treated centrally. The installations started industrial operation in 1983, and an extension to the WAB building was made operational in 1992.

### III.G.2. Description and Operation of the Installation

Figure 29 : The WAB building (empty drums waiting for the next conditioning campaign

The liquid waste is transferred to the treatment building via pipes running in the underground galleries that link the generating units to the treatment building. The waste is segregated according to the following principle:

- recyclable waste, which are aerated and deaerated waters coming from the primary system and its auxiliary systems containing borated water. These effluents are concentrated by evaporation. A (4 %) boric acid solution and degassed demineralised water can be recovered for re-use;
- the non-recyclable waste coming from the industrial drain systems, waters from the laundry, from chemical drains and from regeneration of ion-exchange resins. This waste is stored and if necessary concentrated through evaporation. After these treatments the resulting liquid waste is discharged to the river Scheldt via the single sewer common to all the units of the Doel site. Several measurement channels permanently monitor the activity of the water in this common discharge sewer, the discharge being interrupted automatically should the authorised limit be exceeded. With this sewer, it is possible to mix and dilute effluents in the condenser cooling water system of the units.

The solid waste originating from the various units or produced within the WAB comprises spent resins, concentrates from evaporation, cartridges of filters, compressible and incompressible wastes. The installation allows resins and concentrates to be encapsulated in concrete and drummed. The drumming station is entirely remote controlled. The drums are then stored inside the WAB, which has storage capacities of 500 drums (temporary storage in the basement for the high-activity drums) and 1 800 drums for the main storage. Compressible and incompressible waste is either drummed on-site (when the dose rate is > 2 mSv/h) or transferred to an off-site treatment facility.

The installations also comprise halls devoted to decontamination of certain bulky equipment (e.g. a primary pump) and to the destructive testing of contaminated components (e.g. a steam generator tube).

### III.G.3. Protection against Accidents

#### *a) Protection against flooding*

Part of the building is below the natural ground level. For protection against floods the lower part of the walls (in 1.4 m thick concrete) has been made impervious with a synthetic liner, up to the maximum level of the groundwater table.

#### *b) Protection against an external accident and an earthquake*

A 1.2 m thick slab divides the building into two parts : the part of the building below this slab is used for waste storage and houses most of the pipes that convey radioactive material; the part above the slab mainly accommodates the main storage for the drums. This slab, as well as the walls and foundations situated below it are designed to withstand for instance an aircraft crash or an earthquake, as this is the space where the waste is stored. The portion of the WAB building above that floor slab is not earthquake-qualified as the radioactivity that might be released from it in such an event is very limited.

### III.G.4. Major Modifications

In 1990 the licence was obtained to extend the building in order to increase the storage capacity for contaminated equipment and solid waste, as well as to increase the surface area of the workshops. It was put into operation in 1992.

## III.H. The Intermediate Storage Building for Spent Fuel at the Doel Site

### III.H.1. General

This building is dedicated to the storage of spent fuel assemblies originating from the units 1, 2, 3 and 4 of the Doel site. Indeed, following the present moratorium on reprocessing, the necessity arose for greater intermediate spent fuel storage capacity, considering the lack of extra storage capacity in the spent fuel pools of the Doel units. The first (spent) fuel container which arrived from Doel 3 was stored in this building in November 1995.

## III.H.2. Description and Operation of the Installation


Figure 30 : Intermediate Storage Building for Spent Fuel of Doel

The spent fuel assemblies are placed under inert gas in sealed containers as soon as they leave the spent fuel pool within each generating unit. Residual heat removal is by natural convection and the structure of the spent fuel storage building provides a biological protection against the radiation from the containers (this protection is achieved partly by the concrete structure that shields against gamma radiation and neutrons, and partly by the roof which, as boron has been added to the roof concrete, provides additional protection against neutrons). By design, the containers themselves can withstand the impact of missiles or an aircraft crash. These are containers that are qualified for transport, but are at this time used for storage.

The first module of this building allows to store 53 containers. An extension with a capacity of 112 containers was put into operation in March 98. The capacity of the containers is either 37 assemblies (containers for Doel 1 & 2) or 28 assemblies (containers for Doel 3) or 24 assemblies (containers for Doel 4). The design of the containers is such that the cladding of the fuel rods remains undamaged in most of the accident scenarios. The residual heat is removed by natural air circulation (fresh air being let in at the base of the building, it exits the building via several outlets in the roof of the building).

## III.H.3. Protection against Accidents

Protection against accidents is provided by the containers rather than by the building structure.

The containers are designed to withstand external accidents (aircraft crash, fire and earthquake) and a free drop from a height of 2.5 metres.

The containers have a primary cover fitted with double seals and equipped with a leak detection device. The space between the two seals is filled with helium at positive pressure (6 bar) compared to atmospheric pressure and is connected to a helium tank fitted with a pressure sensor that can generate an alarm. Therefore, in the case of a loss of tightness of one of the two seals, helium will escape either to the atmosphere or to the inside of the container, and the seal deficiency is detected. In no case can radioactive gases escape.

## III.I. The Intermediate Storage Building for Spent Fuel at the Tihange Site

### III.I.1. General

Following the moratorium on reprocessing, a significant increase in intermediate storage capacity for spent fuel assembles became necessary, due to the limited storage capacities of the spent fuel pools of the Tihange units. A storage building was constructed as an extension to the Tihange 3 installations. This extension is designed to store, in water, the spent fuel assemblies removed from the cores of the Tihange units 1, 2 and 3 at least two years before. This building was put into operation in July 1997.

### III.I.2. Description and Operation of the Installation

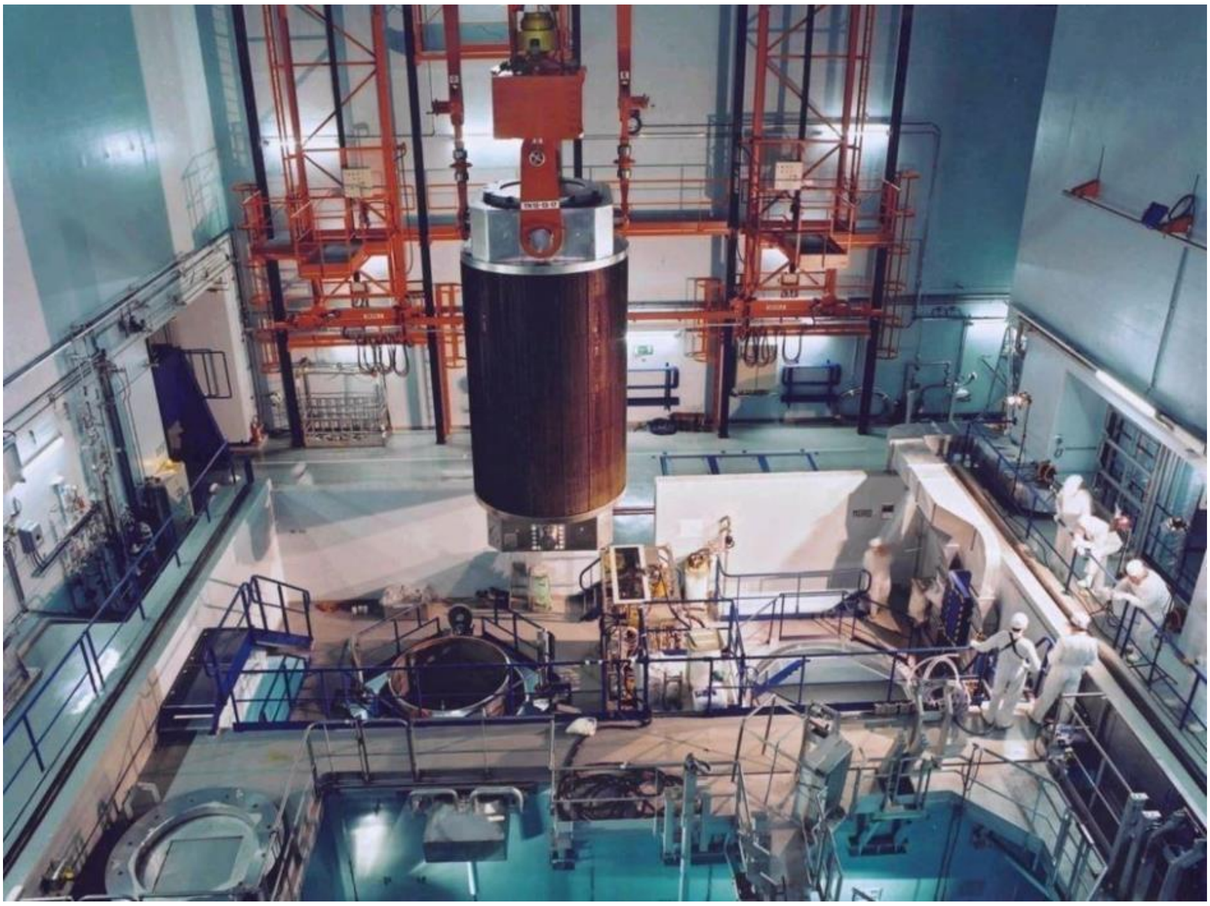

Figure 31 : Intermediate Storage Building for Spent Fuel of Tihange

This building is dimensioned to store 465 assemblies in each of its 8 pools. The fuel is transferred from the three units to this building in containers similar to those used for off-site road transport . The transfer is dry or wet, depending on the type of container.

