BELGIAN STRESS TESTS

FANC
federal agency for nuclear control

National report for nuclear power plants

23rd December 2011

Belgian stress tests
National report for nuclear power plants

This national report is provided by the Belgian regulatory body to the European Commission, as part of the stress tests program applied to European nuclear power plants in response to the Fukushima-Daiichi accident.

Review	Review date	Modification description	By
0	2011-12-23	First edition	FANC-Bel V

Introduction

Belgium has always been a pioneering country in the development of nuclear sciences and technologies for peaceful purposes. As such, the country is endowed with seven pressurized water reactors currently in operation on two distinct sites:

- The Doel site, located on the Scheldt river close to Antwerp (Flanders), home of four reactors:
  - Doel 1/2: twin units of 433 MWe each, commissioned in 1975,
  - Doel 3: single unit of 1 006 MWe, commissioned in 1982,
  - Doel 4: single unit of 1 039 MWe, commissioned in 1985.
- The Tihange site, located on the Meuse river close to Liège (Wallonia), home of three reactors:
  - Tihange 1: single unit of 962 MWe, commissioned in 1975,
  - Tihange 2: single unit of 1 008 MWe, commissioned in 1983,
  - Tihange 3: single unit of 1 054 MWe, commissioned in 1985.

Both sites are operated by the same licensee, namely Electrabel, a company of the GDF-SUEZ energy and services Group.

For all nuclear safety related matters, the licensee's activities are under the control of the Belgian regulatory body[1], which is composed of:
- the Federal Agency for Nuclear Control (FANC),
- and Bel V, its technical subsidiary.

The current features of the nuclear power plants operated in Belgium result from:
- the design basis of each unit,
- the modifications that were implemented subsequently over the life of the facilities.

During the design phase, the power plants were dimensioned to fulfil the safety, reliability and availability requirements applicable at that time, and to resist predefined accidents and hazard scenarios. The design rules that were used included safety margins in the process (conservative assumptions in the models, safety coefficients in the calculations, penalizing hypothesis in hazard scenarios…).

The design rules in force at a given period take into account the latest scientific knowledge (e.g. evaluation of the seismic hazard at a given location), the available techniques (e.g. pre-stress of the concrete), as well as the best practice usually applied in the considered field (e.g. use of a double containment building). These design rules have evolved over time, and therefore the units currently in operation in Belgium present some differences depending on their date of commissioning.

In some cases, specific hazards were not taken into account during the design phase, either because the threat was not considered plausible at that time (e.g. terrorist aircraft crash), or because the annual probability of facing an accident leading to unacceptable consequences was negligible (e.g. tornado). This is particularly true for the earliest units (Doel 1/2 and Tihange 1). In those specific cases, the resistance of the units was evaluated retrospectively in order to determine the maximal admissible sollicitations, and to decide the relevant corrective actions to undertake where necessary.

Some modifications have therefore been implemented over the life of the facilities, in order to bring the necessary improvements where appropriate, according to the latest knowledge and available technologies, as well as the current state of the art. These improvements take into account the feedback of the accidents that occurred abroad (Three Mile Island, Tchernobyl), and the evolution of

[1] Additional information about the Belgian regulatory body and nuclear facilities is available on the FANC website (http://www.fanc.fgov.be), specifically in the 2010 report for the Convention on Nuclear Safety

the doctrine at the national level (federal regulation) and at the international level (standards and guides from the International Atomic Energy Agency, rules of the American Nuclear Regulatory Commission…). They are put into effect during the periodic (ten-yearly) safety reviews, or through specific action plans implemented spontaneously by the licensee or at the request of the regulatory body.

The basic safety principles, such as defence in depth, redundancy of safety related equipment, physical or geographic separation, and diversification, were applied from the design phase, and upgrades were performed on the earliest units to increase their robustness when facing scenarios that were not considered yet. Some structure reinforcements were also achieved where required.

All units now have:

- first level safety systems, aimed at facing internal and external hazards that might threaten the facilities;

- second level emergency systems, aimed at compensating the loss of the first level equipment, e.g. as a result of hazards that were not considered in the design of the first level;

- multiple power supply sources: high voltage lines from the external grid, self-powering during house load operation, back-up diesel generators, battery/inverter sets;

- multiple ultimate heat sinks, with several means to draw water: river by the site (Scheldt river at Doel, Meuse river at Tihange), artificial ponds (Doel), and wells in the water table (Tihange);

- internal emergency plans in line with the public authorities' emergency plans: emergency management centres, diagnostic tools, emergency procedures…

These resources allow to deal with accident scenarios considered individually.

However, the accident that occurred on 11 March 2011 at the Japanese Fukushima-Daiichi nuclear power plant showed that the conjunction of several events (earthquake, tsunami, flooding, hydrogen explosion) could lead to particularly unfavourable conditions for which the facilities and the licensee were not sufficiently prepared: failure of the containment, total loss of power supplies, total loss of cooling means, difficulties in accessing the site… The fact that several units on the same site were affected at the same time also constituted an aggravating factor with respect to the accident management.

As a consequence, a wide-scale targeted safety reassessment program was set up among the member states of the European Union operating nuclear power plants on their soil. This "stress tests" program is designed to re-evaluate (based on technical studies, calculations and engineering judgment) the safety margins of the European nuclear power plants when faced with extreme natural events, and to take relevant action wherever needed. The approach is meant to be essentially deterministic, and should focus not only on the preventive measures but also on the mitigative measures.

The scope of the Belgian stress tests covers all seven reactor units operated by Electrabel, including the spent fuel pools of each reactor unit and the dedicated spent fuel storage facilities at both sites, namely:

- "SCG" building at Doel (dry cask spent fuel storage facility),
- "DE" building at Tihange (wet spent fuel storage facility).

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

1. The licensee carries out the stress tests in its facilities and communicates a final report to the Belgian regulatory body. In this report, the licensee describes the reaction of the facilities when facing the different extreme scenarios, and indicates, where appropriate, the improvements that could be implemented to reinforce safety.

2. The regulatory body examines the licensee's report and evaluates the approach and the results. Based on these data, the regulatory body writes its own national report.

3. The report of all national regulatory bodies is subject to an international peer review: the national reports are examined by other regulatory bodies representing 27 European independent national Authorities responsible for the nuclear safety in their country. This method increases consistency in the whole process and ensures the sharing of experience between regulatory bodies.

From that stage, the European Commission will establish a final report that will be presented to the European Council, so as to provide an overall view of the current situation in the European power plants.

The first phase of the Belgian stress tests for nuclear power plants was achieved by the licensee on a short-time period until 28 October 2011 (communication of the licensee's reports to the regulatory body). This phase mobilized around 40 engineers and experts from Electrabel and its technical subsidiary Tractebel Engineering, as well as a number of third-party resources specialized in selected fields (seismic hazard, flooding…).

The second phase of the program was then carried out by the FANC and its technical subsidiary Bel V, whose experts have a thorough knowledge of the facilities. The assessment of the approach and results provided by the licensee included detailed examination of the licensee's stress tests reports and the supporting documents, technical meetings with the licensee, and on-site inspections to check on the field the reality, relevance and robustness of the key data valued in the licensee's safety demonstrations. That process led to the publication of the present national report.

As required by the ENSREG specifications, the Belgian national report for nuclear power plants covers the following risks:

- earthquake,
- flooding,
- extreme weather conditions,
- loss of electrical power and loss of ultimate heat sink,
- severe accident management.

Upon demand of the Belgian Federal Government, terrorist attacks (aircraft crash) and other man-made events (cyber attack, toxic and explosive gases, blast waves) were also included as possible triggering events in the Belgian stress tests program. The assessment of these man-made events were however not in the scope of the European stress tests programs, and are thus developed in a separate national report which will not be part of an international peer review.

In order to provide a self-standing national report for the subsequent peer review process, the relevant data supplied by the licensee in its stress tests reports are recalled in each chapter.
At the end of each chapter, a final section provides the conclusions and the assessment of the Belgian regulatory body (FANC and Bel V).

As part of the Authorities' transparency policy, this national report is made available to the public and media on the Belgian regulatory body's website (http://www.fanc.fgov.be).

Table of Contents

Introduction 3
Table of Contents 6
List of Figures 8
1. General description 9
1.1. Site characteristics 9
1.1.1. Main characteristics of the units 10
1.2. Significant differences between units 13
1.2.1. Doel site 13
1.2.2. Tihange site 16
1.3. Use of probabilistic safety assessments as part of the safety assessment 19
1.4. List of acronyms 20
2. Earthquake 26
2.1. Design basis 26
2.1.1. Earthquake against which the plants are designed 26
2.1.2. Provisions to protect the plants against the design basis earthquake 30
2.1.3. Compliance of the plant with its current licensing basis 38
2.2. Evaluation of safety margins 40
2.2.1. Range of earthquake leading to severe fuel damage - Description of SMR methodology 40
2.2.2. Range of earthquake leading to loss of containment integrity 47
2.2.3. Earthquake exceeding the design basis earthquake for the plants and consequent flooding exceeding design basis flood 49
2.3. Synthesis of the main results presented by the licensee 52
2.4. Assessment and conclusions of the regulatory body 53
3. Flooding 54
3.1. Design Basis 54
3.1.1. Flooding against which the plants are designed 54
3.1.2. Provisions to protect the plants against the design basis flood 56
3.1.3. Plants compliance with its current licensing basis 60
3.2. Evaluation of safety margins 62
3.2.1. Estimation of safety margin against flooding 62
3.2.2. Measures which can be envisaged to increase robustness of the plants against flooding 69
3.3. Synthesis of the main results presented by the licensee 72
3.3.1. Tihange NPP 72
3.3.2. Doel NPP 73
3.4. Assessment and conclusions of the regulatory body 75
3.4.1. Tihange NPP 75
3.4.2. Doel NPP 76
4. Extreme weather conditions 77
4.1. Heavy rainfalls 77
4.1.1. Reassessment of heavy rainfalls used as design basis 77
4.1.2. Evaluation of safety margins against heavy rainfalls 79
4.1.3. Measures that can be envisaged to increase robustness against heavy rainfalls 80
4.2. High winds 81
4.2.1. Reassessment of high winds used as design basis 81
4.2.2. Evaluation of safety margins against high winds 81
4.2.3. Measures that can be envisaged to increase robustness against high winds 82
4.3. Tornadoes 83
4.3.1. Reassessment of tornadoes used as design basis 83
4.3.2. Evaluation of safety margins against tornadoes 84
4.3.3. Measures that can be envisaged to increase robustness against tornadoes 86
4.4. Lightning 88
4.4.1. Reassessment of lightning used as design basis 88
4.4.2. Evaluation of safety margins against lightning 88
4.4.3. Measures that can be envisaged to increase robustness against lightning 88
4.5. Snowfalls 89
4.5.1. Reassessment of snowfalls used as design basis 89
4.5.2. Evaluation of safety margins against snowfalls 89

4.5.3. Measures that can be envisaged to increase robustness against snowfalls 90
4.6. Hail 91
4.7. Other extreme weather conditions 92
4.8. Synthesis of the main results presented by the licensee 93
4.9. Assessment and conclusions of the regulatory body 94
5. Loss of electrical power and loss of ultimate heat sink 95
5.1. Loss of electrical power 96
5.1.1. Loss of offsite power (LOOP) 99
5.1.2. Loss of offsite power (LOOP) and loss of the first level on-site back-up power supplies (Station Black-out) 102
5.1.3. Loss of external power (LOOP) and loss of all on-site back-up power provisions (total Station Blackout) 110
5.2. Loss of heat sink 116
5.2.1. Loss of the primary ultimate heat sink (LUHS) 116
5.2.2. Loss of the primary ultimate heat sink and alternate ultimate heat sink(s) 125
5.3. Loss of the primary ultimate heat sink combined with loss of off-site power and loss of first level on-site back-up power supply 134
5.3.1. Autonomy of the site before fuel damage 134
5.3.2. (External) actions provided to prevent fuel damage 136
5.3.3. Measures that can be considered to improve the robustness of the installations............. 136
5.4. Loss of the primary ultimate heat sink combined with a total Station Black-out 137
5.5. Loss of the primary ultimate heat sink combined with the loss of off-site power and Design Basis Earthquake 138
5.5.1. Autonomy of the site before fuel damage 138
5.5.2. (External) actions foreseen to prevent fuel damage 140
5.6. Spent nuclear fuel storage 141
5.7. Synthesis of the main results presented by the licensee 142
5.7.1. Scenario “Loss of offsite power (LOOP)” 144
5.7.2. Scenario “Station Black Out (SBO)” 144
5.7.3. Scenario “Total SBO” 144
5.7.4. Scenario “Loss of the primary ultimate heat sink” 145
5.7.5. Scenario “Loss of primary and alternate ultimate heat sinks” 146
5.7.6. Scenario “Loss of the primary UHS with SBO” 146
5.7.7. Scenario “Loss of the primary UHS with total SBO” 146
5.7.8. Scenario “Loss of the primary UHS, LOOP and earthquake DBE” 146
5.7.9. Spent Fuel Pools 147
5.8. Assessment and conclusions of the regulatory body 148
6. Severe accident management 150
6.1. Organisation and arrangements of the licensee to manage accidents 150
6.1.1. Organisation of the licensee to manage the accident 150
6.1.2. Possibility to use existing equipment 155
6.1.3. Evaluation of factors that may impede accident management and respective contingencies 161
6.2. Loss of core cooling: accident management measures in place at the various stages of a scenario of loss of core cooling function 167
6.2.1. Before occurrence of fuel damage in the reactor pressure vessel 167
6.2.2. After occurrence of fuel damage in the reactor vessel 168
6.2.3. After failure of the reactor vessel 169
6.2.4. Cliff-edge effects and timing 170
6.2.5. Adequacy of current accident management and possible additional measures 174
6.3. Accident management measures to maintain the containment integrity after core damage ... 178
6.3.1. Management of hydrogen risks inside the containment 178
6.3.2. Prevention of overpressure of the containment 178
6.3.3. Prevention of re-criticality 179
6.3.4. Prevention of basemat melt through 180
6.3.5. Need for and supply of electrical AC and DC power and compressed air to equipment used for protecting containment integrity 180
6.3.6. Cliff-edge effects and timing 182
6.3.7. Current accident management measures for a return to a stable and controlled state 184

6.3.8. Overview of the accident management strategies and means 185
6.4. Accident management measures to restrict the radioactive releases 188
6.4.1. Mitigation of fission products releases 188
6.4.2. Injection of water into the steam generators to trap the fission products leaking from damaged steam generator tubes 188
6.4.3. Injection of water into the primary system to trap fission products released from the core debris 188
6.4.4. Injection of water into the containment building 189
6.4.5. Monitoring containment building conditions 189
6.4.6. Injection of water in the reactor pit 189
6.5. Accident management measures for loss of cooling of spent fuel pools 190
6.5.1. Current accident management measures 190
6.5.2. Cliff-edge effects and timing 191
6.5.3. Instrumentation needed to monitor the spent fuel and to manage the accident 193
6.5.4. Hydrogen accumulation 194
6.5.5. Adequacy of current management measures and possible additional arrangements 195
6.5.6. Returning to a stable and controlled state... 195
6.6. Synthesis of the main results presented by the licensee 196
6.7. Assessment and conclusions of the regulatory body 197
7. General conclusions 199
7.1. Mains results and safety improvements proposed by the licensee 199
7.1.1. Earthquakes 199
7.1.2. Flooding 200
7.1.3. Extreme weather conditions 201
7.1.4. Loss of electrical power supply or heat sink 201
7.1.5. Emergency organisation and severe accident management 202
7.1.6. Action plan 203
7.2. Synthesis of the assessment and additional improvements required by the regulatory body .. 205
7.2.1. Earthquake 206
7.2.2. Flooding 206
7.2.3. Extreme weather conditions 207
7.2.4. Loss of electrical power and loss of ultimate heat sink 208
7.2.5. Severe accident management 209

List of Figures

Figure 1 - Nuclear power plant sites in Belgium 9
Figure 2 - Facilities at Doel site 9
Figure 3 - Facilities at Tihange site 10
Figure 4 - Double containment of the Doel 3 and Doel 4 reactor building 11
Figure 5 - Comparison of the design spectra of the three Tihange units 28
Figure 6 - Spectrum at ground level based on the ROB study 29
Figure 7 - Classification of SSC in categories H, L, M. 42
Figure 8 - Comparison of the RLE spectrum and the Tihange DBE spectrum. 43
Figure 9 - Comparison of the RLE spectrum and the Doel DBE spectra 43
Figure 10 -The different altimetric zones of the Tihange site 57
Figure 11 - Design provisions at the Doel NPP against DBF (Cross section of the embankment) 57
Figure 12 - Example of decamillenial flood and proposal for peripheral protection of the site............ 70
Figure 13 - Plan of the electricity power supplies in Tihange 2 and 3. 97
Figure 14 - Plan of the electricity power supplies in Doel 3 and 4. 98
Figure 15 - Plan of heat sinks in Tihange. 116
Figure 16 - Plan of heat sinks in Doel. 117

1. General description

1.1. Site characteristics

The Belgian nuclear power plants are located on two distinct sites: Doel and Tihange. They are operated by Electrabel, a company of the GDF-SUEZ energy and services Group.

Figure 1 - Nuclear power plant sites in Belgium

Doel NPP

The Doel nuclear power plant is located in the port of Antwerp, on the left bank of the Scheldt river, at 15 km northwest of Antwerp (Flanders) and at only 3 km from the border between Belgium and the Netherlands.
The site houses the following facilities:

- Doel 1/2 twin reactors units (A),
- Doel 3 reactor unit (B),
- Doel 4 reactor unit (C),
- SCG building (spent fuel dry storage) (D).

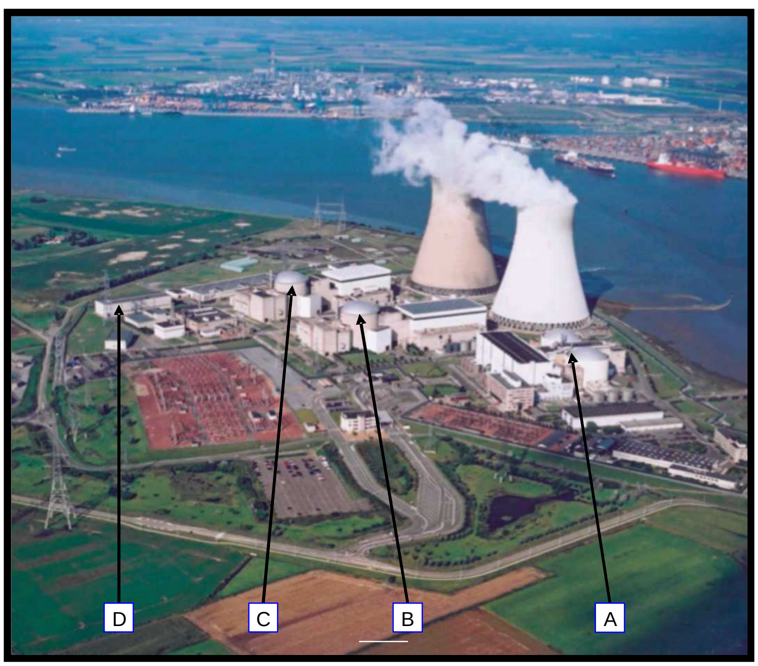

Figure 2 - Facilities at Doel site

Tihange NPP

The site is located on the territory of the former municipality of Tihange along the right bank of the Meuse river. Tihange is now part of the City of Huy at a distance of 25 km from Liege.
The site houses the following facilities :

- Tihange 1 reactor unit (A),
- Tihange 2 reactor unit (B),
- Tihange 3 reactor unit (C),
- DE building (spent fuel wet storage) (D).

Figure 3 - Facilities at Tihange site

1.1.1. Main characteristics of the units

1.1.1.1. Doel site

The table hereafter lists the main characteristics of the units located at Doel site:

Table 1: Characteristics of Doel site units

<table>
<tr><th>Units</th><th>Type</th><th>Thermal power (MWth)</th><th>Date of first criticality</th><th>Containment building characteristics</th><th>Steam generator replacement</th><th>Fuel storage pool capacity</th><th>Designer</th></tr>
<tr><td>Doel 1</td><td>PWR (2 loops)</td><td>1 312</td><td>1974</td><td>Double containment (steel and concrete)</td><td>2009</td><td rowspan="2">664 positions</td><td>Westinghouse</td></tr>
<tr><td>Doel 2</td><td>PWR (2 loops)</td><td>1 312</td><td>1975</td><td>Double containment (steel and concrete)</td><td>2004</td><td>Westinghouse</td></tr>
<tr><td>Doel 3</td><td>PWR (3 loops)</td><td>3 064</td><td>1982</td><td>Double containment with inner metallic liner</td><td>1993</td><td>672 positions</td><td>Framatome</td></tr>
<tr><td>Doel 4</td><td>PWR (3 loops)</td><td>3 000</td><td>1985</td><td>Double containment with inner metallic liner</td><td>1997</td><td>628 positions</td><td>Westinghouse</td></tr>
<tr><td>SCG building</td><td>Spent fuel dry storage</td><td>-</td><td>-</td><td>-</td><td>-</td><td>165 spent fuel containers</td><td>Tractebel Engineering</td></tr>
</table>

The four Doel reactor buildings are equipped with a double containment.

At Doel 1/2, the primary (inner) containment consists of a steel bulb. The secondary (outer) containment consists of a reinforced concrete cylinder on which a reinforced concrete hemispherical dome is placed. The secondary containment encapsulates the primary containment, thus protecting it against accidents.

At Doel 3 and Doel 4, the primary containment consists of a cylinder on which a dome in the shape of a spherical cap is placed. Both structures are made of pre-stressed concrete. This containment is internally covered with a steel liner guaranteeing its air tightness. The secondary containment of Doel 3 and Doel 4 reactor buildings also consists of a reinforced concrete structure enclosing the primary containment and thus protecting the primary containment against external accidents.

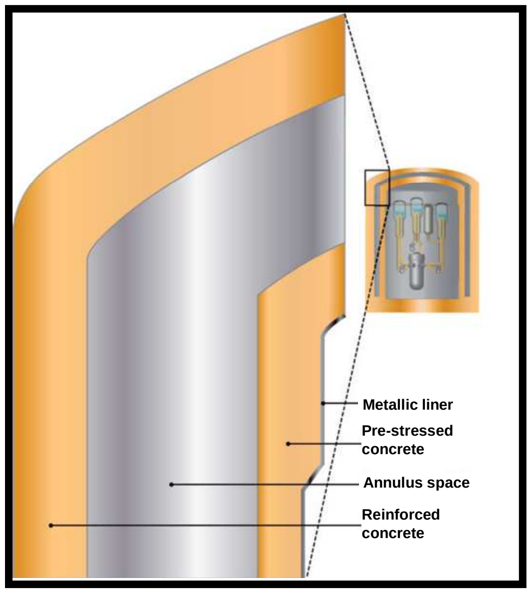

Figure 4 - Double containment of the Doel 3 and Doel 4 reactor building

The spent nuclear fuel of Doel 1/2 is stored in shared pools housed in the nuclear services building (GNH).

The spent nuclear fuel of Doel 3 and Doel 4 is stored in pools on each unit. The pools, as well as the cooling systems, are housed in the bunkered nuclear fuel building (SPG).

After a sufficient cooling period in the pools, the spent fuel from Doel 1/2, Doel 3 and Doel 4 is transferred to the spent fuel container building (SCG). This reinforced concrete building functions as a dry storage where the spent fuel is placed in special shielded containers and under inert gas. The residual heat is evacuated via natural convection. The containers are designed to resist severe accidents (aircraft crash, fire and earthquake).

1.1.1.2. Tihange site

The table hereafter lists the main characteristics of the units located at Tihange site:

Table 2: Characteristics of Tihange site units

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
DE building	Spent fuel wet storage	-	-	Bunkered building	-	3 720 positions + 30 temporary positions	Tractebel Engineering

Each of the three reactors has a cooling pool designed for the temporary storage of spent fuel assemblies. After at least two years in the cooling pools of the units, the fuel assemblies are transferred to the DE building that houses 8 storage pools, each with a capacity of 465 spent assemblies. The power of this building is supplied by Tihange 3 unit.
Safety-related systems and components for the DE building were designed to resist to the effects of natural events, earthquakes and accidents of external origin (aircraft crash, explosion) without losing their safety functions.

The reactor buildings of all three units in Tihange have a double containment structure. The inner containment is made of pre-stressed reinforced concrete with internal metallic liner while the outer containment is made of reinforced concrete.

1.2. Significant differences between units

1.2.1. Doel site

With respect to the initiating events considered at the design phase, there are differences between the Doel 1/2 units, and the Doel 3 and Doel 4 units:

- a number of systems are shared by the Doel 1/2 twin reactors,
- there is a strict physical separation between the redundant safety systems at Doel 3 and Doel 4,
- during the initial design of Doel 3 and Doel 4, the following internal or external hazards were considered:
    - aircraft crash,
    - large-scale fire,
    - explosion (including gas explosion),
    - malicious act,
    - and conditions leading to inaccessibility or unavailability of the main control room.

The accidents or events mentioned above were taken into consideration within the framework of the ten-yearly periodic safety reviews, and they led for Doel 1/2 to the implementation of specific safety systems, such as the emergency systems building (GNS) which is seismically qualified.

All Doel units have two types of safety systems: the first level safety systems intended for incidents and accidents of internal origin (e.g. a loss of primary water inventory or a secondary piping rupture) and earthquakes, and the second level emergency systems dedicated to external hazards.
The first level systems are operated from the main control room and the second level systems are operated from a separate control room.
The first level and the second level are entirely independent from one another. This applies to the electrical diesel power supplies, control rooms, water supplies, instrumentation, compressed air, primary pumps' seals injection, steam generators feedwater, shutdown cooling systems…

The table hereunder lists the specificities of the first level safety systems of Doel 1/2 units, and Doel 3 and Doel 4 units.