The building is designed to withstand external accidents. The same design bases as those for the similar building of Tihange 3 (i.e. the spent fuel deactivation pools building) were adopted.

Most of the systems installed in this intermediate storage building are extensions of the equivalent systems of Tihange 3.

### III.I.3. Protection against Accidents

The systems or parts of systems relating to the intermediate storage building are classified into different groups depending on their importance to safety :

- the safety-related systems whose operability must be secured in the medium term after an external accident : cooling of the pools. Pool cooling and treatment is achieved via the intermediate cooling system of Tihange 3 and is backed up by water drawn from the groundwater table. This backup connection is activated manually.
- the safety-related systems that must permanently remain operable. These are:

- o the building depressurising system. The extracted air is filtered prior to being released via the plant stack of Tihange 3;
- o the isolation devices of the building and of the piping conveying radioactive fluids in the event of an external accident.

- the non-safety-related parts.

  The safety systems are redundant: the single failure of an active component is taken into account in the design. Similarly, for the systems that must permanently remain operable, the signals that activate them are redundant.

## III.J. The Storage Buildings for the disused Steam Generators at the Doel and Tihange Sites


Figure 32 : Storage Building for Doel's Steam Generators

The operator applied for the licence to build at the Doel and Tihange sites a building where the disused steam generators can be stored. At Doel, this building was initially dimensioned to store the steam generators dismantled from Doel 3. It was later enlarged to store also the steam generators dismantled from Doel 4, Doel 2 and Doel 1. The reactor vessel head from Doel 4 is also stored in this building. At Tihange, the storage building was designed to accept dismantled steam generators from the three units of that site; the reactor vessel heads from Tihange 1 and 3 are also stored in this building.

After removal of the heat insulation, the external surfaces of the steam generators were decontaminated and the SGs hermetically sealed; as for the reactor vessel head, this was enclosed in a hermetically welded box. In this way they became sealed radioactive sources. As a result, the storage buildings for disused steam generators require no additional protection against accidents such as earthquake, flood or an aircraft crash. However, these buildings meet the radiation protection requirements, and the thickness of their reinforced concrete walls is sufficient to provide the required biological protection.

## III.K. Training Centres

The personnel of the power plants and especially the operators in the control room and the operation engineers are given initial training and further retraining as prescribed by the safety requirements.

The training centres of each of the two nuclear sites are equipped with adequate training facilities and equipment.

### III.K.1. Tihange Units

The training centre of Tihange is located within the nuclear site itself. There are 2 full-scope simulators, one is a precise replica of Tihange Unit 1, and the second one of Tihange Unit 2. Extensions such as additional hardware panels and screens have been added to the equipment of the Unit 2 simulator in order to provide the best possible training of Unit 3 operators.

The full-scope simulators provide the operators with all the auxiliary tools that are available in the units; for instance, data acquisition is reproduced and allows for post-transient analysis of the process just like in the real installations. The functions of the Centre Opérationnel de Tranche (the On Site Technical Centre) are also provided and make it possible to simulate accidental situations of the type that requires response of the intervention teams.

A third simulator, with a non-replica man-machine interface, is used to illustrate specific aspects related to regulations, primarily through the projection of images. This simulator is not intended to realistically mimic the control rooms. Instead, it focuses on realistically mimicking the behaviour of the installation, and on highlighting also the behaviour of parameters about which the information is not available in the control rooms, which is most valuable for gaining full understanding of the phenomena at play. The three units being simulated on this "Multifunction simulator", it suits as a complement for the training of all units.

These facilities are updated regularly to make certain that they keep reflecting the actual installations. As part of the Tihange 1 LTO action plan, there is now a full scope simulator including all LTO modifications, such as the new emergency systems control panels (SUR étendu control panels).

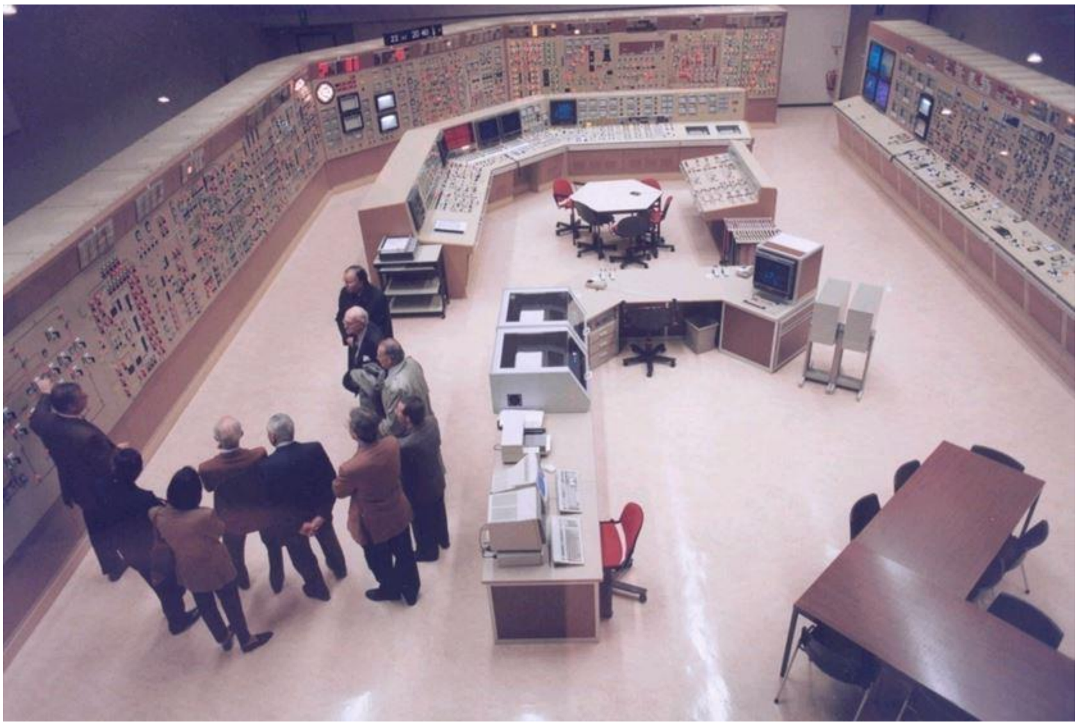

Figure 33 : Tihange Simulator

### III.K.2. Doel Units

The training centre is situated at Kallo, a few kilometres distant from the Doel nuclear site.

Figure 34 : Doel Training Centre

The centre is equipped with two simulators.

The first one, full-scope, simulates the main control room and the emergency control room of Doel 4. The emergency control room of unit 3 is also simulated, and the simulator can mimic the behaviour of unit 3.

Figure 35 : Doel Simulator

The second simulator (Doel 1 & 2) mimics the control room of Doel 1, the panels of the safety systems that are common to both units, the mimic panels of the emergency systems that are common to both units, and the control panels of the electrical systems.

As this simulator was originally intended for training the operators regarding accident-management procedures, only the primary systems and the safety systems were covered. Later were added reactor control via the control rods, control rod position indicator systems, the emergency control room and the feedwater station.

These facilities are updated regularly to make certain that they keep reflecting the actual installations.

# IV. Appendix 2 - Description of the BR1 and BR2 Research Reactors

## IV.A. General

The SCK CEN has its laboratories located in the northeast of the province of Antwerp. The installations are:

- The BR1 and BR2 reactors, which are subject of this report.
- The critical facility VENUS, which is at the moment in use for testing the coupling of a fast neutron core with an external neutron source generated by an accelerator.
- The hot cell laboratories for research on nuclear fuel and irradiated materials
- Laboratories for radiochemistry with a dedicated part for plutonium handling.
- Laboratories for research on radiobiology and radioecology.
- Laboratories for spectrometry
- Workshops

## IV.B. The BR1 reactor

### IV.B.1. General description

The BR1 reactor is a natural uranium graphite reactor, comparable to the reactor ORNL X-10 (USA) and BEPO (Harwell, UK). The core is composed of a pile of graphite blocks thus forming a cube with a side of 7 meter. The blocks are machined in such a way that 829 horizontal square channels with a side of 5 cm are formed with a length of 7 m. The channels are located in a square grid with 18 cm step. They are located within a cylinder with a radius of 2.9 m. A number of these channels contain the fuel elements. Beside these standard fuel channels, the graphite is bored in all directions with a number of channels destined for experiments. Additionally, there are vertical channels for the control and regulation rods and horizontal ones for neutron detectors.

The graphite block is surrounded by a structure of high density concrete which serves as a shielding. The thickness of the concrete is 2.10 m. It is bored by various horizontal and vertical channels for access to fuel channels, experiment channels and control rods. On two places, one horizontal and one vertical, the graphite continues through the concrete to form two thermal diffusion columns.

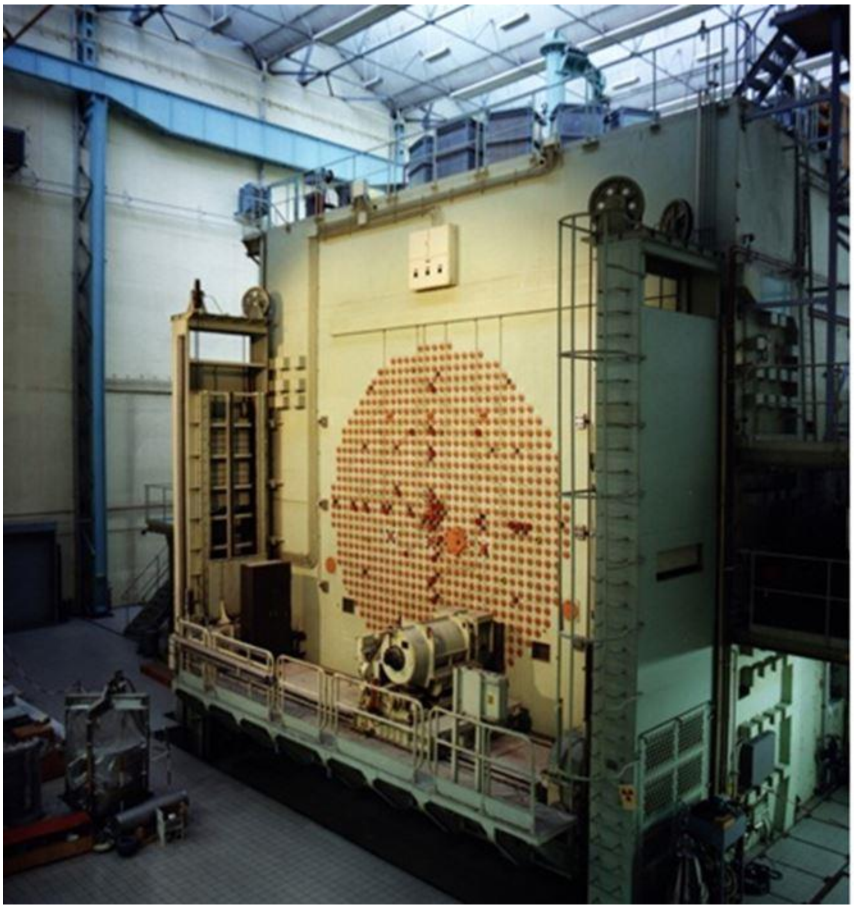

Figure 36 : Front view of the BR1 Reactor

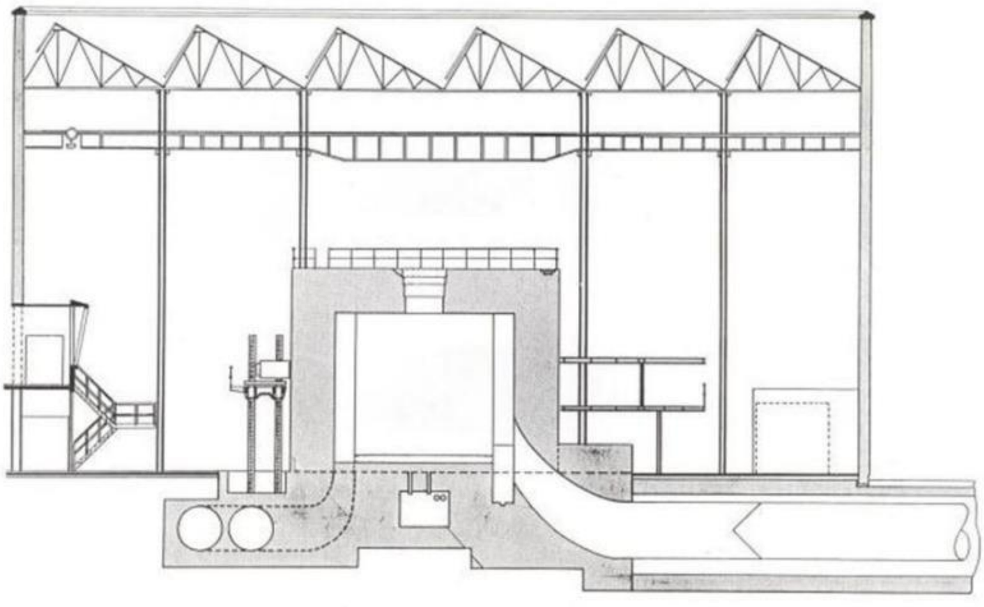

Figure 37 : East-West Cross section of BR1

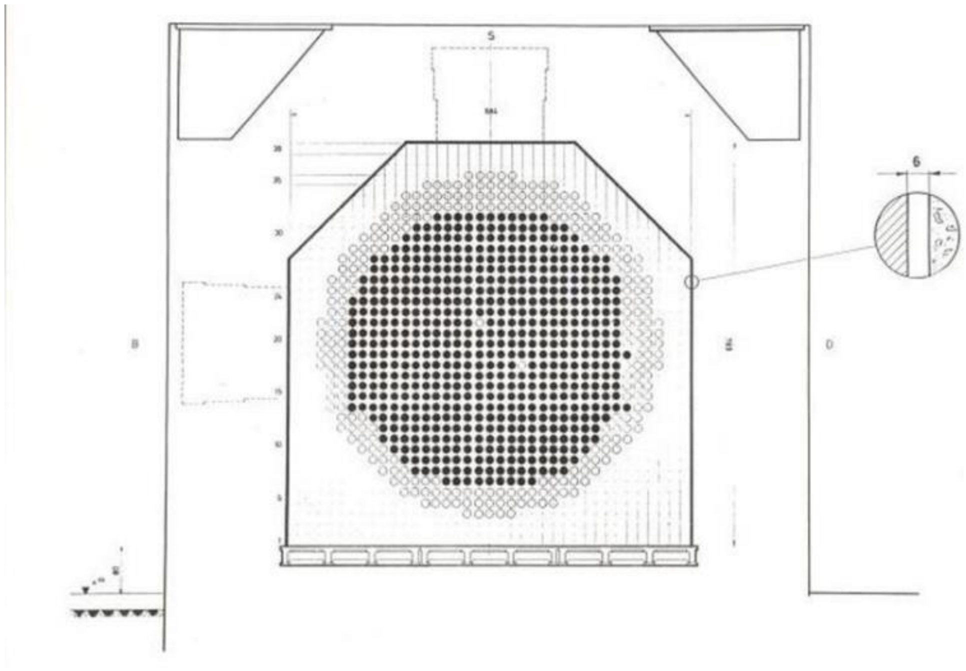

Figure 38 : South-North Cross Section of BR1

### IV.B.2. Fuel

The fuel elements of the BR1 are cylindrical bars of metallic uranium with a diameter of 25.4 mm and a length of 203.4 mm with an aluminium cladding. The reactor contains about 25 tonnes of uranium and is still loaded with its original fuel. The average burn up mid 2010 is about 278 MWd/t, with an increase of 0.6 MWd/t per year (maximum burn-up for the central rod is circa 673 MWd/t).

### IV.B.3. Heat removal

The reactor is cooled with air, which is blown through the reactor by ventilators on the outlet side. The cooling line is composed of:

- inlet filters
- a cold air collector on the inlet of the reactor
- the reactor
- a hot air collector on the outlet of the reactor
- outlet filters, composed of pre-filters and HEPA filters, in order to eliminate activated dust particles
- ventilators
- the stack.

The air pressure in the part of the cooling system upstream of the ventilators is lower than the atmospheric pressure, even in natural ventilation regime. The air itself is activated while passing through the reactor due the presence of argon in the air. The activation product, Ar-41, which has a half-life of 1.8 hr, is produced at a rate of 74 GBq/MWh and causes a radiation dose in the environment of 0.65 µSv per year.

The power is BR1 is limited to 700 kW for 7-8 hours or less than 1 MW during 2 to 3 hours. The safety limit is the maximum temperature of the graphite.

| | **Auxiliary ventilators** |
|---|---|
| **Maximum thermal power** | 700 kW (1 MW few hours) |
| **Power take up by the ventilators** | 25 kW |
| **Total air flow** | 10 m³/s |
| **Air speed in the central fuel channels** | 15 m/s |
| **Maximum temperature of the fuel cladding** | 200 °C |

| | |
|---|---|
| **Maximum temperature of the graphite** | 104 °C<br>Technical specification |
| **Outlet air temperature** | 90 °C |

Table 17 : Operating Characteristics of BR1

### IV.B.4. The nuclear control

The reactivity is controlled using neutron absorber rods composed of cadmium. These rods can be displaced in vertical channels. The reactor has a set of safety rods, which are out of the core during operation, a set of control rods to keep the reactor in critical state. A separate regulation rod is used for high precision control. An automated control system is also available for reactor power control.

The configuration of the fuel is normally not changed, except minor changes for experimental reasons.

### IV.B.5. Safety aspects

The potential accidents which are considered are a too high fuel temperature, which can lead to failure of fuel cladding, and too high temperature of the graphite, which could cause a fuel and/or graphite fire. Potential causes for these high temperatures are:

- Uncontrolled increase of reactivity.
- Failures of the cooling system.
- Sudden release of Wigner energy.

The most probable cause of an uncontrolled increase of reactivity could be the sudden extraction at maximum speed of all safety rods. It is calculated that a scram will be caused before the temperature reaches an unacceptable high level.

Failure of the cooling system will not cause excessive high graphite temperatures. This is shown by calculations and different tests.