Table 3: First level safety systems on Doel site reactors

First level safety systems	Doel 1/2	Doel 3 and Doel 4
Physical separation	• Not all of the first level systems are physically separated, but all systems have been tested for mutual interaction (e.g. high-energy line break) so as to ensure that internal accidents would have no impact on these systems • The accidents leading to the potential unavailability of multiple safety systems are covered by the physically separated GNS (building housing the second level systems)	• The first level systems are, as a rule, physically separated.
Seismic design	• Not all of the first level systems are design basis earthquake (DBE) resistant, but all systems essential to function after the DBE have been seismically designed for the DBE • The functions that are not guaranteed, are performed from the second level (GNS)	• The first level systems are, as a rule, seismically designed for the DBE

Train design	• The first level systems with regard to electrical power supply and instrumentation are, as a rule, designed per train and the trains are mechanically linked to one another	• The first level systems are, as a rule, designed per train and these trains are not linked
Shared systems	• Many of the first level systems are shared by both units • The capacity/redundancy level of these systems is sufficient for both units	• For the Doel 3 and Doel 4 units' first level systems, there is, in addition to the already existent safety diesels, a spare backup diesel shared by both units
High pressure safety injection (SI)	• 4 high pressure injection pumps shared by the two reactors • 4 injection paths per unit: 2 injection paths on the cold legs and 2 injection paths at the top of the reactor vessel • 2 safety injection reservoirs for high and low safety injection pressure (1 reservoir per unit) • 2 accumulators per unit (1 on every cold leg) • 3 low pressure injection pumps per unit • The same pumps perform the shutdown cooling function of the unit	• 3 independent trains with: o 3 high pressure injection pumps, o 6 injection paths per unit: 2 per train, 1 on every hot leg and one on every cold leg o 3 safety injection reservoirs for high and low pressure safety injection (1 reservoir per train) o 3 accumulators per unit (1 on every cold leg) o 3 (independent) low pressure injection pumps
Containment spray system (SP)	• 4 commonly shared spraying pumps (for direct injection) • Spraying function possible via the low pressure injection circuit (during recirculation)	• 3 independent trains with three spraying pumps
Shutdown cooling system (SC)	• 3 physically separated and independently supplied pumps per unit, also performing the low pressure injection function • 2 physically separated shutdown heat exchangers per unit with potential interconnection with every one of the 3 pumps	• 3 independent trains with: o 3 shutdown cooling pumps, o 3 shutdown heat exchangers per unit, also performing the heat evacuation function during the recirculation phase
Component cooling circuit (CC)	• Shared component cooling circuit consisting of four pumps and four heat exchangers, divided into two groups	• 3 independent trains with 3 parallel and identical cooling circuits, each equipped with its own pump and heat exchanger
Electrical power supply and instrumentation	• There are 4 independent electrical polarities (2 per unit). The safety functions consisting of 3 equipments make use of the polarity of the other unit. In case a diesel is unavailable, one of the other unit's diesels will automatically take over this polarity so as to guarantee a maximum independence between the polarities. There is a limited physical separation of the electrical power supply and instrumentation cabling	• There are 3 independent, physically separated electrical polarities, 1 per train • Each train is equipped with its own independent instrumentation that is physically separated from the other trains • There is also a manual take-over possible via the backup diesel in case of a failure of a first level diesel

Fire extinction water system (FE)	• 2 pumps: one with electrical power and one with diesel supply • Non-seismic design, with exception of the filling of the second level feedwater	• 3 independent trains with seismically designed pumps with electrical power supply fed by the second level diesels
Auxiliary feedwater for the steam generators (AF)	• 3 pumps: a turbine-driven pump and two motor-driven pumps. • The amount of auxiliary feedwater is sufficient to bring both units to a cold shutdown, in which case the cooling continues via the shutdown cooling system	• 3 independent trains with a turbine-driven pump and two motor-driven pumps
Safety-related ventilation	• The ventilation for many of the safety systems is shared by both units and the 4 trains; in this case, the ventilation is single failure proof	• 3 independent trains with safety systems ventilation for each train

With regard to the accidents covered by the second level emergency systems, the following differences can be noticed:

- the second level systems at Doel 1/2 units are not housed in bunkered buildings, but there is a physical separation between the Doel 1/2 first and second level systems.
- The second level systems at Doel 1/2 units are mainly manually operated from the GNS building emergency control room, while Doel 3 and Doel 4 units benefit from a three-hour automatic (unmanned) control phase.

The table hereunder lists the specificities of the second level emergency systems of Doel 1/2 units, and Doel 3 and Doel 4 units.

Table 4: Second level emergency systems on Doel site reactors

Second level emergency systems	Doel 1/2	Doel 3 and Doel 4
Emergency feedwater for the steam generators (EF)	• One emergency feedwater circuit per unit feeding both steam generators of every unit • It is possible to feed both units with one emergency feedwater circuit of one single unit	• One emergency feedwater circuit for each of the three steam generators
Emergency component cooling (EC) and emergency cooling ponds (LU)	• The emergency component cooling circuit partially assumes the functions of the raw water and component cooling circuits • Two air coolers linked in parallel are connected to the shutdown cooling system's coolers and motors by means of two circulation pumps	• There is an emergency cooling pond circuit per unit consisting of a large cooling pond and three independent circulation pumps • There is also a backup cooling pond shared by Doel 3 and Doel 4 units • The heat is evacuated by natural evaporation of the water present in these cooling ponds
Emergency compressed air (EI and IAK)	• In case the normal compressed air supply is unavailable, the emergency compressed air circuit sends compressed air to the most important valves so that the reactor unit can be brought to a cold shutdown	• The emergency compressed air circuit consists of 3 independent emergency compressors with the corresponding distribution network

Emergency boric acid injection circuit (RJ and EA)	• The circuit also regulates the water inventory of the primary reactor cooling circuit • The circuit is strongly borated and adds boric acid in order to compensate for the added reactivity as a result of the contraction of the reactor coolant	• The circuit regulates the water inventory of the primary reactor cooling circuit • The circuit is strongly borated and adds boric acid in order to compensate for the added reactivity as a result of the contraction of the reactor coolant • The system disposes of 3 independent pumps at Doel 3 unit and of 2 independent pumps at Doel 4 unit
Emergency injection at the primary pumps' seals (RJ)	• There is an independent circuit per unit. Manual operations can be performed to enable the injection of both units' pump seals by the circuit of one single unit • There are connections with manually operated valves on every one of the two circuits • The circuit has 1 pump and 1 boric acid tank	• There are 2 volumetric pumps per unit for the intake of boric acid from an emergency boric acid tank with shared filter • The piping leading up to the containment is redundant

1.2.2. Tihange site

With respect to the initiating events considered at the design phase, there are differences between the Tihange 1 unit and the Tihange 2 and Tihange 3 units:

- partially physically separated redundant safety systems at Tihange 1,
- totally physically separated redundant safety systems at Tihange 2 and Tihange 3,
- for Tihange 2 and Tihange 3, external hazards were taken into account right from the design phase, in particular:
  - military and commercial aircraft crash,
  - large-scale fire,
  - explosion (including gas explosion),
  - malicious act,
  - and conditions leading to inaccessibility or unavailability of the main control room.

Tihange 2 and Tihange 3 both have two types of safety systems: the first level safety systems and the second level.

The differences related to the first level safety systems for each reactor are highlighted in the following table.

Table 5: First level safety systems on Tihange site reactors

First level safety systems	Tihange 1	Tihange 2 and Tihange 3
Safety injection system (CIS)	• 3 high pressure pumps (180 bar) also used as pumps in the chemical and volume control system • 3 injection accumulators of 25 m³ • 2 low pressure safety injection pumps (8 bar) that can be autonomously replaced by the 2 containment spray system pumps if unavailable • No heat exchanger on safety injection lines • 1 pool water tank	• 3 fully independent circuits • 3 high pressure pumps (120 bar) • 3 injection accumulators of 35 m³ • 3 low pressure safety injection pumps (20 bar) backed up by 3 containment spray system pumps • 3 heat exchangers for recirculation water cooling • 3 interconnected (only for Tihange 2) pool water tanks

Containment spray system (CAE)	• 6 pumps • 2 direct injection lines from the tank (with no exchanger) • 2 internal recirculation lines from the reactor building sumps (with exchangers) • 2 lines – either direct injection from the tank or recirculation from the sumps (with exchangers) – which can autonomously replace the low pressure safety injection pumps	• 3 fully independent circuits • 3 injection lines – either direct injection from the tank, recirculation from the sumps (with exchanger) – which can autonomously replace the low pressure safety injection pumps
Shutdown cooling system (RRA)	• 2 circuits with common piping parts (collectors) • Pumping in hot leg 2 and injection in cold legs 3 and 1 • The low pressure safety injection pumps can autonomously replace the shutdown cooling system pumps	• 3 fully independent circuits
Safety diesel generators	• 2 safety diesel generators • A spare back-up diesel generator can be connected to units 1, 2 or 3 should a safety diesel generator be unavailable	• 3 safety diesel generators • A spare back-up diesel generator can be connected to units 1, 2 or 3 should a safety diesel generator be unavailable
Fire water system (CEI)	• A pump that can be powered by a safety diesel generator and a thermal motor-driven pump (diesel)	• Electric pumps powered by the safety diesel generators
Auxiliary feedwater system (EAA and EAS)	• 1 turbine-driven pump (100 %) with water supply from the emergency system and 2 motor-driven pumps (2 x 50 %) powered by the safety diesel generators.	• 1 turbine-driven pump (100 %) with water supply from the emergency building and 2 motor-driven pumps (2 x 50 %) powered by the safety diesel generators.

The second level emergency systems had not been considered in the initial design of Tihange 1. However, as a result of the first periodic safety review (in 1986), an emergency system (SUR) was installed to respond to several accidental scenarios of external origin. This system includes:

- two distinct emergency power supplies (a 380 V diesel generator and a 380 V turbo-alternator),
- a water cooling circuit with two pumps drawing ground water from two different wells,
- an injection pump to the primary pumps seals.

Tihange 2 and Tihange 3 benefit from a three-hour automatic (unmanned) control phase after an accident of external origin.

The features of the second level emergency systems for Tihange 2 and Tihange 3 are highlighted in the following table.

Table 6: Second level emergency systems on Tihange 2 and Tihange 3 units

Second level emergency systems	Tihange 2 and Tihange 3
Emergency injection system (CIU)	• 3 fully independent circuits and 2 boric acid injection pumps (7 000 ppm)
Emergency injection in the seals of the primary pumps (CRU and IJU)	• For Tihange 2 and Tihange 3, the system cools the thermal barriers of the primary pumps (1 pump for each primary loop) • For Tihange 3, the system provides injection to pump seals (2 pumps 100 %)
Emergency core cooling system (CUS)	• 3 redundant circuits cooling the thermal barriers of the primary pumps and cooling the exchangers and pumps of the Emergency System and DE building

Emergency feedwater system (AUG)	• 3 circuits ensuring water supply to steam generators. Water comes from a 100 m³ tank in each circuit that can be refilled with demineralised water (from the normal water system), ground water or Meuse river water
Meuse river and ground water supplying system	• Water can be supplied by three wells or directly pumped from the Meuse river
Emergency diesel generators	• 3 emergency generators with fuel tank providing up to 7 days autonomy

1.3. Use of probabilistic safety assessments as part of the safety assessment

The probabilistic safety assessments (PSA) were started on the initiative of the licensee prior to their integration in the ten-yearly reviews. The PSA studies contain:

- level 1 PSA, determining the probability of a nuclear core melt (core damage frequency),
- level 2 PSA, calculating the probability of a release into the environment (release frequency).

The assessments cover the following nuclear power plant conditions:

- power operation,
- shutdown (shutdown cooling system connected),
- operation with low water inventory (mid-loop operation).

The PSA studies deal with events of internal origin. The considered groups of initiating events are:

- loss of primary coolant accident (LOCA),
- secondary piping ruptures (inside and outside containment),
- loss of electrical boards power (safety and non-safety, AC and DC),
- loss of offsite power (LOOP) (short and long period),
- loss of instrument compressed air,
- steam generator tube rupture, whether or not combined with secondary pipe ruptures,
- primary transients with, among other things, loss of safety cooling circuits,
- secondary transients with, among other things, loss of normal and auxiliary feed water,
- untimely signals,
- loss of the cooling system, considered as an initiating event.

The station black-out (SBO) scenario is considered through the LOOP initiating event combined with the potential failure of first level and second level diesel generators.

Probabilistic safety assessments have been initiated to evaluate the risk of fire and flooding on all Belgian units. So far, the PSA for the Belgian units have not considered any accident of external origin or initiating event related to the spent fuel pools. The failure modes of the containment building were within the scope of the PSA conducted in the 1990’s on the units Doel 1/2 and Tihange 1. Currently, a complete PSA – including fission product releases in the various failure modes of the containment building – is in progress for every representative Belgian unit.

1.4. List of acronyms

Acronym	Dutch or French meaning	Translation to English
AC		Alternating current
AF		Auxiliary Feed
AFW		Auxiliary Feedwater
ASME		American Society of Mechanical Engineers
ATWS		Anticipated Transient Without Scram
AUG	Alimentation Ultime secours des GV	Emergency feedwater system (Tihange)
B	Bâtiment bureau	Office building
B01Bi	Réservoir de remplissage piscine de Tihange 1	Refueling water storage tank (Tihange 1)
BAE	Bâtiment Auxiliaires Électriques	Electrical auxiliary services building
BAN	Bâtiments Auxiliaires Nucléaires	Nuclear auxiliary services building
BAN-D	Bâtiments Auxiliaires Nucléaires - D (D pour piscine de Désactivation)	Nuclear auxiliary services building - Spent fuel pool
BAN-N	Bâtiments Auxiliaires Nucléaires - N (N pour Normaux)	Nuclear auxiliary services building - Main
BAN-profond	Bâtiments Auxiliaires Nucléaires (unités 2 et 3)	Nuclear auxiliary services building (units 2 and 3)
BAR	Gebouw reactorhulpdiensten	Reactor auxiliary services building
BDBE		Beyond Design Earthquake
BDBF		Beyond Design Basis Flooding
BK/BKR	Bunker	Bunker
BKZ	Bunker Controle Zaal	Bunker control room
BMMT		Base Mat Melt Through
BP	Basse Pression	Low pressure
BR	Bâtiment Réacteur	Reactor building
BUR	Bâtiment d’Ultime Repli (Tihange 1)	Emergency Building (Tihange 1)
BUS	Bâtiment d’Ultime Secours (Tihange 2-3)	Emergency Building (Tihange 2-3)
CAB	Circuit d’Appoint en Bore	Boron injection system
CAE	Circuit d’Aspersion d’Enceinte	Containment spray system
CAR	Circuit d’Air comprimé de Régulation	Regulated compressed air system
CARA	Centre d’Accueil et de Repli des Awirs	Emergency and reception Centre of Awirs
CAU	Circuit d’Air Ultime	Emergency Air system
CCV	Circuit de Charge et de contrôle Volumétrique	Charging and Letdown system
CD		Cooling Diesels
CEB	Circuit d’Eau Brute	Raw water system
CEC	Circuit d’Eau de Circulation	Recirculation system
CEG	Circuit d’Eau Glacée	Cold water system
CEI	Circuit d’Eau d’Incendie	Fire water system
CEU	Circuit d’Eau Ultime (Tihange 2-3)	Emergency system (Tihange 2-3)
CEX	Circuit d’exhaure dans les bâtiments nucléaires	Draining circuit
CF	Gekoeld Water	Cooled water
CFR	Code of Federal Regulations	Code of Federal Regulations
CGCCR	Centre Gouvernemental de Coordination et de Crise	Coordination and crisiscentre of the federal government
CIS	Circuit d’Injection de Sécurité	Safety Injection System
CIU	Circuit d’Injection Ultime	Emergency injection system
CMCPB	Centre de Management de Crise Production Belgique	Crisis Management Centre Production Belgium
CMU	Circuit de Moyens Ultimes	Ultimate means circuit

CNSI		Committee on the Safety of Nuclear Installations
CNT	Centrale Nucléaire de Tihange	Nuclear power plant of Tihange
COS	Centre Opérationnel de Site	Site operation centre (Tihange)
COT	Centre Opérationnel de Tranche	Unit operation centre (Tihange)
CPR	Circuit de Protection du Réacteur	Reactor protection system
CRDM		Control Rod Drive Mechanism
CRDS		Control Rod Drive Shaft
CRI	Circuit de Réfrigération Intermédiaire	Intermediate cooling circuit
CRP	Circuit de Réfrigération Primaire	Primary cooling circuit
CRU	Circuit de Refroidissement Ultime	Ultimate cooling circuit
CTP	Circuit de Traitement des Piscines de désactivation	Spent fuel pool loop system (Tihange)
CUS	Circuit d'Ultime Secours	Emergency core cooling system
CV	Chemische en volumetrische controle	Chemical and volumetric control
CVA	Circuit Vapeur Auxiliaire	Auxiliary steam system
CVC	Circuit de Vapeur de Contournement	Steam by-pass system
CVD	Contournement Vapeur Désurchauffe condenseur (Tihange 1)	Steam by-pass system to condensor (Tihange 1)
CVP	Circuit de Vapeur Principal	Main steam system
CW		Cooling Water pipes
D	Bâtiment Désactivation	Spent fuel building
DBE		Design Basis Earthquake
DBF		Design Basis Flooding
DC		Direct Current
DD	Ontgast gedemineraliseerd water (secundair)	Degassed demineralized water (secundary)
DE	Bâtiment entreposage des assemblages de combustible usé	Building for wet storage of spent fuel (Tihange)
DG	Dieselgroepen	Diesel groups
DUR	Diesel d'Ultime Repli (Tihange 1)	Emergency diesel (Tihange 1)
DW	Ontgast gedemineraliseerd water (primair)	Degassed demineralized water (primary)
EA	Nood-boorzuur injectiekring	Emergency boric-acid injection circuit
EA	Espace annulaire	Annulus space
EAA	Eau Alimentaire Auxiliaire (Tihange 2-3)	Auxiliary feedwater system (Tihange 2&3)
EAN	Eau Alimentaire Normale	Main feedwater system
EAS	Eau Alimentaire de Secours (Tihange 1)	Auxiliary feedwater system (Tihange 1)
EC		Emergency component cooling
ECA		Emergency Contingency Actions
ECOS		Emergency Call Out System
ED	Emergency Dieselgroepen	Emergency Diesel groups
EDMG		Extensive Damage Mitigating Guidelines
EDN	Eau Déminéralisée Normale	Demineralized water
EF		Emergency Feedwater
EF2	Vitesse sur échelle Fujita entre 50 m/s et 60 m/s	Windspeed between 50 m/s and 60 m/s on Fujita tornado scale
EF3	Vitesse sur échelle Fujita entre 61 m/s et 75 m/s	Windspeed between 61 m/s and 75 m/s on Fujita tornado scale
EF4	Vitesse sur échelle Fujita entre 75 m/s et 89 m/s	Windspeed between 75 m/s and 89 m/s on Fujita tornado scale
EI		Emergency compressed air
ENSREG		European Nuclear Safety Regulators' Group
EOP		Emergency Operations Procedures
EPA	Circuit d'Échantillonnage du liquide Post-Accidentel	Post Accidental Liquid sampling system

EPRI		Electric Power Research Institute
EQE		European Qualifying Examination
ERF		Emergency Response Facility
ERG		Emergency Response Guidelines
EV		Emergency Ventilation
EW	Extractie water	Extraction Water
FE		Fire water system
FR	Filter	Filter
FRG		Function Restoration Guidelines
FR-C		Function Restoration core Cooling
FROG		FRamatome Owner Group
GBR	Échantillonnage des Gaz dans le Bâtiment Réacteur	Gas sampling in the reactor building
GCH	Échantillonnage rejet atmosphérique (Gaz CHeminée)	Atmospheric releases sampling (gas chimney)
GDR	Groupe Diesel de Réserve	Back-up diesel group
GDS	Groupe Diesel de Secours	Safety diesel group
GDU	Groupe Diesel Ultime (Tihange 2-3)	Emergency diesel group (Tihange 2-3)
GMH	Gebouw Mechanische Hulpdiensten	Mechanical auxiliary services building
GNH	Gebouw Nucleaire Hulpdiensten	Nuclear auxiliary services building
GNS	Gebouw voor de Nood Systemen (Bâtiment d'ultime secours Doel 1-2)	Emergency systems building
GRC	Groupe Diesel de réserve circuit de combustible du GDR/M03	Fuel system back-up diesel group of GDR/M03
GSC	Groupes Diesel de secours circuit de combustible	Fuel system emergency diesel group
GUS	Groupe turbo-alternateur d'Ultime Secours (Tihange 1)	Emergency Turbo Alternator (Tihange 1)
GV	Générateur de Vapeur	Steam Generator
GVD	Gebouw volledige Demineralisatie	Complete demineralization building
HCLPF		High Confidence, Low Probability of Failure
HKZ	Hoofdcontrolezaal	Main control room
HP	Haute Pression	High Pressure
IAEA		International Atomic Energy Agency
IA-IAK		Emergency compressed air
IDF	Intensité-Durée-Fréquence	Intensity-Duration-Frequency
IJU	Injection aux Joints Ultime (Tihange 3)	Emergency injection in primary pump seals (Tihange 3)
IPS	Important Pour la Sûreté	Relevant to safety
IRE	Institut National des Radioéléments	National institute for radioelements (Belgium)
IRM	Institut Royal Météorologique	Royal metrological institute of Belgium (ROB)
IS	Injection de Sécurité	Safety injection system
ISBP	Injection de Sécurité Basse Pression	Low pressure safety injection system
ISHP	Injection de Sécurité Haute Pression	High pressure safety injection system
ISLOCA	Interfacing System Loss Of Coolant Accident	Interfacing System Loss Of Coolant Accident
JCO	Justification for Continued Operation	Justification for Continued Operation
K	Bâtiment des pompes EAA	Building for EAA pumps
KD	Bunker/gelijkstroomnet	Bunker/direct current
KVR	Koelvijver	Emergency cooling ponds
KZ	Controlezaal	Control room
LDSI	Lage Druk Safety Injection	Low pressure safety injection
LOCA		Loss Of Coolant Accident
LOOP		Loss Of Offsite Power
LPA	Liquide Post-Accidentel	Post Accident Liquid
LTO		Long Term Operation
LU	Koelvijver	Emergency cooling ponds

LUHS		Loss of Ultimate Heat Sink
MORV		Motorised Operated Relief Valve
MPA	Moto Pompe Alimentaire (Tihange 2-3)	Feedwater motor pump
MSK	Medvedev-Sponheuer-Kamik schaal	Medvedev-Sponheuer-Kamik schale (for earthquakes)
MTU	Alimentation électrique Ultimes Secours	Emergency electrical supply
MW	Niet-ontgast gedemineraliseerd water	Non-degassed demineralized water
MW		Megawatt
MWP	Gebouw pompkelder	Building with basement for pumps
N	Bâtiment des auxiliaires nucléaires	Nuclear auxiliary services building
NA		Not applicable
NEI		Nuclear Energy Institute
NKZ	Noodcontrolezaal	Emergency control room
NP	Noodplan	Emergency Plan
NPK	Noodplankamer	Emergency operations facility Doel
NPP		Nuclear Power Plant
NPSH		Net Positive Suction Head
NRC		Nuclear Regulatory Commission
NUREG		Nuclear Regulatory Group
O	Bâtiment stockage fuel GDU	Fuel stock building GDU
OBE		Operating Basis Earthquake
OTSC		On-Site technical Support Center
OVG	Ondergrondse Verbindings-Galerij	Subterranean connection duct
P	Station de pompage	Pumping station
PAMS		Post-Accident Monitoring System
PAR	Passive Autocatalytic Recombiner	Passive Autocatalytic Hydrogen Recombiner
PB	Boorzuurbereidingskring	Boric-acid preparation system
PCA	Piège à Charbon Actif	Activated carbon filter
PED	Circuit de Production d'Eau Déminéralisée	Demineralized water production system
PGA		Peak Ground Acceleration
PIS	Pompe d'Injection de Secours (Tihange 1)	Emergency injection pump (Tihange 1)
PIU	Plan Interne d'Urgence	Emergency plan (interal)
PL		Pool Loop
PORV		Pressurized Operated Relief Valve
PORV		Power Operated Relief Valve
PP		Pump
PR		Pressurizer
PR	Panneau de Repli	Panel for emergency situations
PS	Primaire Staalname	Primary sampling
PSA		Probabilistic Safety Assessment
PSHA		Probabilistic Seismic Hazard Analysis
PU	Zuivering primaire kring	Purification of primary circuit
PUR	Panneau d'Ultime Repli (Tihange 1)	Panel for emergency situations (Tihange 1)
PWR		Pressurized Water Reactor
PWROG		PWR Owners Group
RC	Reactorkoeling	Reactor Coolant System - Primary Circuit
RF	Résistant au Feu	Fire Resistant
RG		Regulatory Guide
RGB	Reactorgebouw	Reactor building
RJ	Noodkoelsysteem dichtingen primaire (RC) pompen	Emergency cooling system of primary pumps seals
RLE		Review Level Earthquake
RM		Radioactivity Monitoring