The Wigner energy in the graphite must remain lower 360 kJ/kg. The graphite was annealed in 1962 after a period of operation at high power. Since the reactor is operated at 700 kW and with the auxiliary ventilators only, the low flux and higher working temperature of the graphite avoid Wigner energy build up. The Wigner energy is actually decreasing

## IV.C. The BR2 reactor

The BR2 reactor is a heterogeneous thermal high flux engineering test reactor, designed in 1957 for the SCK CEN by NDA [Nuclear Development Corporation of America - White Plains (NY - USA)]. It has been built on the site of the SCK CEN laboratories in Mol, Be1gium. Routine operation of the reactor started in January 1963.

The reactor is cooled and moderated by pressurised light water in a compact core of highly enriched uranium positioned in and reflected by a beryllium matrix. The maximum thermal flux approaches $10^{15}$neutrons / (cm²·s) and the ultimate cooling capacity, initially foreseen for 50 MW, has been increased in 1971 to 125 MW.

### IV.C.1. BR2 Main Data

Beginning of utilization : 1963

Maximum heat flux:

- Nominal : 470 W/cm²
- Admissible : 600 W/cm²

Nominal power : 60 to 100 MW

Maximum neutron flux (for 600 W/cm²):

- thermal : $1.2 \times 10^{15}$ neutrons / (cm²·s)
- fast (E > 0.1 MeV): $8.4 \times 10^{14}$ neutrons / (cm²·s)

Irradiation positions : up to 100

Fissile charge at start of cycle : 10 to 13 kg $^{235}U$

Operation cycle:

- minimum 7 days shut-down
- nominal 21 or 28 days operation
- possibility of short cycles

Days of full-power operation per year : variable, presently 210 days/year

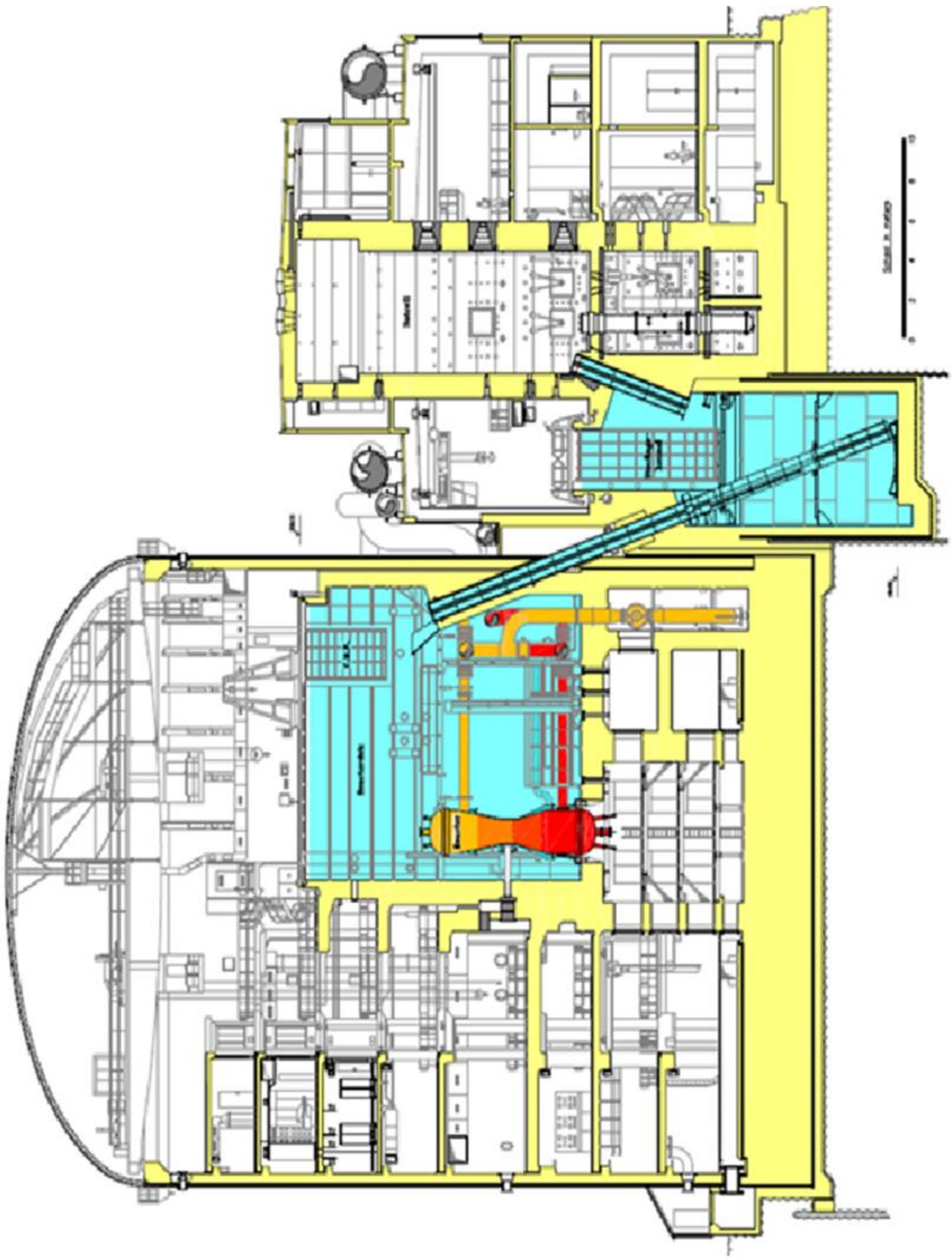

Figure 39 : The BR2 Reactor Building, Hydraulic Channel and Hot Cell

### IV.C.2. The fuel elements

Standard fuel elements are assemblies of concentric tubes about 3 inches (76.22 mm) in outer diameter, each with 30 inches (762.2 mm) fuel length. The tubes are made of bended plates. The plates contain a fuel meat, composed of a cermet (compacted powders) of aluminium alloy and pure aluminium, covered with an aluminium cladding. The thickness of a plate is 1.27 mm. The distance between the plates is 3 mm. A standard assembly contains six fuel tubes. It is possible to fabricate fuel elements with less inner plates, in order to have more space for irradiation devices. Beside these standard elements, it is also possible to load elements with an outer diameter of 200 mm in the big H reactor channels. These elements are composed of the same type of plates, but are made of 8 sectors. They can have up to 13 concentric rings.

The density of fissile uranium is 1.3 g/cm³. A standard fuel element contains 400 grams of U235. Burnable poisons are added in order to limit the reactivity variations and to use the elements to higher burn-up.

The analyses of fission products release are routinely performed to check for defective fuel elements after each shutdown of the reactor. The main cause of the fission products release is corrosion pitting. It occurs mainly when the element reaches a high burn-up (> 50%) and is observed at the high heat flux locations. The quantity of fission products released from such pitting is limited and, up to now, the radioactive contamination caused by fission products release in the primary cooling loop of the BR2 reactor is far below the allowed limit; nevertheless, this phenomenon can disturb the operational planning of the reactor.

In the framework of reduction of the use of highly enriched uranium in the world, the BR2 will be converted to low enriched uranium. However, at this moment, there is not yet a qualified fuel type available useable for BR2 without major performance losses. It is recognized that very high density fuel is needed, with a uranium density of more than 7 g/cm³. A choice has been made for the fuel LEU fuel elements. They will have a core of uranium silicide. The thickness of the fuel plates will be slightly increased in order to accommodate a larger quantity of uranium. No other modification is made. Irradiation of the first test elements is planned by the end of 2022. The SCK CEN takes a leading role in this qualification process, by test irradiation in the BR2 and post-irradiation examinations.

Figure 40 : BR2 Standard Fuel Element

### IV.C.3. The beryllium matrix

The beryllium matrix has 79 cylindrical holes, all of them with individual access through holes in the top cover of the reactor vessel. Individual guide tubes join the holes in top cover with the holes in the matrix and so create 79 individual reactor channels. There are sixty-four standard channels (∅ 85 mm), ten reflector channels (∅ 50 mm) and five large channels (∅ 200 mm).

All channels can receive fuel elements, control rods, reflector plugs, experiments; this allows a great flexibility for a great variety of core arrangements.  The five 200 mm channels and thirteen 85 mm standard channels have additional penetrations through the bottom cover of the reactor vessel, which allows through-loop experiments.

At the end of 1978, the BR2 reactor was shutdown to unload the first beryllium matrix and to load a new (second) beryllium matrix. In the first beryllium matrix, the maximum fast neutron fluence obtained was $7.95 \times 10^{22}$ neutrons / cm² (E > 1.0 MeV) in the channel A 30. In total about 224 000 MWd had been produced. Operation of the BR2 resumed mid-1980.

According to the safety evaluation of the first beryllium matrix surveillance programme, the following beryllium matrices have to be replaced when the maximum fast neutron fluence obtained is $6.4 \times 10^{22}$ neutrons/cm² (E > 1.0 MeV).  This fluence was almost reached mid 1995 after a total energy production of about 180 000 MWd. Consequently, a second beryllium matrix replacement operation was executed. In 2016 the matrix was again replaced by a new one. The expected life time of this matrix is up 2036.

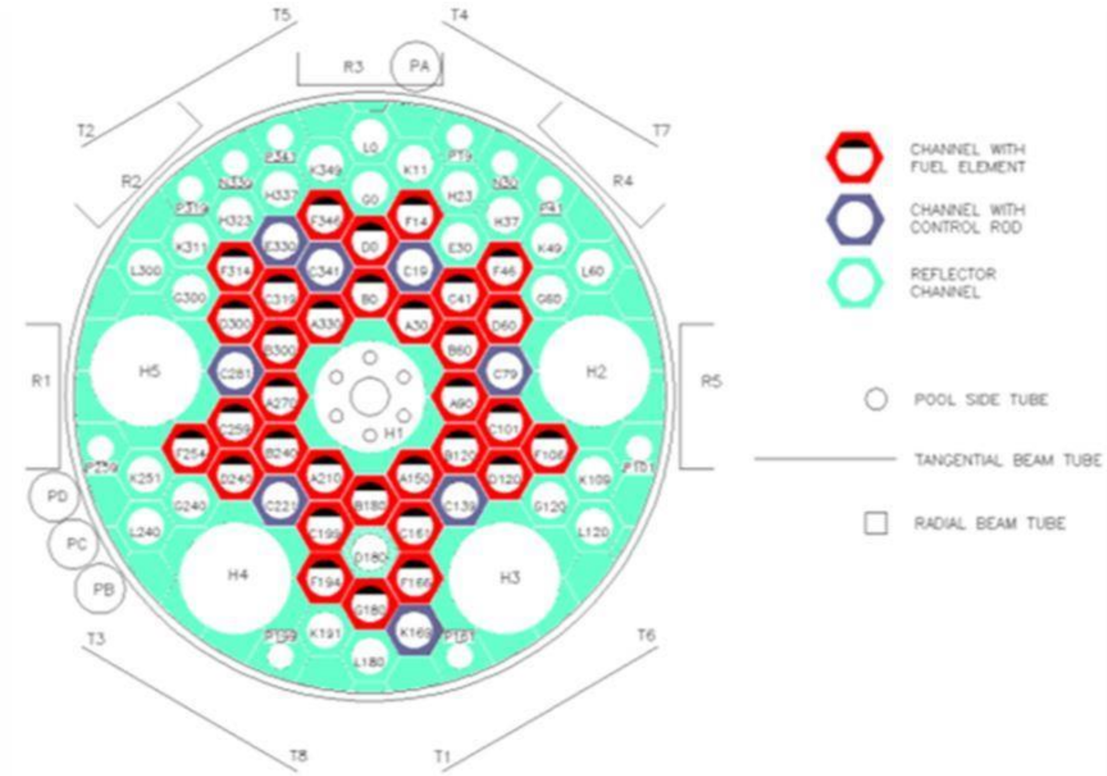


Figure 41 : BR2 Typical Core Configuration

## IV.C.4. The nuclear control

The reactor is controlled by a number of hafnium-beryllium shim-safety rods which occupy matrix lattice positions and have electromechanical drives. Each rod moves inside its own aluminium thimble, which allows them to be placed in various core arrangement positions. It is possible to load a different number of control rods in the reactor and use different irradiation channels, as long as the technical specifications can be fulfilled. During a long time, 6 control rods have always been placed in the C channels. Since a number of years, usually 8 control rods are used in order to have longer operation cycles. These configurations are symmetric with the maximum flux in the centre of the reactor. Additionally, one or more rods can be added to increase the antireactivity margin. These rods remain during irradiation out of the core, but scram together with the others. The rods in high position are also used to clean the beryllium followers from helium-3.

In the years 2006 to 2010 the rods have undergone a renewal program. First the drive mechanisms, including the motors and the position indicators have been replaced. In 2009, the old cadmium absorbers were replaced by hafnium. The only remaining original components are the scram mechanisms. These have always proven to be very reliable and will remain in use.

## IV.C.5. The reactor vessel

The reactor pressure vessel consists of two truncated conical upper and lower sections separated by an essentially cylindrical middle section which is welded to the conical sections. The vessel is sealed on top and bottom by flanged and gasketed covers. It is approximately 28 ft 2 in (8.6 m) in length and 6 ft 8 in (2.0 m) in diameter at the cone bases, narrowing down to 3 ft 10 in (1.2 m) diameter at the middle section. The vessel is designed for 210 psig at 200 °F (1.448 MPa gauge at 93°C) according to the ASME Boiler and Pressure Vessel Code for Unfired Pressure Vessels. Aluminium alloy (5052) is used as the basic material for the vessel, the top and bottom covers are made of stainless steel.

Special cooling of the pressure vessel shell is required when fuel elements are concentrated near beam holes or experiments which are placed directly outside the vessel wall. A 6 mm thick external shroud extends around the circumference of this section, covering the entire length of the core. A header for the inlet water is located at the bottom of the shroud.

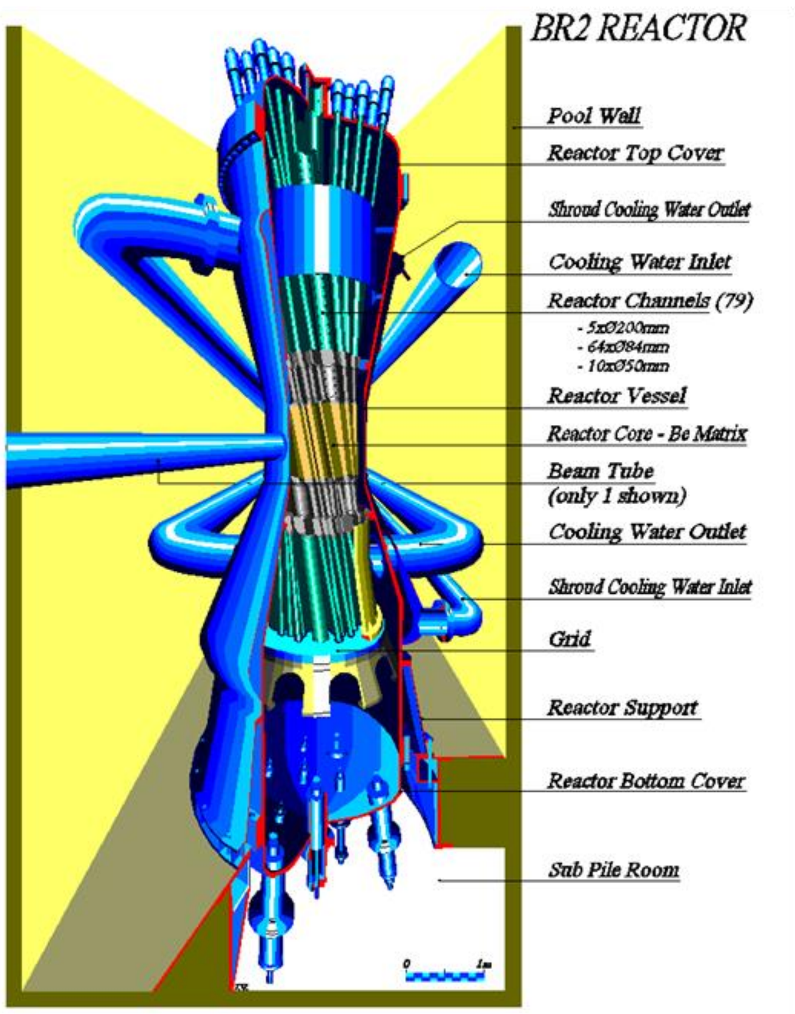


Figure 42 : The BR2 Reactor Vessel

## IV.C.6. The reactor pool

The reactor vessel is located in an open pool, which is filled with water during reactor operation. The pool forms a radiation shielding and makes the reactor building permanently accessible without significant dose for the operators.

The pool allows for additional irradiation facilities in the pool in the vicinity of the reactor vessel. From the original five radial beam tubes and four tangential beam tubes to provide neutrons for physics experiments, only two – one radial and one tangential – remain operational; the others were either removed or shut off.

## IV.C.7. The reactor building

The reactor with its pool and side pools is located within a cylindrical steel containment building which offers ample floor space for various experimental equipment. The reactor building can be isolated in case of an accident with release of fission products. The building is designed for an overpressure of 100 kPa.

Service buildings close to the containment building house all coolant process equipment, a storage canal, hot cells, ventilation equipment, an emergency electric power station, air compressors, liquid waste hold-up tanks, an electric power substation, workshops, laboratories and office space.

## IV.C.8. Thermohydraulics

The reactor is cooled by pressurized water. The nominal working pressure is 1.2 MPa. This pressure is maintained using a pressuriser containing heated water and steam. The primary flow of about 6500 $m^3$/hr is regulated in such way that pressure drop over the reactor is kept constant. Four primary pumps are available. Three of these pumps are running, giving about 70 % of their maximum flow. The fourth pump is in stand-by. The inlet water temperature is about 38 °C, the outlet about 50 °C, depending on the power level and the primary flow. The heat is further evacuated by three primary heat exchangers, which are cooled by an open secondary cooling circuit. The secondary circuit is equipped with 4 cooling towers with forced ventilation. A part of the primary water is constantly passed over ion exchanger to keep the conductivity low and the pH around 6.

The only part of the primary circuit inside the containment building is the reactor vessel. All other components are located outside in the machine. Isolation valves are foreseen between these two parts. These valves close automatically in case of loss of pressure or in case of too high radioactivity.

## IV.C.9. Safety aspects

The most important safety issue of the BR2 is the reactivity control. At the beginning of a cycle the excess reactivity is quite high, more than 7000 pcm, all to be compensated by the control rods. This imposes a number of technical specifications on the control rod drop time and on the antireactivity value.