RN	Koeling CCW-kring (WAB)	Cooling CCW system (WAB)
ROB		Royal Observatory of Belgium
RPP	Circuit de Régulation de Pression Primaire	Control system of primary pressure
RR		Reservoir
RRA	Refroidissement Réacteur à l'Arrêt	Shutdown cooling system
RS	Rapport de sûreté	Safety case
RTGV	RuptureTube Générateur de Vapeur	Steam generator tube rupture
RW	Ruw-Waterkring	Raw water system
RWST		Refueling water storage tank
SAM		Severe Accident Management
SAMG		Severe Accident Management Guidelines
SBO		Station Black-Out
SC	Stilstandskoeling	Shutdown cooling system
SCG	Splijtstof Container Gebouw	Spent fuel container building
SCK-CEN	Centre d'Étude de l'Énergie Nucléaire/Studiecentrum voor Kernenergie (Mol)	Belgium Nuclear Research Centre (in Mol)
SEBIM	Type gepiloteerde veiligheidsklep	Type of pressurizer relief valve
SETHY	Service d'Études HYdrologiques de la Région Wallonne	Water studies department in the walloon region
SEU	Circuit d'Eau Ultime des piscines du DE	DE pools Emergency Water System
SEX	Circuit d'exhaure du bâtiment DE	DE building exhaust System
SFP		Single failure Proof
SG		Steam Generators
SGH	Simpson, Gumpertz & Heger	Simpson, Gumpertz & Heger
SI	Veiligheidsinjectie	Safety Injection
SMA		Seismic Margin Assessment
SMR		Seismic Margin Review
SOER		Significant Operating Experience Report
SP	Sproeikring reactorgebow	Spray System of Reactor Building
SPG	Splijtstofgebouw	Spent fuel building
SQUG		Seismic Qualification Utility Group
SRI	Circuit de réfrigération intermédiaire du bâtiment DE	Intermediate pool cooling circuit of DE building
SSC		Structures, Systems and Components
SSE		Safe Shutdown Earthquake
STP	Circuit Traitement d'eau des piscines du DE	DE pools Water Treatment System
SUR	Système d'Ultime Repli (Tihange 1)	Emergency system (Tihange 1)
TAc	Tableau d'alimentation du contrôle-commande (115 V DC)	Control and Monitoring supply Panel (115 V DC)
TAm	Tableau d'alimentation moyenne tension (380 V AC)	Medium Voltage Panel Supply (380 V AC)
TAr	Tableau d'alimentation à tension régulée (220 V AC)	Supply Panel with Regulated Voltage (220 V AC)
TAW	Tweede Algemene Wateraanpassing	Represents the reference level in which height measurements are expressed. A TAW-height of 0 metre equals the sea level at low tide in the city of Oostende, Belgium
TEF	Traitement des Effluents	Effluents Treatement
TEG	Traitement des Effluents Gazeux	Gaseous Effleunts Treatment
TPA	Turbo Pompe Alimentaire (Tihange 2-3)	Feedwater turbo pump
TPA EAA	Turbo Pompe Alimentaire Eau Alimentaire Auxiliaire	Auxiliary Feedwater turbo pump

TPS	Turbo Pompe de Secours (Tihange 1)	Emergency feedwater turbo pump (Tihange 1)
TS		Technical Specifications
TUR	Tussenruimte reactorgebouw	Annulus space containment building
TW	Stadswater	Surface water in urban areas
UCL	Université Catholique de Louvain	Catholic University of Leuven
ULg	Université de Liège	University of Luik/Liege
USNRC		United States Nuclear Regulatory Commission
VAN	Ventilatie gebouw nucleaire hulpdiensten (GNH) - niet-veiligheidsdeel	Ventilation system of nuclear auxiliary services building - not safety related
VAS	Ventilatie gebouw nucleaire hulpdiensten (GNH) - veiligheidsdeel	Ventilation system of nuclear auxiliary services building - safety related
VBA	Stoomontlastingsklep	Steam relief valve
VBP	Ventilation BAN Piscine de désactivation	Ventilation Spent fuel pools of Nuclear auxiliary services building
VBR	Ventilation Bâtiment Réacteur (Tihange 2-3)	Ventilation of reactor building (Tihange 2&3)
VBU	Ventilation Bâtiment Ultime	Emergency Reactor Building Ventilation
VC	Ventilatie Reactorgebouw	Ventilation system of reactor building
VDA	Atmosferische ontlastingsafsluiters	Atmospheric Relief valves
VDA	Vannes de Décharge à l'Atmosphère	Atmospheric Relief valves
VDE	Ventilation bâtiment DE	Ventilation system of DE building
VE	Ventilatie Electrische hulpdiensten	Ventilation system of electrical auxiliary services (building)
VEA	Ventilation Espace Annulaire	Ventilation system of annulus space
VEE	Ventilation Enceinte Étanche (Tihange 1)	Ventilation system of containment building (Tihange 1)
VEN	Ventilatie Electrische hulpdiensten (GEH) - niet-veiligheidsdeel	Ventilation system of electrical auxiliary services building - not safety related
VES	Ventilatie Electrische hulpdiensten (GEH) - veiligheidsdeel	Ventilation system of electrical auxiliary services building - safety related
VF	Ventilatie splijtstofgebouw	Ventilation of spent fuel building
VH	Ventilatie gebouw mechanische hulpdiensten	Ventilation of mechanical auxiliary services building
VI	Ventilatie tussenruimte en waterbekkens reactorgebouw	Ventilation of annulus space and reactor building pools
VK	Ventilatie Bunker	Ventilation of Bunker
VLE	Ventilation des Locaux Électriques	Ventilation of electric rooms
VP	Ventilatie Controlezaal	Control Room Ventilation
W	Bâtiment BUS	Emergency Building
WAB	Water- en AfvalBehandelingsinstallatie	Water and waste treatment building
WANO		World Association of Nuclear Operators
WENRA		Western European Nuclear Regulators' Association
WOG		Westinghouse Owners Group - (renamed PWR Owners Group or PWROG)
WVP	Watervang Pompstation Doel 3&4	Water intake of pumpingstation Doel 3&4
Z	Espace annulaire	Annulus space containment building

2. Earthquake

In order to provide a self-standing national report for the subsequent peer review process, first the relevant information supplied by the licensee in its stress tests reports is recalled.
At the end of this chapter, a final section provides the conclusions and the assessment of the Belgian regulatory body (FANC and Bel V).

2.1. Design basis

2.1.1. Earthquake against which the plants are designed

2.1.1.1. Characteristics of the design basis earthquake (DBE)

The seismic activity in north-western Europe is low. Nevertheless, the installations in Tihange and Doel are designed to withstand an earthquake of greater intensity than the seismic potential of this zone.

Tihange site

The examination of the geological and seismotectonic environment of the Tihange site was conducted over an area covering a radius of 320 km around the site. From a geological viewpoint, the Tihange site is situated on the northern edge of the Ardennes Massif. The site of Tihange is located in the floodplain on the right bank of the river Meuse. Detailed studies have also demonstrated that the composition of the soil cannot correspond with a fault line that runs across the site.

Tihange 1 was designed to withstand a DBE characterized by a peak ground acceleration of 0.1g. In accordance with the regulatory practice in the nuclear industry (10 CFR 100, IAEA 50-SG-S1) at the time, this value was determined by applying a deterministic approach. This seismic level also corresponds to the standard minimum recommended by the regulations applicable at the time of construction of Tihange 2 and 3.

A new assessment of the seismic level during the first Periodic Safety Review of Tihange 1 (1985) raised the peak ground acceleration of the DBE to 0.17g for all three units in Tihange. This re-evaluation took place after construction of Tihange 1 and during construction of Units 2 and 3. Modifications at that time allowed an effective increase.

Doel site

The site of Doel is located on the left bank of the river Scheldt. From a geological viewpoint, the Doel site is part of the London-Brabant Massif. The Brabant Massif is bounded by a coal field to the north, east and south. This field separates the massif from the Lower Rhine rift to the north, the Ardennes Massif to the southeast, and the Paris Basin to the south and southwest.

During design of Doel 1&2, the Doel site was considered to be non-seismic. As a result, the original design of the two units did not take into account the risk of an earthquake. At the time of the first Periodic Safety Review (1985) it was nevertheless decided to incorporate the risk of an earthquake. The PGA of the DBE for Doel 1&2 was subsequently set at 0.058g.

In accordance with the regulatory practice, a DBE of 0.1g was used for the design of Doel 3&4.

2.1.1.2. Methodology used to evaluate the design basis earthquake

Two different deterministic approaches were used to define the DBE of the Doel and Tihange NPPs.

The seismotectonic deterministic method:

- Definition of seismic source parameters: splitting Belgium into different seismic zones and list all earthquakes ever occurred ;

- Take the strongest earthquake by zones and assume conservatively that earthquake would occur on the site itself or in the immediate vicinity of the seismic zone of the site.
- The intensity of the DBE on site is obtained from an attenuation law, giving intensity as a function of magnitude and distance.

An alternative historical deterministic method:
- Determine the maximum intensity ever observed near the site resulting of an earthquake;
- Add a safety margin corresponding to one degree of intensity.

For both deterministic approaches, the peak ground acceleration is given by correlation curves between intensity and peak ground acceleration

Tihange NPP

Both deterministic approaches yielded the same result, namely an earthquake of an intensity of VII on the MSK scale. The peak ground acceleration corresponding to this intensity was 0.1g, by using Medvedev correlation curves.

For the first Periodic Safety Review of Tihange 1 (1985) new regulatory guides recommended a different scheme of attenuation. This recommendation prompted the licensee to consider a maximum earthquake on the Tihange site of VII 1/2 on the MSK scale. The use of intensity-acceleration correlation curves prescribed in the document NRC - NUREG-0143 resulted in an upgrading of the peak ground acceleration of the DBE from 0.1g to 0.17g.

The horizontal response spectrum, at ground level of the Tihange site was determined for the DBE by compilation of seismic recordings taken on comparable sites.

Doel NPP

The earthquake with the greatest impact on Doel so far is the Zulzeke-Nukerke earthquake (1938): the epicentre was located approximately 75 km from the site. This earthquake is the most relevant in historical terms, reaching the highest intensity and was taken as reference point in the design phase. The tremor had a magnitude of 5.6 on the Richter scale and was observed in Doel with an intensity of V on the MSK scale.

Both deterministic methods were applied for the Doel site based on that earthquake. They both produced approximately the same result. The highest value for the PGA was finally taken into account for the site. The corresponding horizontal acceleration at ground level for the frequencies ≳33 Hz amounts to 0.058g.

Response spectrum was then determined taking into account the specific properties of the subsoil in Doel. This site-specific spectrum was adopted as the basis for checking the seismic capability of structures. As already mentioned,a higher PGA of 0.1g was applied for Doel 3&4.

2.1.1.3. Conclusion on the adequacy of the design basis for the earthquake

Within the framework of additional safety evaluations conducted following the incident in Fukushima, and in order to assure the validity and updated character of the seismic data, the licensee requested the Royal Observatory of Belgium (ROB) to conduct a new study of seismic risk based on a probabilistic seismic hazard analysis (PSHA) taking account of the most recent information and data.

In recent years two developments have taken place in relation to defining the seismic risk:
- with regard to the knowledge of the seismic risk in Belgium, the earthquake in Verviers (1692) was charted and more accurately studied;
- with regard to the method used for establishing the seismic risk, the probabilistic method is being used more and more. By doing this, all historically known earthquakes of significance to the site are taken into consideration. This way the most recent knowledge of the seismic zones in and around Belgium is used.

The probabilistic study from the ROB gives firstly the acceleration in function of exceedance rate and secondly the uniform hazard spectra.

Tihange NPP

The probabilistic study by the ROB established the seismic level, expressed in terms of peak acceleration and spectrum at bedrock level (near the surface in Tihange). The maximum accelerations at that depth are:

- 0.064g for an earthquake with a return period of 1,000 years (84th percentile) ;
- 0.21g for an earthquake with a return period of 10,000 years (mean value).

For a period of 100,000 years the median value is less than 0.21g. Most penalizing value was chosen, i.e. 0.21g on the bedrock.

The current design seismic levels of the three units in Tihange were compared with those deduced from this new ROB study of seismic hazard in Belgium. With the comparison being made at ground level, the ROB data is translated in terms of PGA and response spectrum at ground level of the Tihange site, taking into account the specific characteristics of the soil.
The PGA calculated by the ROB on the bedrock was increased to 0.23g on the surface (10% margin) to allow for ground amplification. The new site spectrum gives a peak ground acceleration of 0.23g and the spectral form of the earthquake to the site is preserved by applying an amplification factor of 2.64 (considered to be conservative, expressed at 84% confidence).

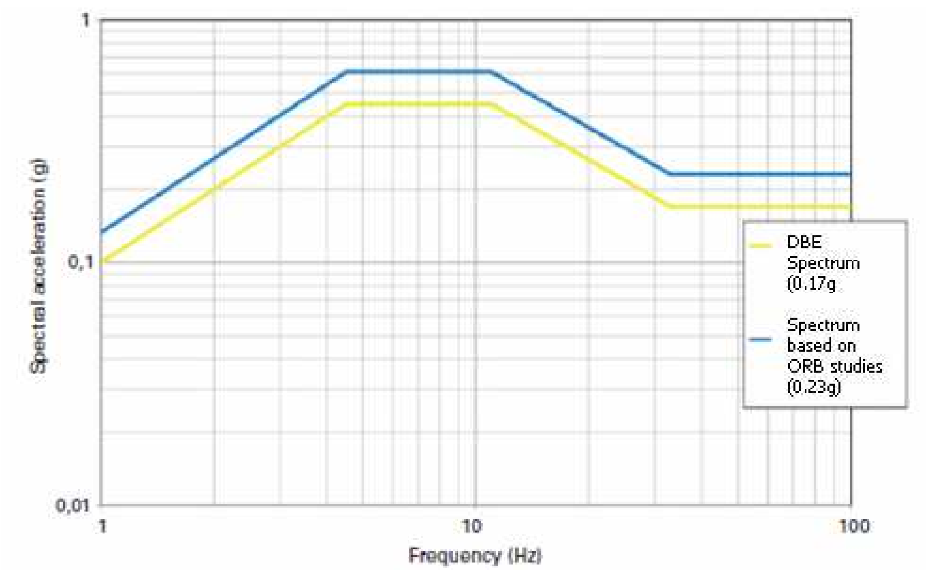

Figure 5 - Comparison of the design spectra of the three Tihange units with the new site spectrum deduced from the ROB study

It should be noted that the difference between the new spectrum, derived from the ROB study, and the DBE is very limited with regards to the margins taken in the initial calculations. In fact, the design assumptions are those required by the applicable construction codes; these requirements are recognized as conservative, especially in the nuclear domain, where the demands greatly exceed those of the Eurocodes.

The spectrum deduced from the preliminary ROB study slightly exceeds the DBE for the Tihange units but this does not have any consequences for the following reasons:

- being qualified for a DBE based on methods considered as being conservative, and bearing in mind the design practices inherent in the conception of nuclear structures, the great majority of structures, systems and components keep their qualification for the earthquake deduced in the ROB study;
- the evaluation of the margin based on the SMA methodology, conducted as part of this exercise and described later, confirms this result.

Nevertheless, a more detailed and complete seismic hazard analysis for the Tihange site will be conducted and will allow conclusions with regard to the adequacy of the DBE.

Doel NPP

The probabilistic study conducted by the ROB determined how great the seismic level is expressed in terms of maximum acceleration and spectrum at a depth of approximately 600 m (bedrock). The maximum accelerations at that depth are:

- 0.053g for an earthquake with a return period of 1,000 years (mean value),
- 0.146g for an earthquake with a return period of 10,000 years (mean value).

The maximum accelerations of the earthquake of which it can be said with 84% certainty that they only occur once every 10,000 years, as well as the 'median' values for 100,000 years, are both lower than 0.146g.

The most penalising value of the maximum acceleration at bedrock level, i.e. the mean value for 10,000 years, was rounded up to 0.15g and surface response spectrum was obtained with the site transfer function. The response spectrum used was coming from the US NRC R.G. 1.60. This then allowed making a comparison with the corresponding values in the design basis. The illustration below demonstrates the results:

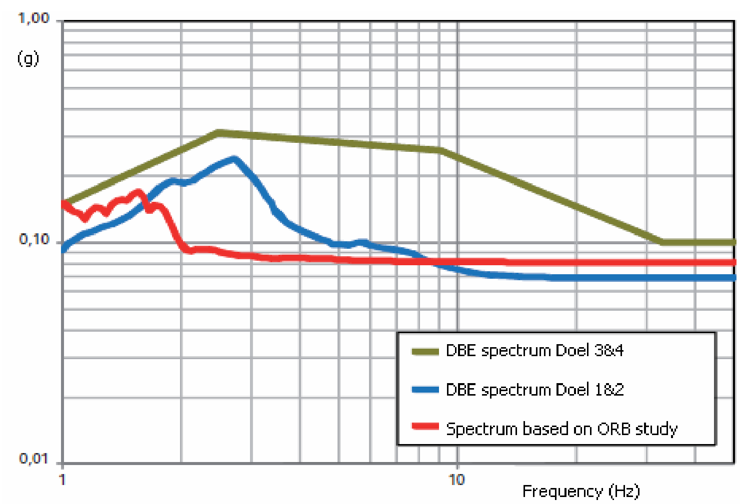

Figure 6 - Spectrum at ground level based on the ROB study and the design spectrum of Doel 1&2, Doel 3 and Doel 4.

- The frequencies to be considered in order to evaluate the resistance of the buildings are between 1.5 and 5 Hz. In this range, the new evaluation produces a substantially lower value for the acceleration at ground level than those taken into account in the design of Doel 1&2 and Doel 3&4;
- Higher frequencies are significant for the equipment inside buildings. The new evaluation gives a PGA of 0.081g. This value is slightly higher than the design values of Doel 1&2 and lower than the design values of Doel 3&4. This small difference is of little significance for the real seismic resistance of the equipment in the case of such an earthquake. All seismically qualified equipment is, after all, designed and constructed with due observance of extensive safety factors. This was confirmed by the SMA study that evaluated the integrity of the relevant equipment at an acceleration of 0.3g.

2.1.2. Provisions to protect the plants against the design basis earthquake

2.1.2.1. Structures, systems and components necessary for stable, controlled shutdown and remaining available after the earthquake

Tihange NPP

Buildings and structures

Buildings and structures protect the following systems against externally induced accidents:

- primary system;
- spent fuel stored on the site;
- tanks containing gaseous effluents;
- systems that ensure a safe reactor shutdown in case of unavailability of the normal shutdown systems.

These structures are seismic category 1 buildings according to RG-1.29 (revision 2, February 1976). They are therefore designed to withstand the DBE.

Systems

To ensure a safe shutdown of the unit and its maintenance in a stable and controlled state, the following systems that provide the vital functions must be capable of withstanding a DBE:

- core cooling system: primary system (and by the EAS/EAA feeding the steam generator, and the AUG for the second level of Tihange 2&3);
- reactivity control: CCV, CIU (second level Tihange 2) and IJU (second level Tihange 3);
- primary pressure control: CCV - CIS - RPP ;
- core inventory control: CCV, CIU (second level Tihange 2) and IJU (second level Tihange 3) ;
- removal of residual heat: RRA - CRI - CEB backed up by the groundwater circuit (Tihange 1) or second-level systems RRA-CRU-CEU (Tihange 2 &3).

Furthermore a seismic capability is also required for the safety systems performing the following functions:

- safety injection system: CIS ;
- containment spray system: CAE;
- depression and filtration of the annular space: VEA;
- isolation of the reactor building;
- inhabitability of the control room: CSC;
- inhabitability of the BUS control room situated in the reinforced building in case of unavailability of the normal control room of Tihange 2 or 3.

In order to guarantee the safety of the fuel stored in the pools of the reactor units, the pool cooling function is also guaranteed in case of a DBE.

In accident conditions it is also necessary to measure and control the radioactivity. The following systems enable this control: CEN-LPA, GBR and the VBP chains (for Tihange 1) and EPA, GBR, GCH (for Tihange 2&3). This allows generating reliable information on potential releases of radioactivity into the environment.

All these systems or the parts of these systems that have to function in case of an accident are designed as seismic category 1 and are located in the interior of seismic category 1 structures. The ventilation/cooling of certain safety equipment is vital for their good functioning.
It is also necessary to keep environmental conditions within the limits defined for the habitable zone. For these reasons the following systems are likewise qualified or partially qualified for withstanding a DBE: VEA, VLE, CSC, VBP and ventilation of the BUR.

The first periodic safety review of Tihange 1 (1985) resulted in the definition of an emergency system to manage events not taken into consideration in the initial design of the electric building of the reactor. This is the Emergency System (*Système d'Ultime Repli* - SUR) which represents an extra level of protection for Tihange 1.

Control-Command

The control room and the BUS control room (for Tihange 2&3) and its panels, desks, instrument cabinets and switch cabinets assure the remote command and control of all the required systems previously mentioned. They are therefore also qualified to withstand a DBE level earthquake.
These control and command systems ensure the automatic protection of the reactor in normal operating conditions, and the actuation of the safety systems and their auxiliary systems.

Electrical systems

In the event of total loss of offsite power supply, autonomous production sources consisting of electricity generators with GDS diesel engines are used.
In case of loss of this first level of protection, a second completely independent level of electrical power supply (three GDU diesel engine generators per unit) powers the second-level emergency equipment of Tihange 2&3. For Tihange 1, a turbine-type generator driven by secondary steam (*groupe d'ultime secours* - GUS) and a diesel generator *(diesel d'ultime repli* - DUR) constitute an emergency power source.
A back-up diesel generator (*Groupe Diesel de Réserve* - GDR), present in Tihange 2, offers additional back-up available for the three units. In fact it can replace one of the diesels (GDS) of each of the units.
The GDS, GUS, GDR and DUR generators are qualified as seismic category 1 and are likewise located inside seismic category 1 structures.

DE Spent fuel pool building

The spent fuel elements from the three units on the Tihange site that have been unloaded for at least two years are stored under water (in pools) in the DE building for "intermediate storage of spent fuel". This too is a seismic category 1 structure.
The circuits of the DE building, that is, the spent fuel pool cooling (STP, SRI and CRI), the ventilation of the building (VDE) and the isolation of the draining circuit (SEX/CEX) are designed according to the same bases and by applying the same rules as those used for the corresponding systems of Tihange 3. For these systems the fitness for functioning of the active pumps, active valves and their motors or actuators, and their respective vital fixtures and mountings is demonstrated. The instrumentation and equipment of the DE building is classified 1E.

Doel NPP

For both Doel 1&2 and Doel 3&4 the required structures, systems and components that are essential for a safe shutdown are categorised as seismic category I.

<u>Doel 1&2</u>

The General Design Criterion 2 of 10 CFR 50 (appendix A) requires structures, systems and components that are of significance for safety to be designed in such a way as to provide for resistance to natural phenomena. Their safety function may not be compromised under any circumstances.

These structures, systems and components are classified as seismic category I and are designed in accordance with the seismic criteria applicable for that category.
In the design of Doel 1 and 2, the seismicity of the area was considered to be too low for it to be taken into account. As a result of the First Periodic Safety Review (1985), the risk of earthquakes was examined once again. The decision was taken at that time to

- consider a reference earthquake (DBE with PGA of 0.058g);
- provide for the necessary means to enable critical safety functions to be guaranteed if such an earthquake was to occur.

Building structures

The resistance of the reactor building (RGB), the reactor auxiliary services building (BAR) and the nuclear auxiliary services building (GNH) to the DBE were calculated based on a mathematical model of the buildings. The calculations showed that the buildings can withstand a DBE.

Systems
The safety systems required to carry out a safe shutdown of Doel 1&2 guarantee that the following functions are maintained:

- removal of residual heat, including cooling of the primary circuit by the secondary circuit;
- preserving the subcritical state of the reactor, also when proceeding with and during cold shutdown;
- monitoring the water balance in the primary circuit;
- monitoring the pressure in the primary circuit.

These functions make it possible to carry out an instant hot shutdown and maintain that state. Proceeding with and maintaining the cold shutdown will be possible over the longer term. These functions also permit removal of the heat from a unit already in a cold shutdown state at the moment of the earthquake (heat removal via the SC-system).

An additional safety function concerns the cooling of the spent fuel pools in the nuclear auxiliary services building (GNH).

For each unit, the emergency systems building (GNS) contains a number of additional provisions which make it possible to bring the units into a safe shutdown mode after an earthquake.
These emergency systems comprise per unit:

- an emergency feedwater circuit (EF);
- an emergency injection system for the seals (RJ) of the primary pumps which also makes it possible to monitor the water balance in the primary circuit and the reactivity of the reactor;
- a number of support systems: compressed air (EI), ventilation (EV), cooling of the equipment (EC circuit that can take over the function of the CC circuit), electrical supply by diesel generators (ED) and batteries, instrumentation;
- an emergency control room (NKZ) that enables the monitoring of all the emergency systems;
- an emergency cooling for the spent fuel pools (PL circuit).

A number of the existing systems was also seismically qualified in order to guarantee the ability to bring the units in hot shutdown mode and subsequently the cold shutdown mode in response to an earthquake and to guarantee ability to cool the spent fuel pools. These systems are:

- the primary circuit, down to and including the second active isolation element of the first passive, normally closed isolation element;
- the secondary circuit, from the steam generators up to and including the first isolation element, with the aim to maintaining the integrity of this part of the circuit;
- residual heat removal circuit (SC) – for removing residual heat over the longer term;
- the cooling circuit of the spent fuel pools (PL) – for removal of residual heat;
- (parts of) systems and equipment, the failure of which can, as the result of an earthquake, cause damage to the above mentioned systems and equipment.

Maintaining the water inventory in the primary circuit as well as cooling and removing the residual heat can therefore be ensured by seismically qualified systems and equipment. These systems and equipment have been qualified against the DBE during the first Periodic Safety Review (1985).

Electrical equipment
The electrical equipment under category 1E (according to the definition in norm IEEE 323-1974) needed to support the systems referred to above is resistant to earthquakes.

<u>Doel 3&4</u>
Depending on the cause of an incident – internal or external – a different safety level comes into effect.

- the first level (safety equipment) protects the environment against any incident caused within the installations;
- the second level (emergency equipment) protects the environment against any incident caused outside the installations.

The structures, systems and components of both levels are designed in such a way that their safety function remains intact after an earthquake. These SSC's can withstand the consequences of a DBE and also comply with the standards of seismic category I according to RG 1.29.

Building structures
Specific safety functions have been assigned to the building structures of the first safety level: leak tightness, biological shielding, protection against projectiles of an internal origin,etc…
The building structures of the second safety level provide protection for the primary circuit, the nuclear fuel stored in the power station as well as the other systems of the second level.
All these structures are classified under seismic category I.

Systems
The systems of the first safety level have the following functions:
- cooling the core (ECCS);
- borating the primary circuit (injection of boric acid);
- safeguarding the integrity of the containment;
- maintaining habitability of the control room.

In the case of an incident with an external cause, the systems of the second safety level ensure the cooling of the core.

Electrical equipment
The electrical equipment under category 1E are subjected to a qualification program in which the seismic properties and environmental factors are examined.