In contrast with a power plant, the BR2 can, after scram, be cooled by natural convection. The reactor pool, which is filled during operation, serves as a cold source. Thus, BR2 needs no dedicated emergency cooling system. However, it is important that the isolation valves in the pool close in case of loss of pressure and that the natural convection loop is established. The flow of the cooling in normal conditions goes from top to bottom, such a flow reversal occurs if the isolation valves close. A by-pass valve between the inlet and outlet pipe facilitates this natural circulation. During this phenomenon no damage to the fuel may occur and this imposes one of the limits on the power density of the reactor.

A probabilistic safety assessment has been performed. This started as a support to define the critical issues for the refurbishment programme 1994 to 1997. On request of the authorities, the basic PSA has been extended with the analysis of several support systems.

A detailed seismic analysis of the installation has been made. As a reference a 0.1 g earthquake was chosen, with a spectrum according to US regulatory guide 1.60. This is quite severe for the region of Mol, but it was shown that the installation can resist such an event. A few structural reinforcements were necessary in order to resist with horizontal forces. Additional supports were added to the primary circuit outside the containment building and to the ventilation support structure between the containment building and the ventilation building.

### IV.C.10. The conversion to low enriched uranium

As a general world policy, highly enriched uranium will no longer be available for civil nuclear installations. However, at this moment there is no qualified fuel type available to replace the highly enriched uranium without significant performance losses. The fuel must also allow a good burn-up in order to reduce fuel cost and a back end solution must be available. A type of fuel, based on a uranium molybdenum alloy, is under investigation at the moment with promising results. The SCK•CEN takes a leading role in this qualification process, with irradiation of test plates in the BR2 and metallurgical investigation in the hot cell laboratories. This programme is targeted not only to the conversion of the BR2 reactor fuel to LEU based fuels, but also to the conversion of other high performance research reactors operating or under construction in Europe.

# V. Appendix 3 - List of Acronyms

| | |
|---|---|
| **AIO** | Authorised Inspection Organisation. |
| **ALARA** | As Low As Reasonably Achievable. |
| **ANS** | American Nuclear Standards. |
| **ANSI** | American National Standards Institute. |
| **ASME** | American Society of Mechanical Engineers. |
| **ATLAS** | Advanced Thermal-hydraulic test Loop for Accident Simulation (NEA/OECD). |
| **AVN** | Association Vinçotte Nuclear. |
| **BEST** | Belgian Stress Tests |
| **BIP** | Behaviour of Iodine Project (NEA/OECD). |
| **BSS** | Basic Safety Standards. |
| **CIPR/ICPR** | Commission Internationale de Protection Radiologique (i.e. International Commission for Radiological Protection). |
| **CNRA** | Committee of Nuclear Regulatory Activities (NEA/OECD). |
| **CNT** | Centrale Nucléaire de Tihange (i.e. Tihange Nuclear Power Plant) |
| **CSNI** | Committee on the Safety of Nuclear Installations (NEA/OECD). |
| **DENOPI** | Spent fuel pool loss-of-cooling and loss-of-coolant accident project (IRSN). |
| **ECURIE** | European Community Urgent Radiological Information Exchange. |
| **EDF** | Electricité de France. |
| **ENSREG** | European Nuclear Safety Regulators Group |
| **EU** | European Union. |
| **EURAD** | European Joint Programming on radioactive waste management and disposal (Horizon2020/EC). |
| **FANC** | Federal Agency for Nuclear Control. |
| **FASTNET** | FAST Nuclear Emergency Tool (Horizon2020/EC). |
| **FBFC** | Franco-Belge de Fabrication de Combustible (i.e. Franco-Belgian Company for Fuel Manufacturing). |
| **FIRE** | Fire Incidents Records Exchange (NEA/OECD). |
| **FPS** | Federal Public Service |
| **FRG** | Function Restoration Guidelines. |
| **FSAR** | Final Safety Analysis Report. |
| **GRR-2001** | General Regulations regarding the protection of the public, workers and the environment against the hazards of ionizing radiation, laid down by Royal Decree of 20 July 2001 |
| **GRR-1963** | General Regulations regarding the protection of the public, the workers and the environment against the hazards of ionizing radiation, laid down by Royal Decree of 28 February 1963. |
| **HPD** | Health Physics Department. |
| **IAEA** | International Atomic Energy Agency. |
| **I&C** | Instrumentation and Control |
| **IEEE** | Institute of Electrical and Electronics Engineers. |
| **INES** | International Nuclear and Radiological Event Scale (IAEA). |
| **INSAG** | International Nuclear Safety Advisory Group. |
| **IRE** | Institut des Radio-éléments. |
| **IRRT** | International Regulatory Review Team (IAEA). |
| **IRS** | Incident Reporting System (NEA/OECD-IAEA). |
| **KCD** | Kerncentrale Doel (i.e. Doel Nuclear Power Station). |
| **MOX** | Mixed-oxide U02-Pu02. |
| **MUSA** | Management and Uncertainties of Severe Accident (Horizon2020/EC). |
| **NCM** | Non-conventional means |
| **NDA** | Non Destructive Analyse. |
| **NEA (OECD)** | Nuclear Energy Agency (OECD). |
| **NORM** | Naturally Occurring Radioactive Material. |

| | |
|---|---|
| **NPP** | Nuclear Power Plant. |
| **NUSS** | Nuclear Safety Standards programme (IAEA). |
| **NUSSC** | Nuclear Safety Standards Committee (IAEA). |
| **ODOBA** | Observatory of the durability of reinforced concrete structures (IRSN). |
| **OEF** | Operational Experience Feedback. |
| **ONDRAF/NIRAS** | Organisme National pour les Déchets Radioactifs et les Matières Fissiles Enrichies/ Nationale Instelling voor Radioactive Afval en verrijkte Splijtstoffen (i.e. Belgian Agency for Radioactive Waste and Enriched Fissile Materials). |
| **ORG** | Optimal Recovery Guidelines. |
| **ORNL** | Oak Ridge National Laboratory |
| **OSART** | Operational Safety Review Team (IAEA). |
| **PAMS** | Post-Accident Monitoring System. |
| **PKL** | Primary coolant loop test facility (NEA/OECD). |
| **PRISME** | Fire Propagation in Elementary, Multi-room Scenarios (NEA/OECD). |
| **PSHA** | Probabilistic seismic hazard analysis |
| **PSA** | Probabilistic Safety Analysis |
| **PSR** | Periodic Safety Review |
| **RASSC** | Radioprotection Safety Standard Committee. |
| **R.D.** | Royal Decree. |
| **RGPT** | Règlement Général pour la Protection du Travail (i.e. Belgium's Occupational Health & Safety Regulations). |
| **RHR** | Residual Heat Removal. |
| **RHRS** | Residual Heat Removal System. |
| **RPV** | Reactor pressure vessel |
| **R2CA** | Reduction of Radiological Consequences of design basis and design extension Accidents (Horizon2020/EC). |
| **SAM** | Severe accident management |
| **SAMG** | Severe accident management guidelines |
| **SBO** | Station black-out |
| **SCK CEN** | Studiecentrum voor Kernenergie, Nuclear Research Centre / Centre d'Etude de l'Energie Nucléaires, situated at Mol, Belgium. |
| **SFP** | Spent fuel pool |
| **SG** | Steam generators |
| **SPDS** | Safety Parameter Display System. |
| **SRNI-2011** | The Royal Decree on the Safety Requirements for Nuclear Installations |
| **SSCs** | Structures, systems and components |
| **SSE** | Safe Shutdown Earthquake. |
| **STA** | Shift Technical Advisor. |
| **STAR** | Stop-Think-Act-Review. |
| **THAI** | Thermal-hydraulics, Hydrogen, Aerosols and Iodine Project (NEA/OECD). |
| **TMI** | Three Mile Island. |
| **TRANSSC** | Transport Safety Standard Committee. |
| **TRC** | Technical Responsibility Centre (Bel V). |
| **USNRC** | United State Nuclear Regulatory Commission |
| **VGB** | Vereinigung der Grosskesselbetreiber |
| **WANO** | World Association of Nuclear Operators. |
| **WASSC** | Waste Safety Standards Committee (AIEA). |
| **WENRA** | Western European Nuclear Regulator's Association. |

Table 18 : List of Acronyms

# VI. Appendix 5 - List of the Web Sites of the Different Nuclear Actors in Belgium

## VI.A. Regulatory Body

| | | |
|---|---|---|
| Federal Agency for Nuclear Control: | http://www.fanc.fgov.be | (site in French and Dutch) |
| Bel V | http://www.belv.be | (site in French, Dutch and English) |

## VI.B. Licences, Architect-engineers, Research Centres

| | | |
|---|---|---|
| ENGIE Electrabel: | http://corporate.engie-electrabel.be/ | (site in French, Dutch and English) |
| Tractebel ENGIE : | http://www.tractebel-engie.com/ | (site in English) |
| SCK CEN: | http://www.sckcen.be | (site in English) |
| Belgoprocess: | http://www.belgoprocess.be | (site in English) |
| ONDRAF/NIRAS: | https://www.ondraf.be/ | (site in French, Dutch, English and German) |
| AIB-Vinçotte | https://www.vincotte.be/en_be/home/ | (site in French, Dutch and English) |