<u>Spent Fuel Container Building</u>
The spent fuel is stored in leak tight containers in the Spent Fuel Container Building (SCG).
The containers were designed in accordance with the requirements of IAEA Safety Series no. 6 of the Safety Standard Series No. TS-R-1.
The seismic spectra taken into account are those for the Tihange site, which means that the containers can also be used there. The applicable values – 0.17g horizontal acceleration, 0.11g vertical acceleration – are higher than those necessary for the Doel site.

2.1.2.2. Main operating dispositions

<u>Instructions after Earthquake</u>
On both the Doel and Tihange site the EPRI (Electric Power Research Institute) guidance has been used to define, after an earthquake, the shutdown requirements, the conditions of restart and the long-term action to be taken to ensure that the unit can continue to function at the level of safety required by the design basis. As required by regulation (10 CFR 100), the sites are equipped with adequate instrumentation allowing rapid assessment of the intensity of the earthquake and to decide whether the NPP is able to continue to function safely.
The Tihange procedures for post-earthquake action are in compliance with the EPRI Guides. Formalised by command instructions for each unit (incident procedure in Tihange 1), they set out the appropriate actions staggered over time. Doel 1&2 and Doel 3&4 have a specific procedure 'actions after an earthquake' that is based on 10CFR50, app. S (92) and the EPRI guidelines.
The instructions are described in procedures depending on the initial state of the reactor unit when an incident occurs. The unit may in fact be in normal operation (or in hot shutdown), in intermediate shutdown or in cold shutdown (RRA connected). The shift crew teams are trained to follow these post-accidental instructions.

Internal emergency plan
The Doel and Tihange NPPs have an internal emergency plan that is flexible enough to counter any incident which could threaten the safety of the installations or persons or which could have an impact on the environment.

Operational procedures
The purpose of these operational procedures is to lay down elementary rules of best practice in order to control/eliminate temporary seismic interactions during each operation. The personnel is trained to pay particular attention to avoid undermining the seismic qualification of equipment through changing their environment:

- temporarily by introducing the tools, machinery, etc., necessary for the execution of their tasks (scaffolding, ladders, step ladders, etc.);
- permanently be leaving any non-fixed object in the proximity of a safety device.

On their daily rounds the operations supervisors will also check that no material installed/placed near safety equipments can adversely affect these equipments by falling, collapsing, shifting or toppling over.

Mobile equipment
Doel and Tihange are able to cope with the DBE without having to use mobile devices. The licensee, nevertheless, keeps a number of devices on standby for the purpose of mitigating the residual risk in the unlikely case that the safety systems of both the first and the second group fail.

- electrical power supply cables;
- mobile compressor;
- mobile diesel pump.

2.1.2.3. Indirect effects of earthquakes taken into account during design

Tihange NPP

The studies conducted in the framework of seismic margin assessment show that the systems mentioned in the earlier paragraphs allow the shutdown of the unit in the following scenarios:

- a breach of the dam caused by an earthquake;
- an earthquake combined with a Loss of Offsite Power (LOOP).

They also allow, in each of these scenarios, the management of internal flooding following an earthquake.

Internal flooding
During the second Periodic Safety Review (1995) a study was conducted to analyse the effects of an internal flood in the buildings containing safety equipment. SQUG inspections (Seismic Qualification Utility Group) were organized for the unclassified pipework (medium energy lines) to ensure that pipes will not rupture as a result of the DBE.
Building N in Tihange 1, buildings Z, P, O, B, D, N, W, galleries K, BAE, GDS/GDR in Tihange 2 and buildings BAE, W, K, B, P and galleries in Tihange 3 have had SQUG inspections. A study of the consequences of an internal flood has been conducted for the non-seismic buildings.

It may be concluded that, for the buildings inspected according to the SQUG method, an internal flood following an earthquake would not represent any hazard. For the other buildings the most critical scenario - that is to say, a break in a CEC pipe in the machine room - has not been studied in any great depth but, given the speed of flow compared with the surface and the volume of the building, the alarms should allow the shift crew teams to react rapidly in order to avoid damage to important equipment.

External flooding
An assessment of potential flooding was conducted on the Tihange site taking into consideration the sources of flooding situated outside the buildings: cooling towers, tanks, CEC circuit, etc.

The rupture of each of these pieces of equipment was analysed. For the specific case of packing[2] falling from the cooling towers, an overflow discharge from the CEC in the order of around 2 m³/s has been studied (partial packing fall). None of these cases represent a safety problem on their own.

These conclusions have been reused and two additional hypotheses were added:

- the simultaneous rupture of all equipment (water tanks, diesel fuel tanks) that does not withstand the Design Basis Earthquake;
- the fall of all the packing at the feet of the cooling towers, which induces an overflow of 50% of the nominal CEC flow rate.

Effects of simultaneous rupture of water tanks

All tanks presenting a risk of rupture are situated outside the buildings. The water that escapes from these tanks in case of rupture will follow the slope of the ground and runs off away from the buildings into the drainage channels and gutters.

The water will very quickly be evacuated by the drainage network, the capacity of which is 540 m³/ha/h (150 l/ha/s). The water therefore cannot reach the entrance level to the buildings (71.5 m) except for a very short period. Only a minimum quantity of water can penetrate, given the presence of industrial doors that are obligatorily closed. Consequently no safety equipment will be affected if these tanks should burst.

Effects of simultaneous rupture of diesel fuel tanks

The two diesel fuel tanks are placed in a concrete container structure. Even if the tanks are cracked by the earthquake, these containers will considerably slow down the spread of diesel fuel escaping.

Effects of packing falling on the three units

In 2002 two of the numerous concrete pillars supporting the packing of the cooling tower of Tihange 3 fell after the rupture of one of their bases. This caused the fall of the packing, which then partially obstructed the outlet grid at the foot of the tower. During this incident about half of the rated discharge of the CEC overflowed instead of returning to the Meuse. A large quantity of water spilled over the site.

Following this incident the design of the packing was reviewed on Tihange 2 and 3. Based on the experience feedback of the 2002 incident the overflow discharge is conservatively estimated at 50 %.

Impact on the site

In Tihange 1 the fall of the packing has no effect because the wall around the cooling tower basin has an aperture creating a preferred run-out large enough to shed 50% of the rated discharge, or 100% of the overflow discharge, in the direction away from the safety related buildings. In Tihange 2 and 3, 50% of the rated discharge of the CEC circuit will overflow the cooling tower basin in less than one minute and then begin to flood the site. The water level can vary between 15 cm and 25 cm. This means that Tihange 2 and 3 are surrounded by water except on the North, facing the river Meuse.

Impact on the units

Water infiltration in the various zones is analysed taking into account all openings in the buildings (such as the air inlet holes in the doors, the apertures under the doors, the free gaps and passages in the walls, etc.). The analysis is conducted taking account of the fact that the CEC pumps will reasonably be stopped 30 minutes after the packing fall.

Tihange 1

Tihange 1 will be the last to be affected, being farthest removed from the cooling towers of Tihange 2 and 3, and would be concerned for only a very brief period. It is expected that the unit's diesel generators will be immersed. They will be the only affected components. With the offsite power supply undamaged, all the components will remain powered and available, in particular those necessary for the stable and controlled shutdown of the core and for the cooling of the pool. The consequences are identical in time of shutdown.

[2] The packing is the water dispersion modules in the cooling tower. They consist of a bed of a thickness of about two metres of honeycomb-structured polyethylene. It helps to disperse the water to maximize the exchange surface with the air.

Tihange 2

The first buildings to receive significant quantities of water will be the machine room and the BAN-N. Water infiltrations towards the BAN-D or the lower floors will not have time to build up into volumes sufficient to cause serious damage. The BUS equipments will in any case be available for the cooling of the fuel as the infiltrations will be reduced, the volumes to fill large and the pumping systems still operational. However, two of the three CEU groundwater pumps will be lost since they stand in the direct line of the water flow from the tower of Tihange 2 towards the Meuse. This will not entail any non-availability of the equipment supported by these pumps, since three additional CEU pumps can draw water from the Meuse and serve as a source of cooling. Building O will be flooded, but the offsite power supply will still be available, so this will be without consequence for the safety equipment necessary for the cooling of the fuel.

Thanks to their location alongside the Meuse, on the North side and therefore sheltered from water flows, the GDS (and their diesel fuel storage building), the CEB and CEU Meuse pumps and the EAA zones will not experience any direct water attack and will remain available.

Despite the volume of the flow and the size of the affected zone, the systems and equipment still available will allow to maintain efficient cooling for an unlimited time thanks to first- or second-level safety equipment.

In a shutdown state, the CEC pumps stop running for 80% of the time (during maintenance of the equipment of the secondary circuit). The other 20% of the time a large number of staff are present on the site, and the overflow of the tower tank will very rapidly be reported and then halted (a tank level alarm is also available).

Tihange 3

The first parts of the installation affected will be the machine room, the workshop and building E. This will not have any consequence for the safety equipment. In fact, although building E contains classified equipment (the main electric switchboards), these are situated on the upper floors and will therefore not be affected by water from the CEC.

Only one of the CEU well pumps will be lost. The three Meuse CEU pumps will remain available.

The water ingress in the DE spent fuel building will come from outside and from its connection with the PHI building. Bearing in mind the large surface of the subsoil, low ingress flows and the availability of pumping systems, the spent fuel pool cooling pumps will remain available.

Furthermore, the passive inertia of the DE pools allows for more than 24 days before the fuel rods are uncovered, even if the pumps are stopped and no action is undertaken.

The CEB pumps, the EAA pumps, the EAA tank, the GDS and the main fuel-cooling equipment situated in the BUS, the BAN-N and the BAN-D will remain operational. Building O will be flooded but, since the offsite power supply will still be available, this will be without consequence for the safety equipment necessary for cooling the fuel.

As with Tihange 1 and 2, the equipment still available will allow to maintain efficient cooling, for an unlimited time, by the first- and second-level safety equipment. The analysis for a shutdown state is identical to that for Tihange 2.

Foreseeable measures to increase robustness of the site

Even if this major but unlikely event does not have serious consequences, the following actions are undertaken for Tihange 2 and 3:

- modification of the earthquake management procedures in order to very quickly send an agent to verify whether the cooling tower is overflowing. In that case the CEC pumps will be rapidly stopped;
- study of the relevance of an automatic stop of one of the two CEC pumps in case of high water level in the cooling tower basin.

<u>Access to the site and access to buildings and zones</u>

Various access routes are identified to the control room after an earthquake: two pedestrian/vehicular access routes are the favoured routes in a post-accident situation. These access routes may later be cleared of debris by a bulldozer-type heavy vehicle. If the pedestrian access is not possible, a helicopter lift can be arranged and various landing zones are possible.
With the concerned buildings being seismically qualified, the access routes that must be used after an earthquake are designed in such a way as to provide free access after an earthquake.

Doel NPP

Interactions between structures, systems and components
Structures, systems and components that cannot withstand the Design Basis Earthquake could cause damage to other SSCs with a safety function.
For this reason, SQUG inspections were organised as part of the Periodic Safety Reviews of the four Doel units in all buildings where safety equipment is present. Where necessary, equipment not capable of withstanding the DBE was removed or seismically qualified.

Internal flooding
During the last Periodic Safety Review a study was conducted to analyse the effects of an internal flood in the buildings containing safety equipment. SQUG-inspections were organized for the unclassified pipework (medium energy line) to ensure that pipes will not rupture as a result of the DBE.
Such SQUG inspections have taken place in the following buildings:

- Doel 1&2: GNS, TUR ½, BAR, MWP, GNH. There has not been any SQUG inspection for MAZ and GMH, though there has been a study on internal flooding.
- Doel 3&4: GEH, BKR, GMH. There has not been any SQUG inspection for GVD and GNH, though there has been a study on internal flooding.

In buildings where an SQUG inspection was conducted, the safety equipment is not exposed to potential internal flooding as the result of an earthquake. In the other buildings measures have been taken to protect the safety equipment against flooding as the result of a rupture of a pipeline.

External flooding
The danger of flooding was also examined extensively, taking account of all possible sources outside the buildings: cooling towers, tanks etc. Preventive measures have already been taken in the context of the Periodic Safety Review (subject B4). Analysis of the consequences of this type of flooding shows that the risks are fully covered by the measures and procedures provided for in the Periodic Safety Review.

Access to the site and access to buildings and zones
There are two access routes to the site in Doel. A helipad is available in the event of both overland access routes being blocked. Access can also be granted along the river Scheldt via a landing stage at the water intake for Doel 1&2.

On the site, all entrances to the control rooms and emergency control rooms were checked. In Doel 1&2, the control room is not located in a building seismically qualified under category 1. In view of the many access possibilities, it can be assumed that the control room remains accessible.
In Doel 3&4, the control room is located in a seismically qualified building, which means that access is not compromised after an earthquake.
The emergency control rooms of the four units are all accessible via at least two different routes.
The fire service trucks have equipment to clear away small obstacles so as to force a passage through fencing, etc.

Account was also taken of the possibility of the earthquake causing the release of a toxic gas cloud outside the site. The normal control rooms are, for this purpose, equipped with a detection system that automatically isolates the control room from the outside air. Full-face gas masks with a filter are also provided for, as well as autonomous oxygen bottles for the work shift and assisting executive staff. In Doel 1&2, oxygen bottles are also provided in the emergency control room.

2.1.3. Compliance of the plant with its current licensing basis

2.1.3.1. General organization of the licensee to guarantee conformity with design basis

The ageing of systems, structures and components involved in the safety of a nuclear installation is monitored in order to ensure that the required safety functions remain available throughout the life of the unit.

The Technical Specifications (Chapter 16 of the Safety Analysis Report) describe the obligatory surveillance measures for each system. This allows for verification of the availability of equipment through procedures indicating the limits of each measured parameter. This chapter also lays down the measures to be taken - and the relevant time limits - in case of unavailability of equipment. Furthermore, the programme of periodic tests conducted on these systems, describes the surveillance measures applied to classified equipment. It concerns more particularly the pipework, tanks, valves and pumps, including their supports and shock absorbers.

2.1.3.2. Organization of the licensee for supplies and mobile equipment

The various design scenarios in connection with an earthquake do not normally require the use of mobile equipment. First response equipment may however be used for beyond design scenarios, situations that would involve, for example, falling debris or falling pipes.

The necessary material is stored on or near the site.

Special equipment is provided for on the site itself with the aim of making it possible to carry out the emergency procedures (beyond design). This equipment is checked periodically.

2.1.3.3. Potential deviations from the referential and corrective action

The tests and inspections described above may detect non-conformities. If they are so important that the equipment no longer meets its design criteria, the Safety Analysis Report describes the time limits for intervention and the measures to be taken. In certain particular cases, Justifications for Continued Operation (JCO) are drafted by the licensee and approved by the regulatory body. These documents demonstrate that the (partial) non-conformity of equipment to the regulation does not jeopardise the safety function if the recommended temporary measures are applied.

On 30 June 2011 the only deviation detected on the Tihange site from a seismic point of view was the subject of JCO 2010-01: "The electric board allowing the slow start-up of 7 diesels in Tihange 2 is not seismically classified."

For the Doel site, the following deviations from the seismic concept for the equipment have not yet been resolved (situation as per 30/06/2011). However, none of these deviations jeopardises the due and proper functioning of the equipment.

- Doel 1&2: none;
- Doel 3&4: according to the conclusions of the Periodic Safety Review, subject A4, the polar crane in the reactor buildings have to be equipped with a seismically qualified emergency stop device on the working floor. This is not yet the case; a seismically qualified emergency stop device is only present in the bridge cab.

2.1.3.4. Specific verification of the conformity of installations following the incident in Fukushima

After the events in Fukushima a specific verification was conducted in order to check that the power station respected the current requirements of the operating licence.

During this verification it was thought advisable to raise the level of qualification of the spent fuel pool cooling circuits to 0.17g for Tihange. The necessary studies and modifications were carried out before 30 June 2011.

Furthermore, after the incident at the nuclear facility in Fukushima, the site also organized a specific reliability review: SOER 2011-2, WANO. This concerns verification of:

- measures to limit the effects of beyond design accidents;
- conformity of the installation to the design regarding the resistance to loss of electrical power supply;
- protection against floods (internal and external);
- resistance to flood or fire caused by an earthquake.

No deviation from seismic design was detected during these verifications on the Doel and Tihange site.

2.2. Evaluation of safety margins

2.2.1. Range of earthquake leading to severe fuel damage - Description of SMR methodology

2.2.1.1. Safety margins in design of NPPs

Nuclear power plants are designed according to strict codes and regulations. Their design includes margins intrinsic to each stage of the design process. By way of illustration here are some examples of conservatisms related to seismic design studies:

- The seismic response spectra are enlarged and amplification factors are often increased in order to allow for the variability of earthquakes and the soil parameters;
- The modal responses of buildings that serve to check the behaviour of mechanical and electrical equipment are obtained using a elastic linear method which is conservative in relation to their real behaviour. The shock absorption value of the ground is less than in reality, and the response spectra calculated at different levels of the building are enlarged;
- The response of equipment is determined with a shock absorption value less than reality; the methods of calculation introduce new conservatisms;
- Reserve ductility is not taken into account in the verification of the structural behaviour. Guaranteed minimum values of material properties were used. The construction codes also require combinations of conservative loads.

These conservatisms used in the design have a cumulative effect which leads to generally very high safety margins. For example, the pipes in nuclear power stations are very ductile and may deform quite considerably before the appearance of any failure. The margins commonly observed for nuclear pipework in case of earthquake may be considered to be in the order of 4. In other words, the seismic load can be quadrupled without any problem for the safety of the installation. Electrical equipment and components are tested on vibrating tables with seismic loads much higher than those actually required.
The intrinsic seismic margins of NPPs are therefore generally very high.

Although respecting all the design codes and standards, some equipment may present margins lower than those generally observed. This situation arises in particular in older nuclear power plants verified with methods applicable at the time and whose seismic level has since been reassessed, such as Tihange 1 and Doel 1&2. To respond appropriately it is necessary to examine each structure, system or component of the nuclear installation involved in achieving a stable and controlled shutdown after an earthquake.

2.2.1.2. Seismic margin assessment methodology

An assessment of the seismic margins of the three units in Tihange and the four units in Doel was made. This assessment is based on two main elements:

- an analysis of the behaviour of structures, systems and components subjected to an earthquake of greater intensity than the current design basis earthquake of the units. It uses the available seismic analyses and the results of previous SQUG inspections.
- a new Seismic Margin Review (using a methodology derived from the Seismic Margin Assessment methodology) based on the judgment of experienced engineers, including eminent international experts having numerous references in the field. In particular, these experts inspected during walkdowns the SSC necessary for stable and controlled shutdown for all reactor units of Doel and Tihange.

The purpose of a *Seismic Margin Assessment* (SMA) is to quantify the available margins for a nuclear power station beyond its design seismic level. These studies, used and recognized internationally, follow a methodology developed by EPRI and described in document NP-6041. The method is based on the definition of a *"Review Level Earthquake"* (RLE) that allows (theoretical) demonstration of the seismic behaviour of a nuclear power station beyond its DBE, identification of weak points and determination of available margins. Experience with real events forms the basis of knowledge of behaviour of equipment in case of earthquake. This basis is drawn on in the writing of precise site inspection guides. The SMA studies are therefore used to demonstrate that an NPP is capable of withstanding a much bigger earthquake than that considered during its design. The SMA methodology has been applied to numerous NPPs around the world to demonstrate that the seismic hazards reviewed earlier are acceptable, subject to possible reinforcements of low-margin equipment.

The Seismic Margin Review study (based on the SMA-methodology) for the Belgian NPPs consists of the following phases:

- examination of the seismic design basis and the design documents:
  - data and results of studies of the ground stability and the building foundations,
  - results of seismic analyses of original structures and the results of reassessment (analyses, vibrating table tests, etc.);
  - results of a preliminary SMA analysis conducted for Tihange 1 and Doel 3 as part of a Periodic Safety Review;
- review of the stable and controlled shutdown strategy;
- drafting and review of the list of SSC necessary for stable and controlled shutdown for each unit. This list was completed with the SSC necessary for the spent fuel pool cooling;
- review of the RLE spectrum developed by the licensee;
- inspection of these SSC to evaluate the behaviour during an RLE-level earthquake. These inspections have already been conducted in all the buildings of the different reactor units of Doel and Tihange which are accessible during power operation. For the non-accessible buildings (example reactor buildings) these inspections will be completed during future planned outages of these units;
- additionally, the findings of the first team of experts were verified by another team of internationally recognised experts. This additional verification results in a very high degree of reliability of the results.

These inspections cover the SSC identified as necessary in case of an earthquake to provide stable and controlled shutdown from the following initial states:

- Power operation or hot shutdown (steam generators available);
- cold shutdown (steam generators unavailable);
- core completely unloaded in spent fuel pool.

For the buildings, these evaluations consist of:

- identifying the presence of walls and masonry or other non-seismic elements near seismically classified equipment;
- identifying modifications that may compromise structural integrity of the buildig;
- checking the expansion joints between buildings/structures;
- identifying potential impact risks of adjacent buildings/structures;
- identifying seismic loads and potential failure modes based on a detailed evaluation of the plans of the buildings, including the design details and calculations.

With regard to the electrical and mechanical equipment, the following inspections were conducted:

- evaluation according to the guidelines of EPRI NP-6041.
- evaluation of the capacity of the equipment that needs to continue functioning after an earthquake with an RLE level. It should be noted that the minimum acceleration for which the resistance of the equipment is evaluated according to EPRI-NP-5041 amounts to 0.3g, irrespective of the value of the RLE for the higher frequencies (0.17g in the case of Doel).
- checking the anchoring.
- checking possible interactions with neighbouring equipment.
- evaluation of the possible indirect consequences of an earthquake such as internal and external flooding.

After assessment and inspections, the identified SSC are classified in three categories:

- structures, systems and components having very high probability (95% confidence) of preserving their integrity and performing their function in an earthquake exceeding the RLE level. They are classified as High (H);
- structures, systems and components having a medium probability (50% confidence) of preserving their integrity and performing their function in an earthquake exceeding the RLE level. They are classified as Medium (M). This category also includes, in a provisional way, the elements for which it is difficult to validate their classification as High (H) without additional data and calculations;
- structures, systems and components having a low probability (10% confidence) of preserving their integrity and performing their function in an earthquake exceeding the RLE level. They are classified as Low (L).

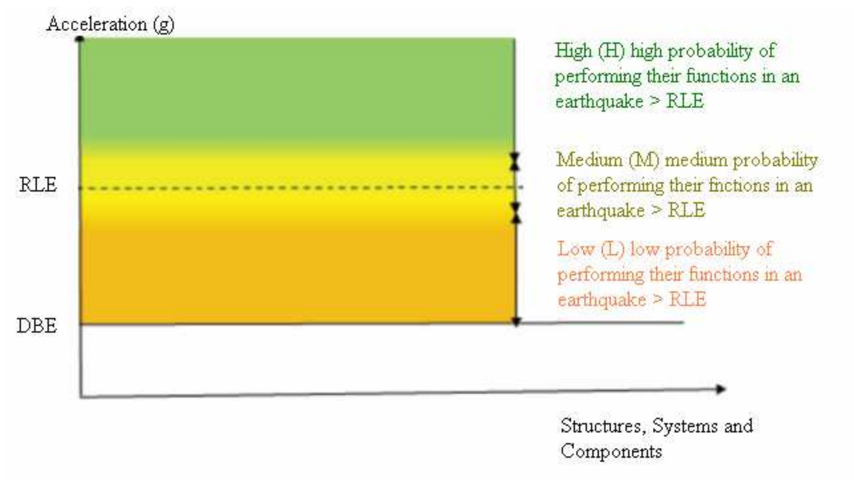

Figure 7 - Classification of SSC in categories H, L, M.

The assessment of margins is conducted with reference to the RLE. All the SSC necessary for stable and controlled shutdown are and remain classified for DBE. This classification of seismic components provides a general picture of the capacity of the components of the installation in relation to the RLE. As shown in the figure 3, elements classified as Low can have a capacity close to the RLE, that can however not be demonstrated by the inspection. A detailed assessment (by calculation or tests) or a modification may allow rapid elimination of weaknesses in the components.

The SSC whose probability of resistance to the RLE is classified Low according to the inspection will be subject of detailed calculations or expert judgments in order to determine their seismic margin more accurately.

2.2.1.3. Choice of Review Level Earthquake

The seismic level higher than the design seismic level of the units, known as Review Level Earthquake, is not a new design basis earthquake but rather a level specific to the SMA-method.
The choice was made based on the following elements:

- the European guide for new nuclear power stations (European Utility Requirements) recommends a ratio of 1.4 between the ground accelerations due to RLE and those due to DBE; other international guides (IAEA) mention ratios ranging from 1.5 to 1.66;
- a seismic spectrum representative of the site conditions;
- the new probabilistic seismic hazard study conducted by the Royal Observatory of Belgium. This study considers the most recent seismic data.

Tihange NPP

The analysis led to the definition of the RLE spectrum given in the diagram below. The maximum response is 0.6 g for frequencies below 12 Hz. For higher frequencies the peak ground acceleration is 0.3g. This corresponds to an earthquake of a magnitude of more than 6.5 on the Richter scale.

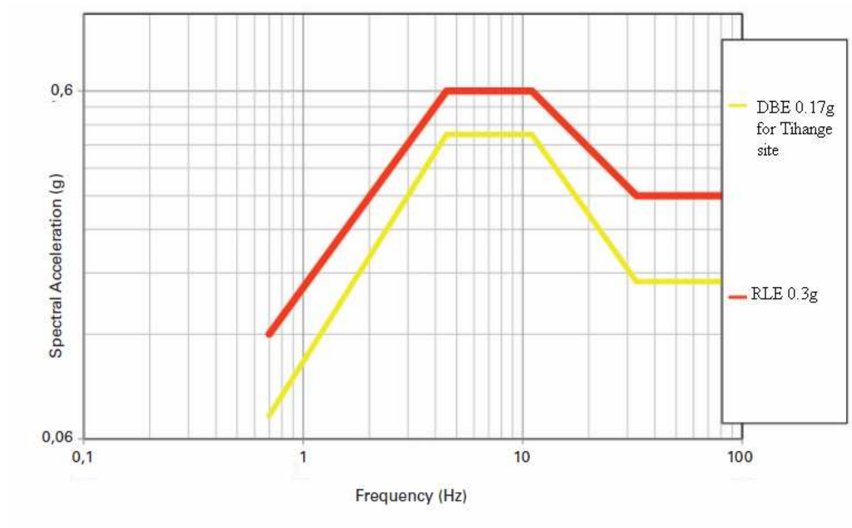

Figure 8 - Comparison of the RLE spectrum and the Tihange DBE spectrum.