## VI.C. Associations

| | | |
|---|---|---|
| Belgian Nuclear Society: | http://www.bnsorg.eu/ | (site in English) |
| Belgian Association for Radiation Protection (BVS/ABR) | http://www.bvsabr.be | (site in French and Dutch) |

## VI.D. Others

| | |
|---|---|
| WENRA (Western European Nuclear Regulators Association | http://www.wenra.eu |
| ENSREG (European Nuclear Safety Regulators Group) | http://www.ensreg.eu |
| HERCA (Heads of the European Radiological Protection Competent Authorities) | http://www.herca.org/ |

# VII. Appendix 6 - Subjects examined during the Periodic (ten yearly) Safety Review

## VII.A. Subjects examined during the First Safety Reviews of the Doel 1 & 2 and Tihange 1 Units

The following subjects have been examined:

- protection against accidents of external origin and industrial risks
- re-definition of the design earthquake
- high-energy line break
- fire protection
- flooding, of internal or external origin
- high winds and extreme climatic conditions
- differential settlement between structures
- systems having safety-related functions to shut down the reactor, for core cooling and for evacuation of residual power:
    - reactor protection system
    - safety systems: emergency feedwater supply to the steam generators,
    - shutdown cooling system, safety injection, spray or internal ventilation inside containment, emergency control room and auxiliary shutdown panel.
    - steam relief to atmosphere
    - ultimate heat sink
    - safety compressed-air
    - emergency electrical power
    - resistance and integrity of various systems
    - safety systems instrumentation
    - primary system leak detection
    - detection of inadequate core cooling
    - seismic and environmental qualification of safety systems
- primary system integrity:
    - protection against cold and hot overpressure
    - protection against pressurised thermal shock
    - pressure vessel venting
    - integrity of primary pump seals
    - leak detection
    - boric-acid induced corrosion
    - list of actually incurred transients
- nuclear auxiliary building: protection against post-accident radiation
- inspection of structures and equipment (mechanical, electrical, civil works)
- test programme
- technical specifications
- operation organisation
- quality management
- spent fuel handling and storage
- gaseous effluent treatment and ventilation systems
- isolation and leak-tightness of primary and secondary containments
- hydrogen control inside containment
- operation experience feedback
- accident analysis review
- radiation protection and ALARA
- post-accident sampling in the reactor building
- updating of documentation, including amendment of the Safety Analysis Report.

## VII.B. Subjects examined during the First Safety Reviews of the Doel 3, 4 and Tihange 2, 3 Units, and Second Safety Review of Tihange 1

- conformity to the design bases: re-evaluation of the environment
- protection of electric safety circuits against lightning

- verification of extreme climatic conditions
- impact of the modifications made to the installations on the original "High Energy Line Break" (HELB) study
- loadings combinations on the structures
- anchorage of safety equipment
- use of the results of the qualification of mechanical equipment : components with a limited lifetime
- verification of the post-accident operability of pneumatic actuators
- dimensioning of miniflow lines of safety related centrifugal pumps
- post-TMI II.D.1 recommendation (mechanical resistance of the pressuriser discharge line)
- instability of the pressuriser safety valves during passage of the water plug
- qualification of the relief and block valves of the pressuriser
- taking into account secondary effects in the calculation of pipe supports in "Level D"
- thermal environment of electric equipment
- qualification of electric connectors: containment penetrations
- post-TMI II.F.2 recommendation (RM chains)
- follow-up of the US rules and practices
- general procedure for reloads safety justification
- follow-up of operational transients
- shift of the set point of the pressuriser safety valves
- pressure vessel embrittlement
- thermal ageing of stainless steel
- primary pumps: re-evaluation of the axial bearing
- risk of recirculation sump clogging during accidents
- containment spray water chemistry
- measurement of the containment free volume
- depressurisation of the safety injection accumulators
- availability of the LHSI pumps during recirculation
- manual initiation of the primary containment spray
- sub cooling measurement with core thermocouples to be qualified in the context of post-TMI II.F.2 recommendation
- verification of the response time of sensors
- protection of diesel groups in case of emergency signal
- availability of diesel groups during the sequence "SI signal followed by the complete loss of external electric grid"
- over speed protection of the emergency diesels
- availability of motors under degraded voltage conditions
- verification of the diesels loads
- loss of low voltage busses: procedures
- evaluation of the tightness of pool joints
- evaluation of the fire detection and protection
- ALARA policy
- post-TMI II.B.2 recommendation (post-accident accessibility)
- revision of the programme for the training and licensing of the personnel
- re-evaluation of the tightness tests of the recirculation lines
- functional tests of the shock-absorbers
- assessment of the periodic tests of pumps, valves and check-valves
- test console for logic and analogic protection signals
- global tests
- welding of the safe-ends on the pressure vessel nozzles
- pressure vessel inspection: underclad defects in the nozzles
- impact of the stainless steel cladding on the pressure vessel inspections with u.s.
- wear of the control rods
- corrosion of the reactor baffle screws
- corrosion of the guide tube pins
- follow-up of the internal structures of the pressure vessels by analysis of neutronic noise

- inspection of the steam generators: tube sheet — evacuation of the risk of under clad cracks
- welding of the partition plate on the water box on the tube sheet and the bottom of the steam generators
- steam generators: weld between the upper ring and the transition cone
- corrosion problems of valve bolts
- control of the pipe whip restraints
- internal corrosion of the SI accumulators
- post-earthquake procedure
- evolution of the ASME Code section XI
- ASME code section XI: appendices 7 and 8 (ultrasonic inspections)
- steam generator problems: limitation of the primary/secondary leak
- evaluation of the conclusions of generic studies of accidents not considered in the original design
- consideration of severe accidents
- probabilistic safety analysis
- re-evaluation of the Technical Specifications
- assessment of the implementation of the Q.A. programme
- software quality assurance
- quality management: Safety Evaluation Committee
- feedback of operating experience from Belgian and foreign plants
- assessment of incidents and synthesis of their causes
- evaluation of the modifications which can impact safety
- analysis of the influence of the emergency systems
- evaluation of voluntary inspections
- operator aids: shutdown mode
- operator aids during accidents
- primary breaks in modes 3 and 4
- thermal stratification in the pressuriser surge line
- thermal stratification in the main feedwater lines and their connection on the steam generator
- check valves: generic problems

## VII.C. Subjects examined during the Second Ten-yearly Safety Reviews of Doel l and 2

- ageing of electric equipment
- ageing of mechanical equipment
- ageing of the pressure vessel and of the primary circuit
- ageing of concrete structures
- ageing of the steam generators
- pressure vessel irradiation
- availability of the recirculation function
- antisiphoning system of the fuel pools
- seismic qualification
- qualification of safety related equipment
- qualification of high energy lines
- thermal stratification in the pressuriser surge line
- classification of safety-related equipment
- thermal stratification of feedwater lines
- qualification of the auxiliary feedwater system
- secondary overpressure
- loadings combinations in the reactor building cells
- implementation of ASME 1992
- re-evaluation of the Technical Specifications
- fire protection re-evaluation
- toxic gases protection reassessment
- improvement of the availability of the safety diesels

- dismantling
- ALARA
- software QA
- overlapping of tests for safety instrumentation
- quality assurance
- valving systems
- corrosion due to boron
- lightning protection
- operational transients
- protection of motors (under voltage)
- response time of radiological protection chains
- integrity of underground lines
- shielding of the radiological protection chains
- feedback of operating experience
- in service inspection
- procedures after earthquakes
- post-accident procedures
- severe accidents
- probabilistic safety analysis
- reassessment of accidents
- transport container for spent fuel assemblies
- set point statistical study
- re-evaluation of the environment
- inter-systems LOCA
- radiological consequences
- operational problems: follow-up of the pressure vessel internals

**VII.D. Subjects examined during the Second Safety Reviews of Doel 3 and Tihange 2, subjects to be examined during the Second Safety Reviews of Doel 4 and Tihange 3, and subjects to be examined during the Third Safety Reviews of Doel 1 & 2, and Tihange 1**

- follow-up of US rules and practices
- definition of a source term for the reference accident
- post-'92 evolution of ASME XI Code OM
- re-evaluation of the conformity of the Single Failure Proof cranes with current standards
- re-evaluation of the Technical Specifications for the waste treatment building (WAB) at the Doel site
- re-evaluation of the Technical Specifications of Tihange 1
- re-evaluation of the Technical Specifications of Doel 1 & 2
- evolution of the environment and its impact
- re-evaluation of the impact of extreme climate conditions
- re-evaluation of the seismic level on the basis of recent investigations
- risk related to external flooding
- risk related to internal flooding
- systematic approach to assess the fire and explosion risk
- re-evaluation of ultimate heat sink (wells) at the Tihange site
- update of the PSA models
- safety analysis for shutdown modes
- follow-up of knowledge with respect to severe accidents
- analysis of the safety impact of flow dissymmetry between primary loops
- evaluation of main discrepancies with respect to the Position Paper on the application of the single failure criterion for the oldest units only :
- electrical support systems (Doel 1 & 2)
    - safety related systems (Doel 1 & 2)
    - heat sink (Tihange 1)
    - plant air (Tihange 1)
- updating accident procedures