This RLE value (PGA 0,3 g) is frequently used to conduct margin assessment tests on sites with similar seismological characteristics. In parallel a new study of the seismicity of the Tihange site was conducted by the ROB. The results of this study confirmed the choice of the RLE and, therefore, allowed performing the studies on this basis. In fact, the studies by the ROB give an appreciably lower acceleration on the Tihange site (PGA 0,21 g at bedrock level).

Doel NPP

The analysis led to the definition of the RLE spectrum given in the diagram below.
The maximum response is 0.42 g for frequencies lower than 5 Hz. For the higher frequencies, the peak ground acceleration is 0.17g, a value that refers to the first, conservative results of the ROB study (for the earthquake with a return period of 10000 years). This corresponds to an earthquake of a magnitude of more than 6.5 on the Richter scale.

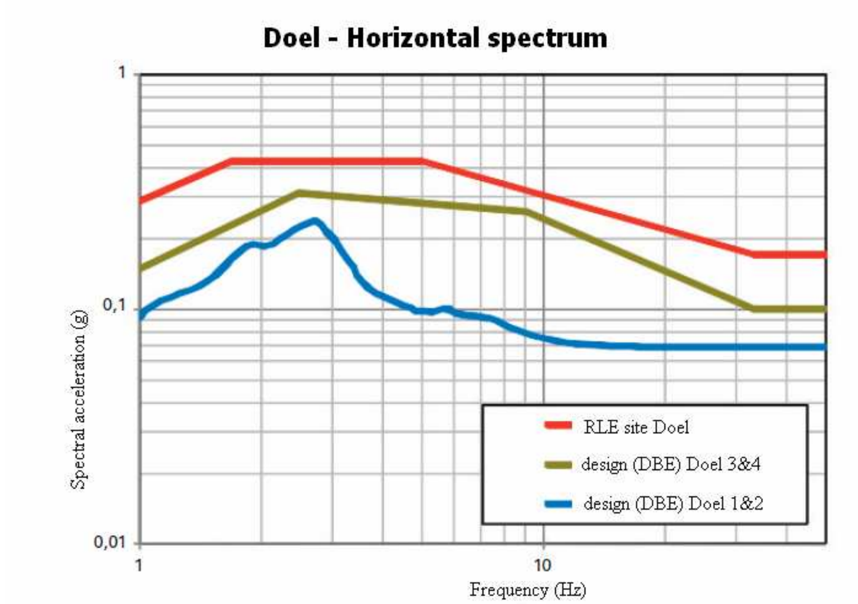

Figure 9 - Comparison of the RLE spectrum and the Doel DBE spectra

2.2.1.4. Results of SMR - Weak points

A general overview of the SMR classification of the SSC necessary in case of an earthquake to provide stable and controlled shutdown based can be found in the table:

Table 7 SMR Results for different reactor units: Percentage of SSC classified as having a 'High', 'Medium' or 'Low' probability of preserving their integrity and performing their function in an earthquake exceeding the RLE

SMA Margin Rating	Tihange 1	Tihange2	Tihange3	Doel 1&2	Doel 3&4
High	43%	78%	75%	88%	76%
Medium-High[3]	34%	2%	2%	-	-
Medium	16%	14%	20%	6%	23%
Low	5%	4%	-	<1%	<1%
Other (Medium)[4]	2%	3%	3%	5%	-

More detailed results from the different reactor units are provided below:

Tihange NPP

Tihange site

According to the international experts who performed the seismic margin review for a RLE characterised by a PGA of 0.3g the following conclusions can be drawn: "The walkdowns of older units (Tihange 1) confirmed the seismic ruggedness of SSCs beyond the design basis; only a few seismic vulnerabilities were identified. Some further evaluations are needed to demonstrate the seismic margin to RLE. The walkdowns of newer units (Tihange 2&3) did not reveal any major seismic issues. These units could easily be shown to survive an RLE."

Soil studies in Tihange, were conducted by French experts. These showed that, for earthquakes reaching RLE level, the soil did not present any risk of liquefaction. These studies also demonstrated that there is no risk of terrain instability on the Tihange site, in other words, no risk of landslide.

Tihange 1

In Tihange 1, 21 SSC were classified Low and are therefore considered as having a low probability of resisting an earthquake exceeding the RLE. These components could very well be raised to the classification High after carrying out more precise calculations or simple modifications. Additional studies are ongoing to confirm the feasibility of such modifications.

Table 8 List of SSC classified "Low" in Tihange 1

Equipment	Type of Equipment
PCT1-CCV-V002PF	Pneumatic valve
PCT1-CCV-V005PV	Pneumatic valve
PCT1-CAE-P01Ba1	Pump
PCT1-CRI-Q01DR1	Exchanger
PCT1-CTP-Q01BD1	Exchanger
PCT1-CTP-Q01BD1BIS	Exchanger
PCT1-CEB-P01EB3	Pump
TAM1/S1	Main switchboard
TAM8/S1	Main switchboard
TR2/S1	Transformer 6 kV-380V
TR3/S1	Transformer 6 kV-380V
PDT/UR1	Transfer Panel
PDT/UR2	Transfer Panel
TAM1/S2	Main switchboard
TAM8/S2	Main switchboard
TR2/S2	Transformer 6 kV-380V

[3] These consist mainly of electical cabinets that could not be inspected during power operation and that were judged by transposition of other electric cabinets of the same design. Studies currently in progress show that the majority of these SSC will finally be classified High (H)

[4] These items could not be inspected and were judged case by case on the basis of available data such as constructor's files, design notice, calculation sheets, international experience, etc. These components are conservatively assessed as Medium (M).

TR3/S2	Transformer 6 kV-380V
PCT1-SCS	Filter
PCT1-SCS	Filter
PCT1-VLE-F13AV	Filter
PCT1-VLE-Q02AC1	Exchanger
PCT1-VLE-Q04AC1	Exchanger

The Electrical Auxiliary Building (BAE), initially classified in category Low (L) during walkdowns is now reclassified in category Medium (M) by independent experts after detailed assessment. The advisability of reinforcing this building is the subject of a feasibility report. It should however be pointed out that the seismic intensity identified for Tihange would not result in any serious damage to the building.

The results of this SMR study are completed by the reassessment of the seismic behaviour of components and supports of the primary circuit. This was done via a preliminary SMA as part of the last Periodic Safety Review. It was concluded that these components have a large margin with reference to a DBE-level earthquake. According to the preliminary SMA study, based on the RLE (PGA 0.3g), the components of the primary circuit and their supports are sufficiently rugged and do not require any particular reassessment.

Tihange 2 and Tihange 3

Regarding the seismic margins, the situation in Tihange 2 and 3 is even more favourable than that in Tihange 1. The great majority of SSC necessary for stable and controlled shutdown of these units have a very high probability of preserving their integrity and performing their functions after an earthquake exceeding the RLE level. Regarding the mechanical and electrical components, no significant vulnerability was identified. It must be pointed out however that certain other components have lower margins: 3 pieces of equipment were assessed Low in Tihange 2 (two of them because of interaction with other, non-seismic, equipment).

Table 9 List of SSC classified "Low" in Tihange 2

Equipment	Type of Equipment
PCT2-CEG-Z01	Cooling unit
PCT2-CSC-A02B	Ventilator
PCT2-CTP-B02R	Tank

The results of this SMR study are completed by the reassessment of the seismic behaviour of components and supports of the primary circuit. This was done via a preliminary SMA as part of the last Periodic Safety Review. It was concluded that these components have a large margin with reference to a DBE-level earthquake. According to the preliminary SMA study, based on the RLE (PGA 0.3g), the components of the primary circuit and their supports are sufficiently rugged and do not require any particular reassessment.

Doel NPP

Doel site

According to the international experts which performed the seismic margin review for the Doel NPP the following conclusions can be drawn: "The walkdowns of older units (Doel 1&2) confirmed the seismic ruggedness of SSCs beyond the design basis; only a few seismic vulnerabilities were identified. Some further evaluations are needed to demonstrate the seismic margin to RLE. The walkdowns of newer units (Doel 3&4) did not reveal any major seismic issues. These units could easily be shown to survive an RLE."

Soil studies in Doel were conducted to show that, for earthquakes reaching RLE level, the soil did not present any risk of liquefaction. These studies also demonstrated that there is no risk of terrain instability on the Doel site, in other words, no risk of landslide.

Doel 1&2

Only one component is given the classification 'Low' (L). This concerns a valve in the injection line on the seals of a primary pump. This shortcoming is being remedied during the outage of Doel 1 in November 2011.

The footbridge to the GNS is a weak point that can be improved. The footbridge is one of the two possibilities to get from the main control room to the emergency control room in the GNS. The bridge runs via the roof of the GNH, part of which has been given the classification 'Low' (L).

A number of additional studies result in the following conclusions:

- The foundations of the reactor buildings and the GNS can be regarded as representative of the foundation type of the different buildings at Doel 1&2. A detailed examination shows that the foundation piles can withstand an earthquake of the RLE level.
- The primary components and supports were also reassessed during the last periodic safety review (preceding the SMA). An additional evaluation was conducted according to the SMA method and confirmed that these components can withstand the RLE.
- The drive mechanism for the control rods of the reactor (Control Rods Drive Mechanisms, CRDM) were evaluated in an ad hoc manner. A margin higher than the RLE level was found.

Doel 3&4

Only one component is given the classification 'Low' (L). This concerns a ventilation shaft with inadequate support. This defect can be remedied in the short term.

The primary components and supports were also reassessed during the last Periodic Safety Review (preceding the SMA). An additional evaluation was conducted according to the SMA method and confirmed that these components can withstand the RLE.

2.2.1.5. Measures to increase robustness

Tihange NPP

In Tihange 1, 21 SSC were classified Low and are therefore considered as having a low probability of resisting an earthquake exceeding the RLE. These components could very well be raised to the classification High subject to more precise calculations or simple modifications. Additional studies are ongoing to confirm the feasibility of these modifications.

In Tihange 2 three pieces of equipment were classified Low. As with Tihange 1, possible improvements are evaluated on case by case basis. Detailed analysis of each case will allow to assess which improvement is best to implement if necessary.

Generally, these results do not show any significant risk of equipment failure. In fact, the points for improvement detected in the three units do not represent any particular difficulty. In most cases these improvements seem easy and are not necessarily indispensable from a safety point of view, but will be carried out in order to bring the installation into conformity with regard to these results.

In conclusion, the Seismic Margin Review conducted did not reveal any gap threatening the safety of the installations. The margins observed within the framework of this study demonstrate the capacity of the nuclear power plant of Tihange to resist a high-intensity earthquake.

Doel NPP

In Doel 1& 2 there is only one component with a 'Low' classification (L). This component will be adapted during the outage for the revision in November 2011.

The footbridge to the GNS of Doel 1&2 is presently still a weak point. An instruction for the operators is to be added to the existing procedures. If the shift crew team wants to get from the main control room to the emergency control room in the GNS, the group will have to split up and follow the two parallel access routes. This allows a minimum number of personnel to get in place quickly in order to resume operation of the Doel 1&2 from the emergency control room.

For the RWST reservoirs and their piping of Doel 1&2 a check will also be conducted to establish whether they comply with the RLE level. As this equipment can facilitate retention of a safe shutdown, they will, if necessary, be adapted by way of 'defence in depth' to ensure that they can withstand the RLE.

In Doel 3&4, there is only one component with a 'Low' classification (L). This component will be adapted in the short term.

In conclusion, the Seismic Margin Review conducted did not reveal any gap threatening the safety of the installations. All the units can withstand the RLE, an earth tremor intentionally rated higher than the design basis earthquake.

2.2.2. Range of earthquake leading to loss of containment integrity

2.2.2.1. Introduction

An analysis was conducted of the seismic behaviour of the containment and penetrations of the units in Doel and Tihange for the RLE. It is based on an "expert judgment" approach, based on the EPRI-NP-6041.

Tihange NPP

Primary (inner) containments of Tihange 1, 2 and 3
The primary containment consists of a prestressed reinforced concrete structure providing protection against internal accidents. It has the shape of a cylinder topped with a hemispherical dome and is clad (on the interior) with a steel liner providing leaktightness. The primary containments contain thick reinforced sheets to resist pressure resulting from accident hypotheses taken into account in their design bases, giving them an inherent resistance to earthquake. Structurally these containments correspond to the descriptions of those analyzed in Appendix A of the NP-6041, which gives them a High Confidence of Low Probability of Failure (HCLPF) well beyond 0.3g in terms of PGA.

Secondary (outer) containment of Tihange 1, 2 and 3
The secondary containment is a reinforced concrete structure surrounding the primary containment and providing protection for the latter against external accidents. Like the primary containment it has a high potential for resistance to earthquakes in excess of 0.3g in terms of PGA.

Foundations
The two containments are founded on a general common base anchored deep in the very solid ground (altered schist). This foundation does not present any particular seismic vulnerability; it is largely capable of transferring seismic action to the underlying ground during earthquakes of up to 0.3g in terms of PGA.

Behaviour of mechanical penetrations
The behaviour of penetrations depends on inertial action and differential shift.
Since the containments and the adjacent nuclear buildings are rigid, their relative displacements are slight and largely compatible with the capacity of these penetrations, mostly due to the presence of expansion compensators. For inertial actions, the fact that the structures are of robust design allowing them to resist, for instance, accidental pressurization change, gives them an inherent resistance to earthquakes in excess of 0.3g in terms of PGA in accordance with NP-6041.

Doel NPP

<u>Doel 1&2</u>

Primary (inner) containment and foundation
The primary containment consists of a steel sphere resting on the concrete base of the internal structures. The sphere absorbs the primary pressure and the seismic load. The steel sphere, which is

itself not subjected to much loading, is characterised by a favourable ratio of rigidity to mass, which makes it resistant to a more powerful earthquake than the DBE.

The most heavily loaded area of the sphere is located near the welds on the personnel hatch. The welds have been greatly strengthened. The concrete floor slab supporting the steel sphere rests on foundation piles, the resistance of which has been calculated for an earthquake with PGA of 0.17g.
All this means there is no risk of instability whatsoever for the primary containment in the case of an earthquake of 0.17g.

Secondary (outer) containment
The secondary containment consists of a reinforced concrete cylinder form supporting a hemispherical dome, also made of reinforced concrete. This entire structure surrounds the primary containment, which is therefore protected against external accidents.
The secondary containment does not display any specific vulnerability, not even in the case of earthquakes exceeding 0.17g.

Behaviour of mechanical penetrations
The behaviour of penetrations depends on inertial action and differential shift.
As the primary and secondary containments are separate entities, it cannot be the intention for the penetrations between the two to form a fixed, rigid connection. Although the penetrations are secured to the steel sphere (primary containment), their second support is a flexible suspension.
The integrity of the penetrations is preserved at all times. It is calculated to withstand an RLE of 0.17g.

<u>Doel 3&4</u>
Primary (inner) containment
The primary containment of Doel 3&4 comprises a reinforced prestressed concrete structure which absorbs the primary pressure and the seismic load. This cylindrical containment with the hemispherical dome is covered with a steel liner to ensure leaktightness.
Structurally these containments correspond to the descriptions of those analyzed in Appendix A of the NP-6041, which gives them a High Confidence of Low Probability of Failure (HCLPF) well beyond 0.3g in terms of PGA.

Secondary (outer) containment
The secondary containment of Doel 3&4 likewise comprises a reinforced prestressed concrete structure running around the primary containment, thus protecting the latter against external accidents: plane crash, tornado, external explosion etc. Just like the primary containment, the secondary containment is also particularly well resistant to earthquakes, in each case above the RLE of 0.17g selected for Doel.

Foundation
The primary and secondary containments rest on a common floor slab supported by a network of foundation piles. The foundation piles of the containments at Doel 3&4 do not present any problem in the case of an earthquake of 0.17g.

Behaviour of mechanical penetrations
The behaviour of penetrations depends on inertial action and differential shift.
Since the containments and the adjacent nuclear buildings are rigid, their relative displacements are slight and largely compatible with the capacity of these penetrations, mostly due to the presence of expansion compensators. For inertial actions, the fact that the structures are of robust design allowing them to resist, for instance, accidental pressurization change, gives them an inherent resistance to earthquakes in excess of 0.3g in terms of PGA in accordance with NP-6041.

2.2.2.2. Conclusion

Tihange NPP

From a structural viewpoint, the situation of the containments of the three units in Tihange corresponds well to those in NP-6041, for which an HCLPF above 0.3g is guaranteed.

Doel NPP

From a structural standpoint, the design of the containments of Doel 3&4 corresponds well to that in document NP-6041, for which a HCLPF value of more than 0.3g is guaranteed, albeit with a limitation up to RLE 0.17g for the foundation piles in Doel 3&4.
The design of Doel 1&2 is more specific. The assessment is based on the available documentation and gives a favourable conclusion with regard to stability in the case of an RLE of 0.17g.

2.2.3. Earthquake exceeding the design basis earthquake for the plants and consequent flooding exceeding design basis flood

Tihange NPP

Flooding of the Meuse

The earthquake exceeding the DBE considered for the Tihange site corresponds to the RLE earthquake characterized by a PGA of 0.3g.
Such an event corresponds to an epicentric intensity of VIII on the MSK scale. For the purposes of this study this earthquake is taken as occurring at the limit of the seismotectonic continuum nearest the site, that is, 11 km south of the Tihange nuclear power station, following the perpendicular to the axis of the Meuse between Namur and Liège (ROB study hypothesis).

Starting from the epicentre, a distinction is made between:

- a first zone with a radius of 15 km in which the seismic intensity is VIII on the MSK scale (the Tihange site, 11 km from the epicentre, is therefore situated within this zone);
- a second zone, 15 to 50 km from the epicentre, in which the seismic intensity is VII on the MSK scale;
- a third zone, 50 to 220 km from the epicentre, in which the seismic intensity is VI on the MSK scale.

Given the radii of the different intensities, the following can be concluded:

- in the first zone of influence (intensity VIII), apart from the site, the only exterior construction that could influence the level of the Meuse near the Tihange NPP is the Ampsin-Neuville dam, situated downstream. If it breaks, the level of the Meuse river will fall to 64.45 m. Based on existing knowledge and additional studies of the resistance of this structure and the consequences of an intensity VIII earthquake, it is believed that the Ampsin-Neuville dam will be able to withstand an earthquake of that intensity.
- in the second zone of influence, the constructions outside the site that might influence the level of the Meuse are the dams situated upstream and downstream. Based on existing knowledge of the resistance of these constructions and the consequences of an intensity VII earthquake, it is believed that the dams will not sustain any damage likely to cause them to break. In fact, intensity level VII corresponds to slight damage, including to relatively vulnerable constructions, which is far from the case for the structure of this type of dam.
- in the third zone of influence (intensity VI) the structures are not influenced by an earthquake of this intensity. No impact is therefore considered.

Sources of flooding situated on the site

The conclusions of paragraph §2.1.2.3 (Indirect effects of earthquakes taken into account during design: internal or external flooding) are also applicable to an earthquake exceeding design level. In this case the affected components are the same as those identified as sensitive to the DBE. Paradoxically however the consequences will most probably be less severe: the offsite power supply supposed lost, the CEC pumps will have stopped running. The remaining equipment will provide an effective cooling, unlimited in time, and thus shut down the reactor in a stable and controlled manner.

In conclusion, an earthquake beyond the DBE on the Tihange site should not trigger a flood exceeding the installation design limits. No modification of material, procedures or organization is therefore required.

Doel NPP

A tsunami of 0.5 m is a theoretical possibility on the Scheldt estuary. However, even if an earthquake were to cause such a maximum tsunami and destroy the Scheldt embankment at the same time, the (raised) platform of the Doel NPP site would still not be flooded.

The site in Doel is located at the Scheldt estuary. A tsunami (tidal wave) and seiche (wave occurring through resonance in semi-closed water basins) are phenomena that might be initiated by an earthquake.

Tsunami and seiche

Earthquakes and submarine landslides are cited as possible causes of a tsunami in Europe. The geological conditions for this are actually only present in a limited number of places. Based on model runs, it has been examined, for example, what the possible effects of a tsunami might be on the British coasts. The worst consequences would appear to occur off the coast of Cornwall – tidal wave 0.5 to 2 m high. The chances of an effective tsunami are regarded as being small: in the order of 10^{-2} to 10^{-4} per year. Given the distance between Cornwall and the Scheldt estuary and the shelter provided by the West-Normandy coastline, the models show that the tidal wave would be substantially subdued towards the Scheldt estuary: the amplitude would not be greater than 0.5 m.

As a consequence of the complex geometry, it is theoretically unlikely that seiches would occur on the river Scheldt. If the phenomenon does occur, however, the amplitude would remain limited to about ten centimetres, and a seiche subdues very quickly.

An earthquake could jeopardise the integrity of the Scheldt enbankment. At Doel, the water level of the Scheldt is, however, considerably below the height of the platform for the site. Even if an earthquake were to cause the maximum tsunami (tidal wave) of 0.5 m and destroy the Scheldt enbankment at the same time, the site platform would still not be flooded. In addition, it is noted that such a tsunami could only occur a long way from Doel, which means that the Scheldt enbankment collapsing as a result of the earthquake would hardly be likely.

Sources of flooding situated on the site

In the periodic safety review a list was drawn up of significant potential flooding sources on the site. The list was further expanded by a selection based on the design basis earthquake. The following potential flooding sources were identified:

- cooling tower basins Doel 3&4,
- bulkhead locations – bulkheads on the cooling water pipes (CW) in contact with the outside air (opening at +11.08 m TAW),
- cooling water pipes (CW) with sections below and above ground,
- storage tanks, a number of which are not seismically designed.

In case of a severe earthquake all these flooding sources could contribute to the flooding on the site.
Initially, there would be the immediate rupture of the different storage tanks. The four most important tank clusters can each discharge several thousand cubic meters of water, or a total of almost 13,000 m^3.
Secondly, a large water flow would occur from the cooling tower basins and, to a lesser extent, also from the cooling water pipes and the bulkhead locations. A leakage flowrate of 11 m^3/s is presumed for each of cooling tower basins of Doel 3&4. The different leakages from the cooling water pipes

would result in a joint leakage flowrate of around 10 m^3/s spread over the site. Added to this would be a leakage flowrate of 0.7 m^3/s for each of the two bulkhead locations.

An analysis of the simultaneous failure of several reservoirs and pipes produced the conclusion that the safe shutdown would not be compromised in this regard:

- At Doel 1&2, the equipment required for a safe shutdown after an earthquake is located in buildings RGB, BAR, GNS and GNH. In the area of BAR, GNS and GNH, the intrusion of a limited quantity of water would be possible in the buildings. BAR does not have a basement and all the important equipment is situated on a base, which means that its functioning would not be compromised. The accesses to the GNS are themselves located at around 0.8 m above the ground, which means that water intrusion is ruled out or, in the worst case scenario, would be very limited. GNH and GNS both have safety-related submersible pumps connected to the power supplied from GNS. This makes it possible to pump out the limited quantity of water that can enter.
- At Doel 3&4, GVD and MAZ can flood but, except for the AF pumps located behind the watertight doors, there is no safety equipment there. Water cannot intrude into the reactor buildings. All other buildings that contain safety equipment can experience very limited flooding. The bunkers are also equipped with safety-related submersible pumps, which means that a safe shutdown is always possible with the equipment from the bunker.

2.3. Synthesis of the main results presented by the licensee

Based on the information in the licensee's stress test reports and the additional information provided by the licensee during technical meetings and on-site inspections, the main results for the topic "earthquake" are as follows.

At first, in the 1970s, no earthquake was considered in the design of the first two units, namely Doel 1/2. For the other units, various peak ground accelerations (PGA) for the safe shutdown earthquake (SSE) were used: 0.10 g for Tihange 1, Doel 3 and Doel 4; 0.17g for Tihange 2 and Tihange 3. The PGA are the main data for characterization of the seismic level for which the seismically qualified structures, systems and components (SSC) are designed in order to keep their integrity and remain functional.
After the first periodic safety review, a PGA level of 0.058 g was defined for Doel 1/2 and the initial PGA level of 0.1g was increased to 0.17g for Tihange 1.
The methodology used to determine the PGA is based on a study of the seismic hazard. Deterministic approaches were used, based on historical data and known seismic faults.

In April 2011, the licensee commissioned the Royal Observatory of Belgium ("ROB") to conduct a new study in order to reassess the validity and adequacy of the reference earthquake level at Doel and Tihange, taking into consideration the recent developments in seismic hazard assessment such as the use of probabilistic approach. The ROB performed a probabilistic seismic hazard Assessment (PSHA) for both sites, using different assumptions in relation with the source-model zone or the attenuation law. Given that there are various uncertainties, a logic tree combining the different hypotheses and laws was performed. Then a statistical treatment gave the corresponding PGA related to a given return period and the mean or percentiles of the exceedance rate. In addition, a sensitivity analysis of the different choices made was performed. This resulted in new values for the PGA on each site, i.e. 0.081 g for Doel and 0.23g for Tihange.

With the results of this study, assessments of the seismic robustness of the seven units could start. A seismic margin review ("SMR") was chosen by the licensee to accomplish this task. The SMR methodology is based on the seismic margin assessment ("SMA") described in the EPRI publication NP-6041. Differences are that the SMR does not look for the seismic robustness of the SSC but rather looks at the probability of the SSC to withstand a certain review level earthquake ("RLE") spectrum for which the PGA level is 0.17g in Doel and 0.3g in Tihange. This is a conservative approach because this RLE spectrum envelops the spectra determined by the ROB study.

In other words, the licensee evaluated the seismic vulnerability of the SSC on a "high", "medium" or "low" scale corresponding to the probability that the SSC will keep fulfilling its safety function. The licensee commissioned the American expert organization Simpson, Gumpertz & Heger ("SGH") to undertake on-site inspections ("walkdowns") according to this SMR methodology. Several teams were formed for different units; an additional team was included for an independent review. Walkdowns focused on the seismic robustness of the SSC, their adequate anchorages, the mounting of internal devices and the potential spatial interactions. These criteria are different depending on the SSC to be assessed.
A preliminary work was done by the licensee to list all SSC to be checked. SGH teams reviewed these lists which contain the identification number, description and location in the buildings.

Walkdowns performed so far concluded that:

- for the three oldest units, few SSC are identified as belonging in the "low" category,
- for the four most recent units, SSC outside the reactor building can easily survive the RLE,
- no cliff-edge effect related to a seismic event can occur.

Corrective actions are planned by the licensee to solve the identified weaknesses of the SSC in the "low" category. Walkdowns concerning the SSC in the reactor building of the four most recent units will be performed next year during outage period.

2.4. Assessment and conclusions of the regulatory body

The approach used to update the seismic hazard and to assess the seismic robustness of the seven units is in conformance with the methodology defined by the licensee and approved by the regulatory body.

The regulatory body performed a dedicated follow-up throughout all steps carried out by the licensee with respect to the seismic reassessment. After examination of the licensee's reports, the PSHA study from the ORB and the seismic walkdown reports from SGH, technical meetings and on-site inspections were organized.

Based on the assessment of the licensee's reports and the supporting documents, the subsequent technical meetings and the on-site inspections, the regulatory body considers that the resulting action plan of this seismic reassessment is adequate.

However, the regulatory body identified additional demands and recommendations to further improve the robustness of the facilities against the seismic hazard:

1. For all weaknesses identified during the walkdowns (SSC assessed as having a "low" probability of preserving their integrity and performing their function in an earthquake exceeding the RLE), the licensee reported that either complementary studies are underway or simple modifications can be undertaken. The licensee shall provide a detailed action plan containing actions taken and actions planned. This also applies to the feasibility study on reinforcement of the electrical auxiliary building ("BAE") at Tihange 1.

2. Due to the stringent timeframe of the European stress tests, the PSHA study of the ROB had to be conducted in quite a short time. As suggested by the ROB, the licensee should carry out a more elaborated study with due consideration of (1) other elements such as the use of a more recent ground-motion prediction equation or such as a cumulative absolute velocity ("CAV") filtering, (2) external reviews by international experts and (3) results arising from other studies such as the EC-project SHARE (seismic hazard harmonization in Europe).

3. The licensee must continue its efforts towards fostering awareness of potential seismic interaction inside the facilities. In particular, thorough attention must be paid to the strict application of the relevant procedures to avoid the interactions of scaffoldings with SSC that are seismically qualified.

3. Flooding

In order to provide a self-standing national report for the subsequent peer review process, first the relevant information supplied by the licensee in its stress tests reports is recalled.
At the end of this chapter, a final section provides the conclusions and the assessment of the Belgian regulatory body (FANC and Bel V).

3.1. Design Basis

3.1.1. Flooding against which the plants are designed

3.1.1.1. Characteristics of the design basis flood (DBF)

Tihange NPP
The three units of the Tihange NPP, situated on the same platform 71.5 metres above sea level, share the same basic design protection against flooding. The potential sources of flooding of the site, identified during design, are

- High water level phenomena in the basin of the Meuse river;
- Dam failure at Andenne-Seille upstream of the Tihange site;
- Malfunction of the downstream dam at Ampsin-Neuville.

The design analysis took into account conservative but still plausible hypotheses. For example, the combination of important high water and a dam breach at Andenne-Seille was not withheld since, in case of high water, the sluice gates of the dams are wide open in order to evacuate a maximum of water (the hydrodynamic load is thus reduced and does not endanger the dam).

The "Reference Flood" against which the Tihange site is protected, corresponds to the highest historically recorded flood level of the Meuse (in 1995), increased by 20%. The flow rate of the river for this Reference Flood reaches 2,615 m^3/s, compared to a normal average flow rate of $300m^3/s$ in winter and $50m^3/s$ in summer. In this situation the Meuse water level near the site reaches 71.30 metres (including uncertainty of 0.1 m) above sea level. In normal situations an average level of 69.25 metres is measured (regulated level of the Meuse to allow navigation).

Doel NPP
The Design Basis Flood (DBF), the reference flood height taken into account in the original design of Doel 1&2 and Doel 3&4, is described in the Safety Analysis Report. Important references for the DBF are the historical data concerning the highest water levels due to tides or storm surges.

- The highest water level ever recorded (1 February 1953) was +8.10 m TAW ("tweede algemene waterpassing" or "second general water level measurement". TAW is the reference height used for measuring topological heights in Belgium. A TAW-height of 0 metre is equal to the average sea level at low tide in Ostende).
- The mean high tide is +5.08 m TAW.
- The report by the DELTA committee states a probability of occurrence of once every 10,000 years for tides with a height of +9.13 m TAW for the strait of Bath (to the north of Doel). This 10,000 yearly flood was used as the Design Basis Flood (DBF).

3.1.1.2. Methodology used to evaluate the design basis flood.

Tihange NPP
The original design basis flood for the Tihange NPP was fixed with reference to the practice used in civil engineering at the time for the design of constructions on the Meuse. It stipulates that: "The dams and embankments on the Meuse in the stretch of the river from Andenne to Liège have been arranged to be able to take a flow rate of 2,200 m^3/s, which is the flow rate of the high water of 1926

(1,862 m³/s) increased by 20%". The design basis flood would thus correspond to a flow rate of the Meuse of 2,200m³/s, causing a rise of water level of up to 69.80m.

Following the important floods in 1993 and 1995 in the Meuse valley (maximum flow rate 2,179 m³/s), the flood statistics have been reviewed as part of the periodic safety review. The "Reference Flood" for the site in Tihange was reassessed using the original methodology. It currently corresponds to the highest historically recorded flood level of the Meuse (in 1995), increased by 20%. The flow rate of the river for this Reference Flood reaches 2,615 m³/s and the the water level reaches 71.30 metres.

The Tihange nuclear power plant is protected against this Reference Flood by the altitude of the platform on which it is built and by the height of its peripheral protections. The units stay dry and function normally. The site is however placed under a state of increased vigilance as a precaution.

Doel NPP

An evaluation of the design basis flood (DBF) was carried out during the periodic safety reviews. The DBF was reassessed on the basis of the most recent data (e.g. meteorological data, calculation models, nuclear regulations). The Doel nuclear power station is situated on the estuary of the river Scheldt. The different possible causes for flooding of a site located on an estuary were evaluated. The basic loadings taken into account and combined in the periodic safety review are:

- Storm surge from the North Sea and the astronomical tide;
- Additional wind surge in the case of a storm tide between Vlissingen and Doel;
- Wind waves, wave run up and overtopping.

The highest water level ever recorded is still that of 1953. A study concluded that the mean high tide shows a slightly rising tendency. The flood level with a 10,000 yearly recurrence was reassessed at (an average of) +9.35 m TAW near the site.

3.1.1.3. Adequacy of design basis flood

Tihange NPP

The site design studies took into account a possible breach of the upstream dam at Andenne-Seille. The resultant wave was compared to the Reference Flood of the Meuse. A failure of the dam upstream of the site will have no consequence on the functioning of the reactors on the site in Tihange, the water wave being sufficiently reduced as not to exceed the level of the embankments.

Furthermore, within the framework of the most recent periodic safety review (2005), the University of Liège recently reassessed the impact of a breach of the dam at Andenne-Seille. In the hypothesis of a breach occurring outside the period of high water, while the Meuse is at its mean level and supposing the obstruction of the downstream dam, this new study estimates that the wave will hit Tihange 36 minutes after the breach and that the crest of the wave will reach the level of 70.64 m. This level remains lower than the level reached by the Reference Flood.

The design studies also dismissed any risk of flooding of the site of Tihange due to a malfunction of the dam at Ampsin-Neuville, situated downstream. Flooding of the site cannot result from a malfunction of the dam situated downstream of the site, since the dam has an emergency electric power supply and each of the flow regulators can be manoeuvred in the absence of electric power.

No top level of the flood protection constructions along the site, whether it is the site platform border or the walls of the water intake channel is situated at a level below 71.35 m. The site is therefore currently protected:

- against the Reference Flood characterised by a water level of 71.30 m (including rises by the drainage network and the margin of uncertainty);
- against breach of the upstream dam at Andenne-Seille combined with the obstruction of the downstream dam, whereby the submersion wave would induce a water level lower than that of the Reference Flood.

On the other hand, the evolution of nuclear regulation has led to the use, in the latest periodic safety review, of a probabilistic methodology to determine the flood level of the Meuse as a function of return period. One of its conclusions is that the Tihange site is currently protected by its design against a Reference Flood with a statistical return period that can be counted in centuries (between 100 and 1,000 years). The level of the Meuse at the site in Tihange was determined up to a flood with a return period of 10,000 years (decamillennial flood). This decamillennial flood was defined as the millennial flood (with a confidence interval of 70%) plus 15%. The corresponding flow rate is 3,488 m3/s. No known historical source mentions a high flow rate of that magnitude. It should be noted that such a flow rate could result only under exceptional circumstances combining rapid melting of snow and a long period of heavy rain. This extreme phenomenon can also be forecast.
Nevertheless, it was decided to adopt this decamillennial flood as the new design basis for the Tihange NPP so as to comply with the international standards. The strengthening of the lines of defence was therefore studied and certain planned modifications have already been effected.

Doel NPP

The periodic safety review concluded that the protection against external flooding of the Doel site is still adequate: the flood level corresponding with a 10,000-year return period (+9.35 m TAW) remains substantially below the minimum height of the embankment at Doel (+11.08 m TAW).

3.1.2. Provisions to protect the plants against the design basis flood

3.1.2.1. Protection of the site

Tihange NPP

The Tihange NPP is located on the right bank of the Meuse, on a horizontal platform 71.5 metres above sea level, or two metres above the regulated level of the river.

The site in Tihange is protected by the height of the borders of the site platform and the water intake channel. The water intake channel is protected by banks topped at its upstream side with a breast wall of seismically anchored concrete blocks. The banks of the water intake channel have been raised particularly in order to be able to accommodate the Reference Flood. No mobile device has to be installed to guarantee this protection. This protection is permanently operational and does not require human intervention.

This stretch of the Meuse is bounded upstream by the Andenne-Seille dam and downstream by the Ampsin-Neuville dam. Access is via the main road Liège-Huy, which marks the southern limit of the site (the Meuse being the northern limit), or by the secundary roads Huy-Hamoir and Liège-Dinant. The whole network is situated at an altitude equal to or higher than that of the Tihange site and has a sufficient number of roads above the flood plain (including foreseeable maximum high waters) to allow access to the site (see Figure 1).

The red zone in figure 1 does not clude any safety related equipment or building. The orange zone includes almost all the safety related buildings. In this zone the entry gates to the buildings are at 71.5 m, or on average 20 cm above the ground. The green zone is situated much higher than the rest of the site, by 2 m on average.

Figure 10 -The different altimetric zones of the Tihange site

Doel NPP

To minimise the risk of flooding, two important measures have been provided for in the design of the site: firstly, the entire site, including all the nuclear installations, is situated on a raised platform and, secondly, the Scheldt embankment, which serves as a barrier for the site, has also been raised. The protection against the DBF is formed by the choice of the height of the platform on which the entire site is located, combined with the height of the embankments near the site.

- The platform was raised to +8.86 m TAW which means that the NPP site is surrounded by lower-lying polders.
- The embankments along the site were raised to +12.08 m TAW, compared to +11.08 m TAW for the Scheldt embankments in the surrounding area. The possibility of settlement of the embankments over the course of time was taken into account. The technical specification of the Doel NPP require that the embankment crown has to have a minimum height of +11.08 m TAW.

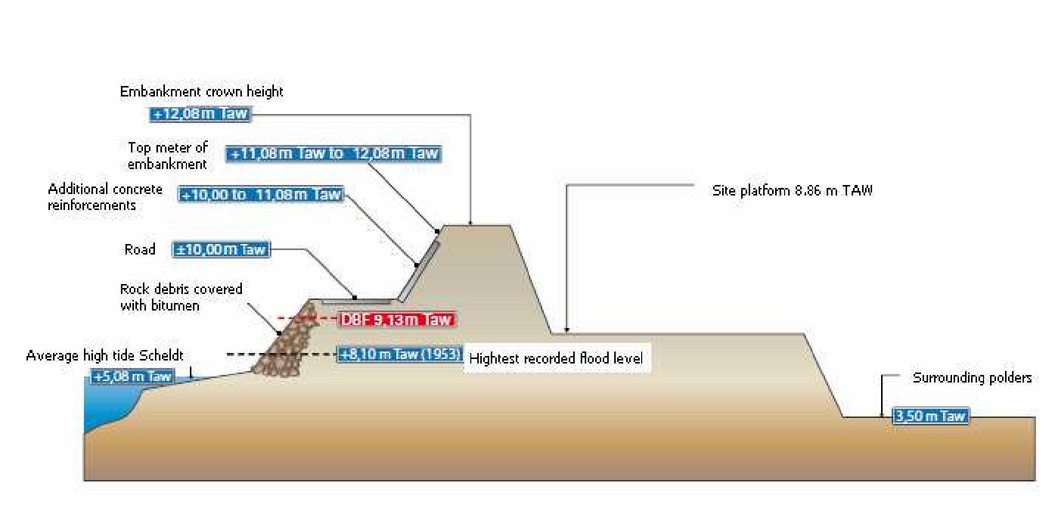

Figure 11 - Design provisions at the Doel NPP against DBF (Cross section of the embankment)

3.1.2.2. Systems, structures and components

Tihange NPP

The objective of the protection against the Reference Flood is to keep the site dry. Thus, in case of high water less than or equal to the Reference Flood, no equipment on the facility will be affected. All the systems, structures and components necessary to ensure stable and controlled shutdown of the units remain available.

The equipment of the pumping stations providing the untreated water intake from and discharges into the Meuse are located at such heights that they do not risk flooding in case of Reference Flood.

Doel NPP

The platform of the Doel 1&2 water intake located in the Scheldt is situated at approximately the same level as the site. The eventual loss of the primary ultimate heat sink (the Scheldt) in the case of a DBF is taken care of by an alternate ultimate heat sink (untreated water circuit (RW)) located on the site within the protection of the embankment. The pumping station for the Doel 3&4 water intake is protected by the embankment.

In the case of the DBF, only the circulation water circuit (CW) of Doel 1&2 may be unavailable, nothing else is destroyed.

3.1.2.3. Additional design provisions to prevent infiltration of groundwater

Tihange NPP

During construction of the installations protective measures were taken against the risk of infiltration by groundwater.
The level of the groundwater table is on average 67.5 m, or about two metres below the regulated level of the Meuse (69.25 m). Along the Meuse the low permeability of the alluvial deposits prevents the immediate transmission to the water table of fluctuations in the level of the river. Given this delay effect a rapid substantial rise of the groundwater table can be excluded, even after a period of high water. The site itself is also protected from fast infiltrations by a surface layer of silt and the covering of much of its ground with asphalt.

In Tihange 1, for the parts of buildings situated in the ground, and for the basemat, the concrete external walls were integrally covered with a bituminous coating in order to strengthen the tightness. In Tihange 2 and 3, a flexible "butyl"-type watertight membrane was placed on the surfaces in contact with the ground in all seismic category 1 buildings and constructions with the exception of the pumping station. This watertight membrane wraps the walls in the subsoil. The ground water tightness of the buildings is therefore guaranteed.

The level of the water table is also measured at regular intervals, allowing its (slow) evolution to be monitored. All the immersed safety related buildings are equipped with sumps with drainage pumps, inspected on daily rounds.

Doel NPP

The following criteria/provisions apply for the protection of the underground structures of the Doel 1&2 and Doel 3&4 buildings:

- In the calculations, a ground water level of + 7.00 m in Doel was taken into account.
- The underground walls are constructed by using reinforced water-repellent concrete.
- The surfaces of the walls coming into contact with the earth are covered with a waterproof layer comprising three coats of tar. The masonry was coated beforehand with a waterproof cementation.
- The joints between the buildings or the connecting joints of the underground channels consist of a waterproof thermoplastic material.

3.1.2.4. Main operating provisions to prevent flood impact to the plants.

Tihange NPP

Taking into account of the actual design of the site, which passively ensures its staying dry in case of Reference Flood, no specific action is required to protect the installations from flooding. However, as a precaution, preventive measures exist, described below.

First, when the regional department responsible for flooding protection (Service d'études hydrologiques SETHY) forecasts a flowrate of the Meuse greater than 1,500m³/s, which happens approximately once every two years, this department goes in a state of alert and warns the Tihange site (shift crew of Tihange 2). The shift crew team of Tihange 2 then has to maintain regular communication with SETHY to stay informed of the development of the situation. In parallel it informs the other two units and signals the passage to an alert state on account of the risk of flooding. In each unit the shift crew takes specific actions to monitor the state of their unit to ensure swift detection of any flooding.

Doel NPP

A proactive flood alarm raises the alertness of the shift crew teams.
The following alarm phases are initiated on the basis of the information provided by the regional department responsible for flooding protection ('Waterwegen en Zeekanaal' departement):

- 'Storm tide Sea Scheldt basin': level of the Sea Scheldt > 6.60 m TAW
- 'Dangerous storm tide in the Sea Scheldt basin': level of the Sea Scheldt > 7.00 m TAW

In accordance with procedure, a number of measures are then taken. This concerns, among other things, actions such as closing the entrances of the Doel 1&2 water intake, checking the leak-tightness of the roll-on-roll-off installation at the embankment, and preventive placing of sandbags at the critical entrances to the buildings.

Sufficient time is allocated for the actions following on the warning "dangerous storm tide in the Sea Scheldt basin". As soon as the water level reaches 7.58 m TAW, there are two hours left before the water reaches the height of the site platform, the water is then still well below the embankment crown.

3.1.2.5. Other possible consequences of the DBF

Tihange NPP

Loss of external power supply
Each unit in Tihange has internal redundant diesel generators, situated on the platform of the site and therefore protected from the Reference Flood. These internal sources are sufficient to power all the systems necessary for the stable and controlled shutdown of the units. Although the external electric power supply can resist this type of high water without damage, the scenario of a Reference Flood combined with a loss of external electric power has been taken into account. Such a situation would not have any impact on the site, which would then use its internal electric power supply.

Circumstances outside the site with the risk of flooding
In case of Reference Flood the road network around the site remains operational and the links to the main towns or external resources (emergency or fire services) remain free. More particularly a four-lane road remains available allowing the passage of large vehicles.

Doel NPP

Loss of external power supply
The protection of the systems (including diesel generators) intended to compensate for failure of the external power supply is included in the design provisions of the site – e.g. the platform height and the embankment.

Circumstances outside the site with the risk of flooding
The Scheldt embankment protects the area around the site against possible flooding. Should the polder embankments fail, it is possible that the access roads to the power station will become unusable.

Embankment failure
In case of a theoretical extreme storm and the accompanying embankment stressing, the risk of an embankment failure near the site cannot be excluded. This does not necessarily mean that the embankment will immediately collapse as an embankment always has a residual strength. This does mean that the embankment could collapse in the event of a subsequent storm if no repairs are made. An inspection and maintenance programme is therefore provided.
A recent study – based on the structural layers of the embankment (determined by means of soil drilling tests) combined with the applied strengthening mechanisms (for example rock debris poured over with bitumen, etc.) – showed that the initiation of an embankment failure can occur for a severe storm with a return period of 1,700 years (this is the value at the most critical point of the embankment, determined on the basis of the layer structure of the soil) combined with wind/storm from the NW to N direction.

3.1.3. Plants compliance with its current licensing basis

3.1.3.1. General organization of the licensee to guarantee conformity with design basis

Tihange NPP
In order to identify possible non-conformities, the equipment protecting the site is inspected regularly:
- the breast wall along the south bank of the water intake channel, built with concrete blocks, is the subject of a maintenance plan to ensure that it can perform its function properly in case of high water;
- the river embankment walls are the property of the Walloon Region, which attends to their maintenance.

Doel NPP
The Scheldt embankment crown height along the ground of the power station must be at least +11.08 m TAW (requirement of the Technical Specifications). If the embankment crown height falls below this level, it must be restored before the water level of the Schelde exceeds +7.58 m TAW. This embankment crown height has to be checked every 10 years.
In practice, the embankment crown is measured every five years – which is stricter than specified in the safety analysis report. The most recent height measurements (2011) were positive: the requirements of the technical specifications are perfectly met.

The roll-on-roll-off bulkheads must be closed at all times. This is also checked on a weekly basis. Tightness of the roll-on-roll-off is checked via an annual inspection plan.

The periodic inspections and maintenance of the Scheldt embankment and the embankment around the LU ponds are conducted according to a maintenance plan and procedure; this is carried out on an annual basis. In this way, the structural integrity continues to be guaranteed. The entire exterior of the Scheldt embankment is also inspected annually and maintained by the Public Service 'Waterwegen en Zeeschelde'.

3.1.3.2. Use of mobile or specific equipment

Tihange NPP

In case of water infiltration despite the design protection of the site and if the fixed drainage pumps are not sufficient to evacuate the water locally, the site will use additional equipment of which the availability is guaranteed at all times. These are:

- forty immersible pumps of different capacities;
- a rapid sandbag-filling installation;
- a stock of sand for about 500 bags, 150 of which are already filled and ready for use.

No off-site equipment is therefore necessary to respond to a Reference Flood.
Certain active equipment, such as the immersible pumps, is used during unit outages for operational purposes. At the end of unit outage ten pumps are systematically returned for maintenance on to the manufacturer. All these operations guarantee there good performance.

Doel NPP

The operating licence does not mention that mobile equipment has to be permanently available in the case of a DBF.

3.1.3.3. Potential deviations from licensing basis and actions to address those deviations.

Tihange NPP

As a result of the disaster in Fukushima, a complete inspection of the installations protecting the site from a Reference Flood was conducted on the basis of WANO SOER 2011-02. No non-conformity was detected on that occasion. No specific corrective action was necessary.

Doel NPP

Doel is protected against flooding by the height of the site platform and by the embankments. This is included in the design basis. For this, there exist no deviations.
As a result of the disaster in Fukushima, Doel has drawn up a response in relation to WANO SOER 2011-2. A number of specific actions have been initiated in relation to the flooding risk; a few examples:

- The stock of sandbags has been increased.
- In order to raise the self-sufficiency of the site, additional autonomous diesel pumps have been purchased.
- Inspections and checks of flooding protections (embankments) are conducted more frequently, with time intervals that are mostly more stringent than those specified in the Safety Analysis Report.

3.2. Evaluation of safety margins

3.2.1. Estimation of safety margin against flooding

3.2.1.1. Measures taken during the alert phase and during flooding

Tihange NPP

Flooding of the site can only occur for floods of the Meuse river exceeding the Reference Flood (2,615 m³/s). Concerning the response strategy for floods exceeding the Reference Flood, the licensee has opted for a unique strategy without making a distinction between floods slightly exceeding the Reference Flood and the decamillennial flood for which the site would be covered by 1.70 m of water at certain locations.

The response strategy starts with a transition to one of the two safe shutdown states that can be stabilised before flooding water begins to invade the site. The safe shutdown states are:

- cold shutdown, characterised as follows:
  - the reactor vessel is open;
  - the BAN-D and reactor building pools are filled and in communication via the transfer tube, which considerably increases their thermal inertia.
- two-phase intermediate shutdown, characterised as follows:
  - a pressure of 10 bars and a temperature between 120 °C and 140 °C in the primary circuit. The pressurizer is partially filled (approximately 75%);
  - all the compartments of the BAN-D pools are filled, but the reactor building pool is empty (the transfer tube is closed);
  - the steam generators are depressurised by opening the atmospheric steam release valves. They are filled to the maximum in order to maximize thermal inertia.

A flooding alert process starts with SETHY which can provide Meuse flow rate forecasts for up to several days in advance. When SETHY records a Meuse flow rate greater than 1,500 m³/s, this department goes in a state of alert and contacts the site of Tihange. The shift crew team of Tihange 2 then has to maintain regular communication with SETHY to stay informed of the development of the situation. In parallel it informs the other two units and signals the passage to an alert state on account of the risk of flooding. In each unit the shift crew takes specific actions to monitor the state of their unit to ensure swift detection of any flooding.

In direct communication with SETHY the shift crew is informed of the expected evolution of the flow rate of the river. As soon as a flow rate prediction of 2,500 m³/s is reported, the shift crew of Tihange 2 activates the Internal Emergency Plan, calling out the emergency team. The task of the emergency team, on the basis of the forecasts from SETHY and the predicted flood level, is to initiate the shutdown of the units and the deployment of the CMU-equipment (Circuit des Moyens Ultimes or Ultimate Means System). Made up of fixed or mobile pumps, pipes and valves, the CMU has an independent electrical power supply and protects the power station against a beyond-design basis flood. Bringing the units in the most appropriate safe shutdown state takes ten hours.

When conventional equipment is rendered unavailable through flooding, the CMU-equipment - preinstalled during the alert phase - of each unit is used. Procedures intended for the shift crew and the maintenance crew describe the operations to be executed. The technical shift crew is sufficient to install the CMU-equipment within the set time limits.

The shutdown of the reactor units, organised at least ten hours before progressive flooding of the site begins, greatly reduces the residual energy to be evacuated. When the water reaches the site there is a maximum of 20 MW of thermal power to be evacuated from each reactor, or less than 1% of the rated power. The CMU can then ensure the continuous cooling of the three reactors and the spent fuel pools.

The (mostly mobile) CMU-equipment, preinstalled during the flooding alert phase, is not brought into service until the time of actual failure of classified equipment so that the latter is not lost while still operational. The components of the CMU are placed at sufficient levels to be protected from a decamillennial flooding, with a margin of more than two metres. Access to the necessary buildings and equipment remains possible during flooding. Movement between the units is by means of boats. Inside the units most movement is on foot, whether in the buildings, on external footbridges installed for the purpose or via rooftops.