- procedure for incidents during fuel handling
- procedure for loss of ultimate heat sink
- updating of incident procedures
- evaluation of PAMS measuring uncertainties
- availability of safety related components
- leak tightness of feedwater isolation valves
- follow-up of prestressing of the primary containment
- re-evaluation of the safety related ventilation
- reassessment of containment isolation
- pressurizing, of isolated piping in containment during accident conditions
- reassessment of ventilation for emergency building (Tihange 2)
- reassessment of ventilation for waste treatment building
- structural integrity reassessment of emergency buildings
- tests and criteria for safety related valves pumps, and diesels (Doel 1 & 2, and Tihange 1).
- evaluation of radiation exposure of plant operators during an accident
- isolation of normal feedwater (Tihange 1)
- optimization of containment spray lay-out (Tihange 1)
- containment spray additive (D12)
- application of ASME XI, Appendix OM to liquid discharging spring loaded safety valves
- verification of the efficiency of safety related heat exchangers
- follow-up of the pressure vessel embrittlement and protection against cold overpressure
- follow-up of ageing of guide tube split pins, of radial guides of the reactor vessel internals, of baffle bolts, of cast elbows, of safety related equipment, of temperature measurement probes in the primary loot by-pass, of CVCS heat exchangers and of elastomer supports
- follow-up of equipment fatigue (including thermal stratification)
- follow-up of corrosion phenomena in piping and line mounted equipment
- renovation of I/C systems and safety related components
- renovation of structures and buildings
- renovation of fire protection systems
- training of personnel and knowledge management
- design basis retrieval
- optimisation of ALARA policy
- qualification of software systems against smoke

## VII.E. Subjects examined during the Third Safety Reviews of Doel 3 and Tihange 2, Doel 4 and Tihange 3 and during the Fourth Safety Review of Doel 1 & 2 and Tihange 1

The third periodic safety reviews of the most recent units (Doel 3 and 4, Tihange 2 and 3), and the fourth periodic safety review of the Doel 1 & 2 and Tihange 1 units was executed according to the IAEA NS-G-2.10. This methodology is based on an assessment of 14 safety factors (SF) which are listed below, 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 evaluated the results (e.g. performance indicators, physical condition of the installations), they also assessed 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 ENGIE). Per safety factor, the conclusions were registered in extensive reports that have been supplied to Bel V and the FANC. A global assessment of the plant's strengths and opportunities for improvement was executed, which led to a plant improvement plan documented in the PSR synthesis report.

For some areas the PSR assessment of the Doel 1 & 2 and Tihange 1 unit differed from the more recent units, because of their LTO programme. Indeed design, actual condition of the SSC, qualification and ageing of SSC were even more thoroughly assessed for the oldest units.

The PSR action plan consists of the following main improvements which are valid for all units, and have been implemented:

- 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 for the Doel site.
- 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.

For Doel 1 & 2 and Tihange 1 units, a specific LTO programme with important improvements regarding design and ageing of SSC has been implemented before restart of the units in 2020.

**<u>Selection of important improvement actions from LTO action plan Tihange 1</u>**

**<u>Mechanical Systems and structures</u>**

| |
|---|
| Replacement of ISBP pumps |

| |
|---|
| Improvement of loose parts monitoring system |
| Replacement of cooling groups |
| Renovation of fire compartment barriers |
| Renovation of cable trays |

**Civil structures**

| |
|---|
| Corrective actions identified after inspections |
| Renovation of reactor building instrumentation |
| Replacement of anchor cables roof nuclear auxiliary building |
| Auxiliary feed water system building: soil consolidation actions after jet grouting incident |

**EI&C systems**

| |
|---|
| Replacement of radioactivity measurement chains PIG (aerosols, iodine, gas) |
| Renovation of alarm management system BETEA, renovation of communication systems |
| Replacement of 6kV switchboard protections |
| Replacement of safety related motors |
| Replacement of AC and DC switchboards |
| Replacement of rectifiers and ondulators |
| Replacement of batteries |
| Upgrade to conformity with qualification rules: electric penetrations reactor building, reactor protection system, pneumatic valves, transmitters |

**Design**

| |
|---|
| BEST – additional ultimate electricity supply |
| BEST – reinforcement building electrical auxiliary building |
| Filtered containment venting system |
| Upgrade reliability residual heat removal system |
| New full scope training simulator, including new "SUR-étendu" panels |
| Upgrade instrumentation: new spent fuel pool level measurements, additional redundant steam generator and RWST level measurements |
| "SUR-étendu" project: new auxiliary feedwater reservoir |
| "SUR-étendu" project |
| Renovation and upgrade of fire detection and fire compartments |

The « SUR-étendu » or « système d'ultime repli » was a project to reinforce the design of the existing ultimate emergency systems "SUR". These independent ultimate emergency systems are designed to able to bring the reactor to cold shutdown and cool the spent fuel pools in case of the unavailability of the main control room or even of the complete electrical auxiliary building "BAE", e.g. due to a fire. To do this the ultimate emergency systems are able to maintain the reactor subcritical, evacuate residual heat from reactor and spent fuel pools, control the primary system inventory and pressure. The improved ultimate emergency systems include an emergency control room, 2 redundant emergency diesel generators, 2 redundant RCP seal injection pumps with 7000ppm borated water source, an improved emergency steam generator feed water system (new redundant motor driven pump, new and larger water tank).

**Selection of important improvement actions from LTO action plan Doel 1 & 2**

**Ageing mechanical**

| |
|---|
| Optimisation maintenance programs active mechanical components (RCM of *Reliability Centered Maintenance*) |
| Establish checklist for visual inspection of structures supporting systems in reactor building, annular space and nuclear auxiliary building |
| Extension of inspection programs on pressure retaining bimetallic welds on reactor building penetrations. |

**Ageing EI&C: Modifications and replacements**

| |
|---|
| Qualified 380V and 6kV motor<br>Scrambreakers<br>Transmitters<br>Fire detection consoles |
| Reactor protection system (CPR)<br>Process control systems (Teleperm, SIP)<br>Reactor flux measurement chains (SIN)<br>Control room alarms, buttons and systems<br>Electrical supply systems (switchboards,…)<br>Non-safety-related 380V switchboards |

**Ageing civil structures: renovations**

| |
|---|
| Concrete renovations river Scheldt water intake |
| Renovation of nuclear auxiliary building stacks |
| Renovation exterior walls nuclear auxiliary building |

**Design-improvements**

| |
|---|
| Improve fire detection reactor coolant pumps |

**Design-improvements**

| |
|---|
| Improvement leak tightness main control room<br>New toxic gas detection on main control room ventilation system<br>Upgrade physical separation of electrical trains |
| New submergible pumps to feed RW cooling towers with water from river Scheldt<br>Automatic emergency feedwater supply to steam generator from GNS building<br>Redundant emergency reactor coolant pump seal injection RJ pump<br>Redundant (parallel) inlet valve for residual heat removal system |
| New seismic fire water pump station with larger pumps and reservoirs<br>Improving turbine hall automatic fire extinguishing system<br>Improving fire compartments and automatic fire extinguishing in nuclear auxiliary and reactor building |
| Containment Filtered Venting System (CFVS) |

**Improvements related to BEST**

| |
|---|
| Spent fuel pool water supply piping |
| New mobile pumps and generators |
| Improve seismic resistance RWST's + additional supply piping |

## VII.F. Subjects examined during the Fourth Safety Reviews of Doel 3 and Tihange 2, Doel 4 and Tihange 3, and during the Fifth Safety Review of Doel 1 & 2 and Tihange 1

These Safety reviews are very specific given that the NPPs will be in their final shutdown.

Currently the Fourth Safety Review has been performed for the final shutdown of the Doel 3 NPP scheduled on October 1st 2022, and is ongoing for the final shutdown of the Tihange 2 NPP scheduled on February 1st 2023. For the final shutdown of the other NPPs, the Safety Review is currently foreseen to start during 2023.

The Safety Reviews in the context of final shutdown cover the post-operational phase, until the new decommissioning licence is obtained. As currently envisioned, all nuclear fuel will be unloaded from the core within approximately one month after the final shutdown and transferred to the spent fuel pools of the corresponding NPP from which the spent fuel assemblies will gradually be transferred to separate dry or wet intermediate storage locations on site.

The focus of the Safety Review is on the safety functions related to the storage and handling of the fuel assemblies in the spent fuel pools. Indeed besides the Safety Review, there is also the legally binding Notification of Final Shutdown which has to be submitted to the Safety Authorities before the final shutdown. The Notification of Final Shutdown considers nuclear safety during the post-operational phase, before the new decommissioning licence is obtained. It defines an optimized nuclear island which evolves during the different phases of post-operation, as well as its operational program, and addresses specific POP activities such as the chemical decontamination of the primary system.

Since both reviews overlap in large parts regarding nuclear safety aspects to be discussed, it has been decided to bundle them together into one joint report 'Notification of Final Shutdown & Periodic Safety Review'.

Specifically for the Periodic Safety Review, the approach follows the recommendations of the IAEA Safety Guide SSG-25 'Periodic Safety Review for Nuclear Power Plants' (2013) for the fuel assemblies in the spent fuel pools. The evaluation is built around 14 safety factors, of which the findings are examined in a global evaluation in particular regarding the needs and opportunities for improvement. The Royal Decree on the Safety Requirements for Nuclear Installations (SRNI-2011; 2020 edition) is an important reference for the evaluation and contains the WENRA 2014 reference levels for the safety of nuclear installations.

FANC

FEDERAL AGENCY FOR
NUCLEAR CONTROL