Once the site is flooded, no external assistance is necessary in the short term. In fact, the CMU-equipment can keep the units in a stable and controlled state for more than 15 days without external supply (of power, fuel, water, oil etc.). This is sufficient for the period of flooding (estimated at 5 days by the University of Liège), and for a protracted post-flood period. This leaves the maintenance services ample time to provide and install the necessary material to restore the essential equipment on a permanent basis.

Doel NPP

Flooding on the site or in the polders can only occur in the case of very severe storms. Proactive warnings should be available as discussed previously. The NPP staff will be in a heightened state of alertness. Emergency plan procedures will be kept on hand and a number of preventive actions are taken. This includes, among other things, inspection tours to ensure swift detection of any flooding and the preventive placing of sandbags at the critical entrances to the buildings. The same emergency plan can also be announced in a reactive manner.

The platform on which the entire site is built is surrounded by polders located five metres lower. In the case of a (beyond-design) embankment breach, there is a very real chance that these polders will flood. In such a situation, the Doel NPP site will become effectively an island. The following elements are important in the case of such a flooding: evacuation and access for people, food supply, fuel supply for safety systems and emergency diesel units. The appropriate measures are described in the emergency plan procedures.

Should flooding on the site occur, both emergency plan procedures and mobile equipment will be used. The emergency plan procedures describe all the actions to be taken in the case of flooding. There are a number of actions to start with: closing the entrances at the Doel 1&2 water intake, checking the tightness of roll-on-roll-off, etc. Then a cascade of notifications occurs – a flow chart indicates who has to be called on what moment and what the task assignments are of:

- members of the guard duty,
- security personnel,
- on-site fire service,
- shift crew teams.

Mobile equipment can be used by three different organisations:

- The Doel NPP has its own resources present on site: five mobile electric pumps and eight diesel pumps (e.g. diesel-driven high-flow-rate pump of 10,000 l/min), approx. 450 sandbags, etc. A number of mobile diesel pumps (capacity per pump: 10 m^3/h) are also available for each reactor unit to remove flooding water in buildings.
- The fire department of Beveren is the closest external fire service and will be called on first. The fire department has four high-flow-rate pumps at its disposal (up to 10,000 l/min).
- The civil defence department of Liedekerke has automatic pumps at its disposal (up to 10,000 l/min), electric pumps, motor pumps, sandbags (150,000 items), motor boats, etc.

3.2.1.2. Analysis of the circumstances under which flooding of the site could occur

Tihange NPP

All safety-related equipment involved in ensuring a stable and controlled state in the three units are situated at more or less the same altitude of 71.50 m. However, the level of the Meuse is not a sufficient criterion for predicting the extent of the affected zone. This will depend on the flow rate of the river since, during high water, the level of the river upstream of the site is 0.5 m higher than the downstream level. Much of the water penetrating the platform from the upstream side will therefore run back to the Meuse across the lower zones of the site without reaching a high water level elsewhere on the platform. The extent of the zone under water will therefore depend on the flow rate of the river Meuse. The higher the flow rate the greater the surface of the site under water. Tihange 1, which is located most upstream, will be the first unit to be hit, followed by Tihange 2, then Tihange 3. At the request of the licensee, the University of Liège conducted a study combining the flow rate of the Meuse, the corresponding water level and the topography of the site in order to model the water flows on the platform.

Doel NPP

Waves overtopping the Scheldt embankment

In a severe storm, a high water level combined with an unfavourable wind direction can cause waves overtopping the embankment.

This risk was analysed during the periodic safety review. This analysis shows that wave overtopping can occur for severe storms with a return period exceeding 200 to 300 years. The water volume running over the embankment becomes relevant for severe storms with a return period of 1,000 to 10,000 years.

Based on a simplified model in which the wave overtopping acts as the source of water on the site and where this water flows to the lower-lying polders at the edge of the site, flooding on the site can be estimated to be an average of 10 cm for a severe storm with a return period of 10,000 years.

Beyond-DBF Embankment failure near the site

In the case of a severe storm combined with an unfavourable wind direction, the embankment can be subjected to such a stress that embankment failure becomes a real risk. In such a case, a breach can occur and water can flow onto the site. This risk was analysed during the periodic safety review. The initiation of an embankment failure can occur for a severe storm with a return period of 1,700 years. An initiation means that the embankment could fail in case of a subsequent storm event if no repairs were performed in the time after initiation.

In the analysis of the consequences of a Scheldt embankment breach near the site, the most unfavourable (most severe) storm that can lead to embankment failure, is assumed, cumulated with a high level of the Scheldt. The maximum Scheldt level for this storm is postulated to be at 10.2m TAW, which is 85 cm higher than the average 10,000-year flood. The analysis shows that the water will reach the first buildings after about 60 minutes; this water will flow further towards the polders via the edge of the site.

An average flooding level of 20 cm is estimated on the site. Taking into account the site topography, greater flooding is expected locally. In general, local water depths between 60 and 30 cm are estimated for places close to the breach location and for lower-lying parts of the site.

3.2.1.3. Consequences of flooding for the safety functions

Tihange NPP

The consequences analysis is based on the height of water reached in the various places on the site and, for each location, on the equipment present there and likely to be affected. All equipment that can assist the cooling of the fuel in the core or in the pool is examined.

This analysis does not depend on the initial state of the units (power operation or shutdown).

Once the flow of the Meuse exceeds 2,615 m³/s, the water penetrates the site without direct consequence since no safety related building is affected: the water stays contained in the area north of the water intake channel. An increase of approximately 200 m³/s is required, or a flow rate approaching 2,800m³/s, before there is any threat to the safety electric power supply for Tihange 1 and before loss in Tihange 2 of the CEU Meuse or groundwater pumps. The cooling by the steam generators (or the residual heat removal system RRA in unit shutdown) is still available since it is provided by the still-dry GDS and CEB-CRI-EAA-EAS equipment.

At 2,800 m³/s Tihange 1 is completely surrounded by water. All the buildings of the unit, except the reactor building, will be flooded. The systems providing the cooling of the pools are out of service, likewise the RRA (the CMU-equipment takes over). The turbopomp of the auxiliary feedwater system (TPA of EAS system) remains functional because it is mounted on a support socle.
The return period of such a flow rate is approximately 400 years.
In parallel the water begins to infiltrate through the entry door of the BAN-D of Tihange 2. The flow can be dammed using sandbags and runs off to the exterior by pumping. Tihange 3 still remains dry.

At 2,900m³/s, a flow rate that occurs nearly every 600 years, the TPA of EAS of Tihange 1 is lost. Only the CMU feeds the steam generators.
The lower parts of the BUS of Tihange 2 are flooded and the associated second-level emergency safety systems are lost. The underground levels of the BAN and EA are flooded, and the spent fuel pool can no longer be cooled by the CTP circuit (the pumps are submerged). Even if the TPA EAA stays above water, some of the steam and/or water isolation valves might be closed on inadvertent automatic signals. It is still possible to open the valves "manually" (from the BUS) and maintain the steam generator cooling function.
In Tihange 3 water begins to penetrate the BAN-N from the rear side of the unit. It causes water infiltration towards one of the three BUS air intakes. This air intake is fitted with a shut-off valve that will be closed during installation of the CMU in order to avoid flooding of the BUS of Unit 3.

At 3,000m³/s the last safety related equipments of Tihange 2 are lost. Only the CMU equipment remain in service to provide cooling of the core. The return period of a flow rate of this magnitude is approximately 900 years.
In Tihange 3 the BAN is flooded. Only the GDS and the CEB pumps remain operational, providing power to the instrumentation and part of the equipment at 380 V. If the unit is in intermediate shutdown, cooled by steam generators, this will be sufficient to maintain the functioning of the TPA EAA and its water supply by the CEB and, thus, to cool the core. If the unit is in cold shutdown the RRA no longer cools the core and the CMU takes over the supply of water to the pools.

Above 3,300m³/s no safety related systems are operational in the three units even if the external power supplies of Tihange 3 remain available a priori (the sensitive points are one metre above ground level).

Finally for a decamillennial flooding (3,488 m³/s), all the electric power panels are lost due to the flood or because of the activation of protective devices by short circuits due to the water. The diesel generators in the three units are now all under water (GDS, GDR, GDU and DUR). Only the batteries of the first safety level (and those of the second emergency level systems in Tihange 1) are still available for the three units.

Doel NPP

The buildings which are flooded first or quickest in the case of wave overtopping or embankment failure were identified. For the most important SSC and their physical location, it is checked whether there are any thresholds, plinths, etc. present to protect against the consequences of flooding in case of wave overtopping or embankment failure. Only the availability of devices set up in basements or at ground level is assessed as there is no danger to the others.
Three factors play an important role: firstly, the height of the respective entrance; secondly, the distance from the Scheldt; and, thirdly, the access threshold.

- The lower-lying buildings will have to cope with greater flooding.

- In the lower-lying parts of the buildings, there are immersible pumps present to remove the inflowing water.
- There are two separated drain systems: the sewer system on the site is not connected to that in the buildings themselves.

Consequences of waves overtopping the Scheldt embankment
The flooding in the case of wave overtopping remains limited to about 10 cm on the site. The SSC required for achieving the safe shutdown state remain available in this case. Furthermore, sandbags are preventively laid at the critical entrances in case of a storm warning.

Consequences of Beyond-DBF Embankment failure near the site
The flooding in the case of beyond-DBF embankment failure is estimated to about an average value of 20 cm on the site. Taking into account the site topography, greater flooding is expected locally.
The emergency systems (2nd safety level) remain available for Doel 1&2 and Doel 3. For Doel 4, the safety systems (1st safety level) will continue to be safeguarded from the intrusion of water; the GVD can flood but the AF pumps remain available. Limited flooding can occur in the BKR.
During storm warnings, sandbags are preventively laid at the critical entrances. These have to protect the important buildings against flooding.

3.2.1.4. Weak points and cliff edge effects

Tihange NPP

To all intents and purposes, the Tihange site is flat in design. The difference between the regulated level of the Meuse and the banks of the site (or the protective breast wall along the water intake channel) is in the order of two metres. Although those two metres are enough to avoid flooding by the river up to a high water flow rate in the order of 2,615 m³/s the absence of higher walls creates a weak point. The same applies for the Meuse river water intake channel and the various outlets (cooling discharge from the three units and sewer system).

Few buildings are designed to be sealed against external flooding water (when that is the case this protection is in the order of 0.2m). The vulnerabilities of these buildings are the entrances that do not stop the infiltration of water. There is not sufficient internal capacity to store the flooding water, and the pumps of the various sumps are insufficient to evacuate the flow entering in such a situation.

In the pumping stations the raw water (CEB) and groundwater pumps are lost once the water level reaches 71.5 m at Tihange 1, while in Tihange 2 and 3 they are flooded when the water reaches a level of about 71.75m. Finally, the vital buildings such as the BAE building (except in Tihange 1 where it is on high ground), the BAN and the BUS are not equipped with doorsteps, and the water entering will flood the underground floors containing 75% of the safety systems (CIS-CAE-CUS). Once they are flooded the annular spaces will be next.

However, if various conventional pumps are damaged by flooding, their repair (or the replacement of electric power supply) will require only a few days once the waters recede. It will then again be possible to pump from the alluvial water table.

As described earlier, the decamillennial high water is not a sudden event; this allows SETHY to alert Tihange well before potential commencement of flooding of the site.

This period of time allows Tihange to organize, not later than ten hours before flooding of the platform, the following actions:

- safe shutdown and control of the three units;
- confinement of the containment and rendering the core subcritical;
- passage to a long-term stabilised safe shutdown state;
- deploying and aligning the CMU-equipment to guarantee maintenance of these safe shutdown states and to cope with failure of safety related equipment.

This mobile equipment, and the diesel generators used for their power supply, are all placed more than two metres above the maximum water level that would be reached bydecamillennial high water. They are therefore completely protected from such high water.

When the high water exceeds the Reference Flood the cliff-edge effects are the following:
- the first cliff-edge effect is a flow rate in the order of 2,800 m³/s, with water entering the essential buildings of Tihange 1.
- the second cliff-edge effect is reaching a flow rate of 2,900 m³/s, corresponding to the flooding of equipment on socles in Tihange 1 and the entry of water in Tihange 2.
- the third cliff-edge effect occurs at 3,000m³/s on the Meuse. Tihange 2 is then without its TPA EAA, the CMU is used for cooling the fuel.
- the final cliff-edge effect occurs for a flow rate between 3,000 and 3,300m³/s, a flow rate that results in the loss of the TPA EAA in Tihange 3. The CMU continues to cool the fuel in the pool and the core.

In conclusion, the progressive flooding of the site will lead to the progressive loss of a lot of classified equipment. When equipment providing the cooling of the fuel is affected, the CMU circuit of each unit will be used to assure the cooling of the fuel in the core and in the pool. The CMU can take over this function for more than two weeks.
None of these cliff-edges will interfere with the cooling of the core.

Doel NPP

The design protection of the Doel site against flooding is solid. Flooding of the site can only occur in case of a combination of a very high Scheldt level with considerable wind waves or with an embankment breach. In such cases, water from the Scheldt can run onto the site.
This water will then flow towards the edges of the site and into the polders. The extent of the flooding caused by this is a few tens of centimeters of water, depending on the site topography and the distance from the embankment or breach.

Cliff edge effects therefore occur either from the moment substantial quantities of water intrude through wave overtopping the embankment or from the moment an embankment breach occurs. The probability of significant cliff edge effects taking place, is however very low.
A weak point is that a number of buildings were not designed to guarantee water tightness in the case of tens of cm of water on the site.

3.2.1.5. Combination of flooding with unfavourable meteorological conditions

The combination of extreme weather conditions and flooding has been considered for the events where a plausible link between the phenomena exists. The purpose is to assess the impact of situations even worse than simple flooding.

Tihange NPP

Reference Flood + heavy rainfall
Given the presence of the silty surface layer and the fact that the Tihange site is largely covered with asphalt, most of the rain water falling on the site is collected in the sewers. The network of sewers is sufficient to evacuate the water in case of heavy rain. Since the level of the sewer outlets is higher than that which can be reached by the Meuse during a Reference Flood, the sewer network will remain operational and still allow discharge of rainwater. All safety functions will therefore remain operational.

Reference Flood + strong wind + LOOP
Wind, even strong wind, should not damage the massive structures of the masonry river embankments or the raised banks of the water intake channel.
However, the wind may set up a wave action on the river, and small quantities of water may then pour in over these protections. Once it reaches the site this water returns to the Meuse, either by the

sewers (the level of the sewer outlets is higher than that of the river during Reference Flood) or by runoff.
The sewer system which works by gravity remains operational. Only a part of the sewer system will be unavailable in Tihange 1 in case of loss of external electric power supply. Given the topography of the site, the surplus water in the sewer ditch will flow to the nearest gullies and, in the most penalizing cases, towards the protective wall of the water intake channel. When the level of this water reaches 71.35m it will flow off towards the water intake channel. No safety equipment will be affected by such a water level in the zone concerned.
Furthermore the buildings accommodating the equipment assuring the safety functions are designed to be capable of withstanding strong winds. All safety functions will therefore remain operational.

Beyond Reference Flood + heavy rainfall + LOOP
This situation combines high water exceeding the Reference Flood with heavy rain and the loss of external electric power supply (LOOP). The site platform being partially or totally flooded by the Meuse, heavy rain will not cause any additional problem. In fact, the CMU equipment standing in for the conventional equipment (rendered unusable by the high water) is situated in places protected from flood and rain. Since this equipment has its own dedicated source of electric power, the loss of offsite power has no impact.

Beyond Reference Flood + strong wind + LOOP
This situation combines high water exceeding the Reference Flood with strong wind and loss of external electric power supply resulting from strong wind. In case of high water beyond design, no classified equipment can be used, but the CMU is installed during the phase preceding the flood so as to guarantee the cooling of the core and the pools. However, some CMU equipment will require access from the outside.
During the actual flood certain buildings will not be accessible except by the rooftops. The movement of personnel will be hindered by the weather, which will slow down operations. However, the thermal inertia of the water in the steam generators will give ample time (at least 11 hours) for execution of the necessary operations.
Some CMU equipment situated outside (on the rooftops) is not designed to withstand storms. Consequently they risk being damaged.

However, the site has three identical mobile motor-driven pumps, each individually able to provide cooling of the core via the steam generators and of the fuel in the pool with make-up water. The thermal inertia of the water in the steam generators (11 to 14 hours, depending on the unit) will give ample time to connect this pump to the appropriate circuit.

Beyond Reference Flood + heavy rainfall + strong wind + LOOP
This situation adds heavy rain to the previous scenario (high water exceeding Reference Flood, strong wind and loss of external electric power supply). No additional constraint is noted compared with the previous situation.

Doel NPP

DBF + heavy rainfall
In the case of DBF, the Scheldt level remains well below the embankment level. Intense rainfall will be drained via the sewers or infiltrate into the absorbing sand ground of the site platform (See chapter 4 on extreme meteorological conditions). The sewers remain operational in the case of a DBF.

DBF + strong wind + LOOP
In the case of DBF, the Scheldt level remains well below the embankment level. Combined with strong wind from an unfavourable direction, this can give rise to wave overtopping of the embankment, as mentioned previously.
Strong wind can also lead to LOOP (see chapter 4 on extreme meteorological conditions). In the case of LOOP, the pumps of the sewer system that evacuate the water to the Scheldt river will fail to operate. The sewers will then lose their draining capacity, though the water retaining capacity of the sewers will be preserved. The analysis of the consequences in section 3.2.1.2 remains valid as it does not take into account the draining or retaining capacity of the sewer system.

Beyond-DBF + heavy rainfall + LOOP
As stated previously, the Scheldt level remains below the embankment level. The intense rainfall will no longer be drained via the sewers since the pumps in the sewer system will fail to operate in case of LOOP. The sewers will lose their draining capacity, though the retaining capacity will be preserved and the rainwater will flow to the edge of the site and further into the polders.

Beyond-DBF + strong wind + LOOP
As stated previously, the Scheldt level remains below the embankment level. Combined with strong wind from an unfavourable direction, this can give rise to wave overtopping of the embankment. Such a combination of a severe storm and unfavourable wind direction also leads to a considerable stress on the embankment with the risk of embankment failure.
Strong wind can also lead to LOOP (see chapter 4 on extreme meteorological conditions). In the case of LOOP, the pumps for the sewer system that evacuate the water to the Scheldt river will fail to operate. The sewers will then lose their draining capacity, though the retaining capacity of the sewers will be preserved. The analysis of the consequences in section 3.2.1.2 remains valid as it does not take into account the draining or retaining capacity of the sewer system and since the analysis assumes a maximum Scheldt level higher than the DBF.

Beyond DBF + heavy rainfall + strong wind + LOOP
This is a combination of the two preceding scenarios. The height of the water on the site in such a case will increase by a few cm compared with the height of water at wave overtopping or an embankment breach as discussed in section 3.2.1.2. The mobile diesel pumps on the site can be used as a replacement for the pumps in the sewer system.

3.2.2. Measures which can be envisaged to increase robustness of the plants against flooding.

3.2.2.1. Improvements to infrastructure

Tihange NPP
Possible improvements of the protection against a beyond-design flood (i.e., a flood exceeding the Reference Flood) have already been identified within the framework of the Periodic Safety Review. Feasibility studies are now in progress. Some modifications, related to finished feasibility studies, are in progress.

These improvements consist of the introduction of three successive independent lines of defence. All operations intended to make these three lines functional will be initiated in the hours before the arrival of the water on the site thanks to the warning from SETHY. The NPP will therefore be ready to face the decamillennial flood once the Meuse reaches the Reference Flood level. The three lines of defence are described in detail below.

- **Peripheral protection of the site** (first line of defence)

The University of Liège has calculated the theoretical onsite water level produced by a decamillennial flood (flow rate 3,488 m^3/s). A project for a peripheral protection of the site adapted to that level is being studied. The objective of such a peripheral protection is to keep the site dry. It consists of a wall of a height greater than that of the level of the Meuse in case of decamillennial flood. This wall would include coffer dams which, in case of threat of flooding of the site, could be used to close off the openings necessary for the normal operation of the NPP (in particular, on the water intake channel and on the discharge outlets of each unit). Additional technical and organisational solutions will allow to discharge cooling water (raw water or groundwater) to the Meuse river and to evacuate water from onsite heavy rainfall.

No equipment will therefore be affected by this flood. All the systems, structures and components necessary to bring the units to stable and controlled shutdown will remain available.

Despite this peripheral protection of the perimeter the units in Tihange cannot remain in power operation since the capacity of the water from the water intake channel will be reduced to the minimum necessary to ensure the vital supply of cooling water. Also, by way of defence-in-depth, and in order to cope with a local failure of this first line of defence triggering a sudden inrush of water on the site, the existing strategy of going to a safe shutdown state for the three reactor units in case of threat of flooding is kept, and, in addition, the implementation of a second line of defence against flooding of the buildings is studied.

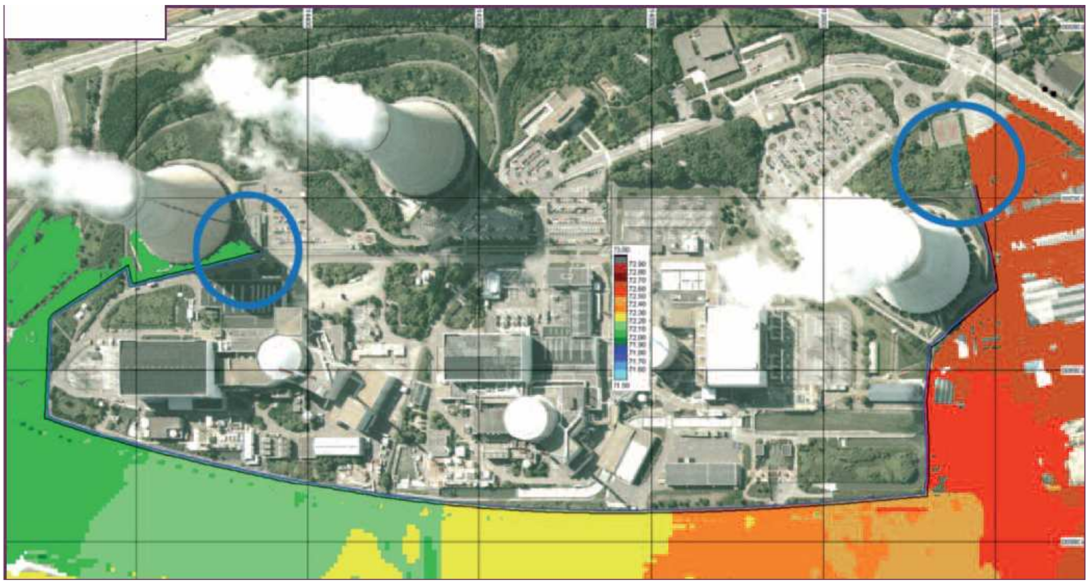

Figure 12 - Example of decamillenial flood and proposal for peripheral protection of the site

- **Local volumetric protection** (second line of defence)

The purpose of this second line of defence is to preserve in each unit, independently, a certain number of buildings accommodating the equipment assuring at least the cooling of the core and the spent fuel pools. To that end coffer dams and other sealing devices will be installed during the flooding alert period. This second line of defence will not be installed integrally in a permanent manner. Some equipment such as the coffer dams may be placed during the flooding alert period.

- **Mobilization of non-conventional means on site** (third line of defence)

As with the local volumetric protection, the deployment of non-conventional mobile means will be done during the flooding alert period. This essentially concerns the improvement of the robustness and reliability of the CMU equipment already available on the site.
These non-conventional means consist of, among other things:

- increasing the power of the CMU diesel generators in order to increase the functions added to the CMU and/or increase the number of pumps that can be powered;
- facilitating access and communication;
- replacing a maximum of flexible elements with fixed pipes in order to reduce the handling necessary for aligning the circuit;
- adding a primary make-up pump;
- increasing the number of instrumentation means powered by CMU equipment to facilitate control in case of accident.

The active equipment of this third line of defence will have to be stored or fixed at heights that are physically unreachable by the flood waters. The flood waters should recede from the site after about five days. The non-conventional devices added to the CMU will also have greater autonomy during this period.

Doel NPP

The Doel site is already well protected against flooding; only in certain extreme circumstances water can intrude onto the site. As a preventive measure, sandbags are laid at the critical entrances. These sandbags will eventually be replaced by permanent barriers to ensure that the water stays outside the buildings.
To prevent any possible weakening of the embankment, the top metre of the embankment will be reinforced with concrete tiles.

3.2.2.2. Procedural improvements

Tihange NPP

A set of procedures should reinforce those already in place to describe the maintenance and bringing into service of the three lines of defence mentioned above.

- For all lines of defence : a coordinating flooding procedure drafted for each reactor unit to be used upon notice of the high water. It will mention a series of individual procedures describing shutdown operations, the placing of mobile devices and the setting up of the three lines of defence;
- For the first line of defence (Peripheral protection)
    - procedures covering the operations for placing coffer dams;
    - procedures must be written for the periodic inspection and maintenance of this protection and storage of mobile elements.
- For the second line of defence (Local volumetric protection)
    - procedures covering operations for placing this protection;
    - procedures must be written for the periodic inspection and maintenance of volumetric protection systems and their storage.
- For the third line of defence (Mobilization of non-conventional means on site):
    - procedures covering the deployment of these non-conventional means;
    - procedures must be written for the maintenance and inspection of mobile and/or fixed devices.

Doel NPP

Additional adjustments will be made to protect the reactor units better. As soon as permanent barriers have been placed at the critical entrances, these will be incorporated into the emergency plan procedures.

3.2.2.3. Organisational improvements

Tihange NPP

The various organizational layers will be adapted to the ongoing improvement of protections against flooding (physical protection of the perimeter, local volumetric protection and use of mobile devices).

The internal emergency plan will also have to be adapted so as to describe specifically the organization chosen to handle a simultaneous flooding in all three units. It will also be necessary to ensure that the necessary resources can be mobilised within suitable time limits to set up the three lines of defence before the site is flooded.

The time limits for the implementation and correct understanding of the operations to be executed in the context of these three new lines of defence will be validated by periodic exercises.

Doel NPP

The emergency plan procedures also provide all the information concerning the internal organisational measures in the case of a risk of flooding. Fixed protocols are drawn up in consultation with the regional department responsible for flooding protection ('Waterwegen en Zeekanaal') and other public bodies.

3.3. Synthesis of the main results presented by the licensee

Based on the information in the licensee's stress test reports and the additional information provided by the licensee during technical meetings and on-site inspections, the main results for the topic "flooding" are as follows.

3.3.1. Tihange NPP

Design basis and verification

The maximum height of the flood postulated in the design of the Tihange site and the three units corresponds with the Meuse river flow rate of the largest known historical flood increased by 20% (this original design basis flood is called "reference flood" in the licensee report). At the design stage, this "reference flood" was estimated at 2200 m³/s, and the corresponding water level of the Meuse river at the upstream border of the Tihange site was estimated at 69.80 m. Hence, the platform of the Tihange NPP site has been constructed at a level of 71.30 m (i.e., with a safety margin of 1.5 m), ensuring a dry site without a need of additional protections of the site and the three units (e.g., peripheral embankment or barriers).

As a result of some recent floods in the Meuse valley, with a maximum measured river flow rate of 2179 m³/s and a corresponding water level of 70.47 m in the water intake channel (in 1995), a re-assessment of the flood risk has been conducted, using a statistical analysis (POT-analysis) of measured high flow rate data (over a period of 47 years, 1958-2004) to derive river flow rates for different return periods, and using a 2D-hydrodynamic model and detailed bathymetric and topographic data of the Meuse river valley to determine the corresponding water heights and flood areas.

This analysis shows that the "reference flood", which has meanwhile been re-assessed by the licensee at 2615 m³/s (flow rate of 1995 + 20%), corresponds with a water height of 71.30 m, being the same as the site platform elevation, and being characterized by a return period between 100 years (95th percentile) and 400 years (median). To strengthen the site protection against this "reference flood" and avoid any non-conformity, a small, seismically anchored wall has been installed along the water intake channel. Moreover, water entering the site by wind waves that are propagating into the water intake channel (return period up to 100 years), should also be impeded by this wall.

A hydrodynamic analysis of a total rupture of the dam located on the Meuse river at Andenne-Seille, i.e. upstream of Tihange, was also carried out. It has been demonstrated that such an event would lead to a water height of 70.54 m in the water intake channel, which is comparable to the 1995 flood and considerably lower than the water level of the "reference flood" which remains bounding.

Evaluation of safety margins and additional measures

During the re-assessment of the flood risk, the regulatory body requested that the units be protected against a 10,000-year flood, being a design basis flood (DBF) often adopted in national nuclear regulations (Germany, France, …). In coherence with French regulation (RFS I.2.e), a 1,000-year flood (70th percentile) increased by 15% was chosen as being representative for such a design basis flood. For the Meuse river in front of Tihange, this DBF, as derived from the above-mentioned POT-analysis, would correspond to a river flow rate of 3488 m³/s. Corresponding water heights would largely exceed the site platform elevation, causing flooding of the three units and loss of a lot of safety-related equipment, including all on-site AC power sources and both primary and alternate ultimate heat sink. The accessibility of the site, however, would be assured as the main road and site entrance would not be flooded.

Consequently, a set of additional protection measures following a defence-in-depth logic, together with a dedicated emergency strategy (with appropriate procedures) has been requested by the regulatory body.

In response to this request, the licensee has proposed to implement three levels of defense, which have, in principal, been accepted by the regulatory body:

- a peripheral protection of the site;
- local protections of the buildings containing equipment required to bring and maintain the units in a safe state, ensuring a "watertight area" for each unit;
- a set of non-conventional means (NCM), which can assure cooling of the three reactors and all spent fuel pools in case of flooding of the conventional means (due to failure of the first and second level of defense), and which can be used even for floods exceeding the 10,000-year flood.

The first two levels of defense are not yet implemented (both design and implementation of these protections are being studied). The first level of defense is intended to protect the Tihange site against the new design basis 10,000-year flood, by ensuring a dry site. The second and third levels of defense then become useful to provide protection against floods beyond the new design-basis 10,000-year flood (BDBF) and also to improve defense-in-depth.

At the end of June 2011, the third level of defense was partially implemented, by installing at each unit a set of non-conventional means (the so-called Ultimate Means Circuit, CMU) to keep the units in a safe shutdown state, awaiting repair or replacement of damaged SSC. An emergency preparedness strategy and organization, with corresponding procedures, has also been developed.

Concerning the further development of the third level of defense, for each unit, and primarily for the upstream unit Tihange 1, the licensee announced that redundant and/or diverse ultimate means (main and alternate means) will be foreseen for pumping either on-site clean water (e.g., from demineralised water tanks) or flood water into the existing systems (EDN, CEI, ...) that are used for water supply to the steam generators and the spent fuel pools (currently, such diversity is foreseen at Tihange 2). In addition, the new ground water wells will be put into service as main water source after flooding of the site.

Additional (external) means or replacement/repair of damaged safety-related equipment, which may be needed for the long-term strategy in order to maintain the units in a safe shutdown state, will also be further identified by the licensee. Corresponding mid- and long-term procedures will be established.

In the action plan proposed by the licensee, it is foreseen to give a high priority to the further implementation of all levels of defense. The proposed planning is 2014 for the peripheral protection of the site (1st level of defense), 2012-2013 for the local protections of the buildings of each unit (2nd level of defense), and 2012 for the further improvement of non-conventional means (3rd level of defense). In addition, the further improvement of the emergency preparedness strategy and organization, including corresponding procedures, is foreseen in 2012-2013. The highest priority is put on the 1st level of defense as it defines the new design basis related to the risk of site flooding. As the 2nd and 3rd levels of defense increase the safety of the site in the meantime for floods exceeding the present 'reference flood', they also receive a high priority.

3.3.2. Doel NPP

Design basis and verification

The maximum water height of the flood postulated in the design of the Doel site and the four units (+9,13m TAW) corresponds with a combination of high tide and storm surge in the Scheldt estuary estimated for a return period of 10,000 years. The site platform (at +8,86m TAW) is protected against such a flood by the embankment along the Scheldt river (initial height at +11,08m TAW, later increased to +12,08m TAW).

Because of recent floods in Belgium (e.g., in the Meuse valley) and in neighboring countries (e.g., at the Blayais NPP in December 1999), a reassessment of the flood risk of the Doel site has been conducted in 2006-2007. This analysis shows that the site is still protected against a high water level of the Scheldt river corresponding with a “design basis flood” (high tide + storm surge, 95th percentile, for a return period of 10,000 year).

Moreover, the effects of wind waves such as embankment run-up and overtopping have been examined. Due to the favorable location of the Doel site with respect to dominant wind directions in case of storm surge, embankment overtopping, which may occur for return periods larger than 300 years, would lead, up to a 10,000-years storm surge, to manageable flow rates because they can be evacuated (e.g. by the local sewer system or, if needed, by a large mobile pump) while water penetration into safety-related buildings can be impeded, if needed, by means of sand bags (already available) or mobile barriers (which are planned to be installed and will be integrated in the on-site emergency plan). Some smaller mobile pumps, that can be used to evacuate water having penetrated in buildings, are also available on site.

Hence, during a design basis flood, the SSC of first-level and second-level protection remain available. In addition, the accessibility of the site is not endangered.

Evaluation of safety margins and additional measures

Besides the effects of wind waves and embankment overtopping, an embankment failure, which could occur after significant erosion which has not been timely repaired, has also been studied. For the worst case scenario, i.e. for a Scheldt river water level (10,2 m TAW) corresponding to a 10,000-years storm surge (95th percentile), the water would reach the first buildings after about one hour and significant water depths could be found around several buildings (varying between 20 and 50 cm and mostly depending on the local site topography).

Therefore, the periodic inspections of the embankments will be improved in order to timely detect any potential embankment degradation (embankment erosion, in particular). A more frequent follow-up of decreasing embankment heights due to embankment settings is also foreseen. Finally, the afore-mentioned mobile barriers that are planned to be installed at sensitive building entrances should also provide appropriate protection against such a embankment failure, as well as against seismically induced on-site flooding risks caused by cooling tower basins overflow and ruptures or large leaks of several non-seismic water tanks and large piping (for which potential consequences have been roughly estimated in the licensee report, chapter 2, section related to seismically induced flooding risks).

3.4. Assessment and conclusions of the regulatory body

3.4.1. Tihange NPP

The approach adopted by the licensee to re-evaluate the flooding risk of the three units on the Tihange site is in conformance with the methodology provided by the licensee and approved by the regulatory body.

The detailed analysis of the licensee report and the subsequent technical meetings and inspections by the regulatory body lead to the conclusion that the presented approach and resulting action plan for improvements is adequate.

However, the regulatory body identified additional demands and recommendations to further improve the robustness of the units and the site against the risk of flooding:

1. The licensee shall include a safety margin for the first level of defense to adequately cover uncertainties associated with a 10,000-year flood (the wall of the peripheral protection should thus be designed higher than the flood level associated with a 10,000-year flood).

2. For the flooding risk, further improvement of the emergency preparedness strategy and organization, including corresponding procedures, should be implemented by mid 2012.

3. The robustness of the currently installed non-conventional means (NCM), i.e. the so-called Ultimate Means Circuit (CMU) should be further improved:
   - Since the CMU is currently needed for floods exceeding the "reference flood" of 2615 m^3/s (i.e., floods with return periods exceeding 100 to 400 years), the licensee should determine specific provisions as applicable to equipment important for safety (tests, maintenance, inspections, …).
   - The currently implemented alternate power sources for I&C systems and emergency lighting should be further improved, where needed, and the sufficiency of available or recovered I&C equipment to safely control the three units should be checked.
   - The technical characteristics of these non-conventional means (NCM) should account for the adverse (weather) conditions they may be subject to during the whole period of operation. If this is not covered by design, an appropriate protection or compensatory strategy should be developed.

4. The robustness of the currently implemented emergency preparedness strategy and organization should be further improved for the following aspects:
   - The flooding alert system, which is based on a direct communication between the regional service competent for forecasting river flow rates in the Meuse basin (SETHY, making use of a dedicated forecasting system) and the NPP (with Tihange 2 being the single point of contact and responsible for warning Tihange 1 and Tihange 3), is a crucial factor. Therefore, its robustness and efficiency should be further improved.
     In particular,
     - the protocol between the NPP Tihange and SETHY should be formalized as soon as possible.
     - The licensee should pursue regular tests of the secured communication channels and transmitted data (i.e., on-line measurements and predictions of river flow rates).
     - The licensee should organize emergency preparedness exercises involving both the NPP and SETHY personnel.
     - Criteria used to launch the internal emergency plan and to start the "alert phase" and associated actions should be unambiguously defined in the applicable emergency procedures.
   - Means for *on-site transport* of personnel and equipment towards the units, inside the units, or from one unit to another, while the site is flooded, should be further implemented and considered in the emergency preparedness strategy.

5. Internal hazards potentially induced by the flooding (fire, explosion) should be examined and additional measures should be taken where needed (e.g., because the automatic fire extinction system is lost during a flood exceeding the "reference flood"). The potential deficiency of the Ultimate Means Circuit (CMU) in case of induced fire, in particular because of dependencies when the CMU is connected to the fire extinction system (CEI), should be examined and potential weaknesses should be resolved.

3.4.2. Doel NPP

The approach adopted by the licensee to re-evaluate the flooding risk of the four units on the Doel site is in conformance with the methodology provided by the licensee and approved by the regulatory body.

The detailed analysis of the licensee report and the subsequent technical meetings and inspections by the regulatory body lead to the conclusion that the presented approach and resulting action plan for improvements is adequate.

However, the regulatory body identified additional demands and recommendations to further improve the robustness of the units and the site against the risk of flooding:

1. The technical characteristics of the non-conventional means (NCM) that can be used in case of flooding of safety-related buildings (for all potential causes) should account for the adverse (weather) conditions they may be subject to during the whole period of operation. If this is not covered by design, an appropriate protection or compensatory strategy should be developed.

2. Improvement of the procedures after earthquake (I-QM-01): after an earthquake, it must be rapidly and visually verified if flooding due to cooling tower basin overflow (e.g. due to obstruction of its outlet channel) is ongoing or imminent. In that case, the CW pumps must be rapidly stopped.

3. As recent inspections evidenced locations with embankment heights approaching the minimal required height (Technical Specifications criterion), embankment height inspections should be done more regularly (e.g., two-yearly, and at least 5-yearly, instead of ten-yearly) in order to avoid a risk of excessive embankment overtopping by wind waves for floods within the design basis (embankment overtopping may occur for return periods larger than 300 years).

4. Extreme weather conditions

In order to provide a self-standing national report for the subsequent peer review process, first the relevant information supplied by the licensee in its stress tests reports is recalled.
At the end of this chapter, a final section provides the conclusions and the assessment of the Belgian regulatory body (FANC and Bel V).

Some extreme weather conditions such as heavy rainfalls, high winds, tornadoes, lightning, snowfalls or hail can affect the sites of Doel and Tihange. For obvious geographical reasons, tropical cyclones, typhoons and hurricanes, as well as sand storms, dust storms and waterspouts, are not relevant and have not been considered.
None of the assessed hazards can affect the safety functions on both sites.

4.1. Heavy rainfalls

4.1.1. Reassessment of heavy rainfalls used as design basis

Tihange NPP

The rainfall data considered when the Tihange units were designed were based on the weather observations made by the Royal Meteorological Institute (RMI) at the station of Huy-Statte over the period 1901-1930. These weather observations are applicable to the site of Tihange which is located at a similar altitude. The heaviest rainfall recorded over this thirty year period reached 59 mm of rain in a single day.

From then on, the Walloon Region has published IDF graphic curves (Intensity/Duration/Frequency) and QDF tables (Quantity/Duration/Frequency) for every municipality. The QDF table for the municipality of Huy is illustrated below.

Table 10: QDF table for the municipality of Huy (extreme quantities of rain fallen over a specific duration D for the considered return period T; values expressed in mm fallen over duration D (1 mm = 1 litre/m²))

D/T	2 months	3 months	6 months	1 year	2 years	5 years	10 years	20 years	30 years	50 years	100 years	200 years
10 min	4.2	5.1	6.7	8.5	10.4	13.1	15.4	17.8	19.3	21.3	24.2	27.2
20 min	5.7	6.9	9.1	11.4	13.9	17.4	20.4	23.5	25.5	28.1	31.8	35.8
30 min	6.7	8.1	10.5	13.2	16.0	20.0	23.4	27.0	29.2	32.1	36.4	40.9
1 hour	8.6	10.2	13.1	16.2	19.6	24.5	28.4	32.7	35.4	38.9	44.0	49.4
2 hours	10.5	12.3	15.7	19.2	23.1	28.6	33.2	38.1	41.1	45.1	50.9	57.2
6 hours	13.7	15.9	19.8	24.0	28.5	35.0	40.4	46.1	49.7	54.4	61.2	68.5
12 hours	16.2	18.6	22.9	27.5	32.5	39.6	45.5	51.8	55.7	60.9	68.3	76.4
1 day	19.6	22.2	27.0	32.2	37.7	45.7	52.2	59.3	63.7	69.4	77.8	86.8
2 days	24.4	27.4	33.0	38.9	45.3	54.6	62.1	70.3	75.3	82.0	91.6	102.0
3 days	28.3	31.7	37.8	44.5	51.6	61.8	70.2	79.2	84.8	92.2	102.9	114.4
4 days	31.8	35.5	42.2	49.4	57.1	68.5	77.4	87.2	93.3	101.4	113.0	125.5
5 days	35.0	39.0	46.1	53.9	62.2	74.1	84.0	94.5	101.1	109.7	122.2	135.7
7 days	40.9	45.3	53.4	62.1	71.5	84.9	96.0	107.9	115.3	125.0	139.1	154.2
10 days	48.9	54.0	63.3	73.3	84.1	99.5	112.3	125.9	134.4	145.6	161.8	179.2
15 days	60.9	67.0	78.1	90.1	102.9	121.3	136.5	152.9	163.0	176.3	195.6	216.4
20 days	72.0	79.0	91.7	105.4	120.1	141.3	158.7	177.4	189.0	204.3	226.4	250.2
25 days	82.5	90.3	104.5	119.8	136.3	159.9	179.4	200.3	213.3	230.4	255.2	281.8

30 days	92.5	101.1	116.8	133.6	151.7	177.7	199.1	222.1	236.4	255.2	282.5	311.7

The digitalisation of historical rainfall data recorded at the station of Uccle was completed in 1999.

As a result, a set of data covering a hundred year period, from 1898 to 1993, is available. The Louvain Catholic University (UCL-KUL) made a research to derive trends from those data. This research concluded that no clear and significant trend could be discerned. It revealed however that heavy rainfall over a relatively short period of time mainly takes place during the summer.

Lastly, the Royal Meteorological Institute research on climate change in Belgium, based on data prior to 2007, confirmed that there is no significant change in the quantities of rain falling over short periods of time (from one to several hours). Extreme rainfalls occurred twice in August 2011. The rainfall values collected by the Royal Meteorological Institute were:

- on 18.08.2011 in Bertem: 36.6 mm in 1 hour and 70.1 mm in 24 hours,
- on 22-23.08.2011 in Uccle: 32.4 mm in 20 minutes, 38 mm in 1 hour and 44.3 mm in 24 hours; compared with the region of Huy, this is close to the 100-yearly rainfall over 20 minutes.

The available data show that the rainfall intensity has not significantly increased since the commissioning of Tihange 1. The values considered in the design phase are still suitable.

Doel NPP

The Royal Meteorological Institute data about highest rainfalls over short periods of time that were available at the design are listed in the safety analysis report of the Doel units. They are based on measurements in the region of Antwerp-Doel over the period 1901-1930. The highest rainfall recorded in a single day was 60 mm.

Table 11: QDF table for the municipality of Antwerp (extreme quantities of rain fallen over a specific duration D for the considered return period T; values expressed in mm fallen over duration D (1 mm = 1 litre/m²))

D/T	2 years	5 years	6 years	10 years	25 Years	30 years	50 years	100 years
1 min	2.0	2.8	3.0	3.3	4.0	4.1	4.5	5.0
5 min	7.8	10.2	10.6	11.8	13.9	14.3	15.5	16.9
10 min	9.2	12.1	12.5	14.1	16.4	16.9	18.2	20.1
20 min	10.9	14.4	15.0	16.6	19.5	20.1	21.7	23.8
30 min	12.0	15.9	16.5	18.4	21.6	22.2	23.9	26.3
40 min	12.8	17.2	18.1	20.7	26.0	27.1	30.6	35.9
1 hour	14.2	19.2	20.2	23.4	30.2	31.8	36.5	44.0
2 hours	16.7	22.7	23.9	27.8	35.8	37.6	43.2	52.2
4 hours	19.8	26.9	28.4	32.9	42.4	44.6	51.2	61.8
6 hours	21.9	29.7	31.3	36.3	46.9	49.2	56.6	68.2
9 hours	24.2	32.8	34.7	40.1	51.7	54.3	62.4	75.3
12 hours	26.0	35.2	37.1	43.0	55.5	58.3	67.1	80.8
18 hours	28.7	38.8	41.0	47.5	61.2	64.4	74.0	89.3
24 hours	30.7	41.6	44.0	51.0	65.8	69.1	79.4	95.8

New IDF graphic curves based on rainfalls measured in Deurne from 1967 to 1997 are available in a more recent edition by the Flemish Ministry. A comparison with these more recent data was performed during the ten-yearly periodic safety review and revealed that the data available when designing the NPP were enveloping.
As a result, the rainfall intensity that was considered as design basis is still relevant.

4.1.2. Evaluation of safety margins against heavy rainfalls

Tihange NPP

Torrential rainfalls are directed by the site drainage to the sewer system.

The sewer system in Tihange is independent from the public network. Each unit is equipped with their own draining system and discharge piping into the Meuse river.
Specific to the network of unit 1 is that it is divided into two parts. The discharge system of the "East-Centre" part has the same configuration as the network of units 2 and 3: a discharge pipe leading to the Meuse river at a depth of a few meters. On the other hand, the "West" part of the unit 1 network consists in collecting the discharged water in a draining area near the pumping station of the unit, from where it is pumped to the raw water outlet.

This sewer system was designed taking into account the hydrographs used for public sewer systems.
The calculation basis in Belgium is a rainfall of 120 litres per second and per hectare over 20 minutes.
These graphs also indicate that heavy rains exceeding 150 litres per second and per hectare (corresponding to 54 mm/h) are uncommon over a period of time long enough to create the conditions for fully filled sewer pipes. In fact, only a part of the rain water is collected by the sewer, the other part is retained by different surfaces, evaporated or infiltrated into the ground.

When the site of Tihange was designed, the sewer system was calculated using a value of 150 litres per second and per hectare for road surfaces, parking areas and other paved surfaces.
When comparing the draining capacity of the sewer system on the site with the IDF data, this capacity can only be exceeded during short periods of time, ranging from a few minutes to a few tens of minutes. In this case, there is a small volume of stagnant water that is evacuated in a few minutes once the rain eases off.

If torrential rainfalls coincide with a heavy flooded Meuse river, the sewer system on the site continues to play its role, provided that the flood is lower than or equal to the design basis flood (flow rate of 2 615 m^3/s, corresponding with a river level of 71.30 m).

Doel NPP

In case of heavy rainfalls, standing water is rapidly evacuated from the site. Two constructions play an important role:

- the sewer system, which was designed to face thunder showers in accordance with the Royal Meteorological Institute's standard values,
- the hydraulic embankment consisting in a draining sand layer that is 6 to 7 m thick.

The sewer system on the site of Doel is divided into five sectors. Rain water is directed to five wells spread over the site (H wells). Each well is equipped with two submerged pumps (and one back-up pump) for evacuating the water.
The flow rate of the sewer system has been reassessed considering the sewer maps and the characteristics of the evacuation wells and their pumps. This consisted in a hydraulic simulation of "composite rainfalls" for various return periods. These theoretical composite rainfalls were set up on basis of Royal Meteorological Institute's historical data. The following cases were assessed: rain periods of 6 hours with a return period of 5, 10 and 20 years and rain periods of 48 hours with a return period of 100 years.
Only for composite rainfalls with a return period of 100 years, the sewer system capacity could be locally exceeded for a few tens of minutes nearby some buildings at Doel 3 and Doel 4 units. In this case, there is a small volume of standing water that is evacuated by the sewers once the rain eases off.

4.1.3. Measures that can be envisaged to increase robustness against heavy rainfalls

Tihange NPP

Calculation is in progress to confirm the draining capacity at every point of the sewer systems. Depending on the results and on their potential consequences, improvements will be implemented.

Doel NPP

Based on the evaluation of the heaviest rainfalls with associated return period, and on the potential limited consequences on site, no improvement measure is currently considered.

4.2. High winds

4.2.1. Reassessment of high winds used as design basis

Anemometric records in Belgium between 1840 and 1949 have revealed that the wind speed exceeded only twice or three times the level of 40 m/s over that period, in particular with a peak at 45 m/s in 1929 in Haren.

More recent data on wind speed, whether on gusty wind conditions or on average wind speed, have been collected since 1949.

The highest wind speed recorded up to now in Belgium is 46.7 m/s in Beauvechain in 1990.

The wind speed considered for the design basis of both Tihange site and Doel site is defined as "exceptional highest wind speed" under the terms of the NBN-460 standard dealing with the effect of the wind on buildings. This design basis wind speed has been set at 49 m/s at 25 m above ground level. A wind speed correlation curve is then applied for other heights.

As a result, the wind speed that was considered as design basis for Tihange and Doel NPP is still relevant.

4.2.2. Evaluation of safety margins against high winds

Resistance of the buildings

The design basis wind speed for both sites, set at 49 m/s in accordance with the NBN-460 standard, is to be compared with the local wind speeds recorded over the past years.

The measures recorded in Bierset, close to the site of Tihange, reveal that:
- according to the most recent data (from 1993 to 2010), there have been no value above the wind speed record set in Beauvechain in 1990 (46.7 m/s);
- the maximum wind speed with a return period of 100 years is 44 m/s (gusty wind), and the maximum wind speed lowers to 34 m/s (gusty wind) in more sheltered places.

Furthermore, in the flooding risk studies of the Tihange site, the highest average wind speed (average measurement over ten minutes) was determined at 25 m/s (Bierset, 1985-2003).

Close to the site of Doel, the measures recorded reveal that:
- according to the most recent data (in Deurne, from 1993 to 2010), there has been no value above the wind speed record set in Beauvechain in 1990 (46.7 m/s);
- the maximum wind speed (gusty wind) with a return period of 100 years is 41.5 m/s in Oorderen/Port of Antwerp and 41 m/s in Deurne.

Furthermore, in the ten-yearly periodic safety review of Doel NPP, the highest average wind speed (average measurement over ten minutes) was determined at 20 m/s (Deurne, 2003-2009).

These wind speeds are significantly inferior to the design basis wind speed.
Furthermore, the NBN-460 standard applies to the construction of every building in general. But safety related buildings were designed to withstand even higher mechanical loads than those generated by high winds (e.g. extreme loads induced by tornadoes).

Loss of power supplies

Another side effect of high winds is that they can affect high voltage power grid outside the sites, or even high voltage stations on site. This can result in a total or partial loss of external power supplies (LOOP), but the facilities were designed to face this situation.

Wind waves

Finally, high winds are likely to create waves on the river, which may overtop the banks, dikes and other protective structures along the sites and lead to local flooding.

The University of Liege made research on wave heights induced by exceptional high winds on the stretch of the Meuse river along the site of Tihange.

Along the site of Tihange, the highest calculated wave height is about 0.5 m for a daily average wind speed of 25 m/s, corresponding to the highest value ever measured in Bierset. For the highest design basis wind, namely wind gusts of 49 m/s, which is supposed to be equal to an average wind of 34 m/s (that is to say 2/3 of the wind gust speed, this conservative value applies for coastal areas and not for inland regions), the theoretical wave height is about 0.7 m. The wave height describes the distance from peak to the trough of the wave. The wave peak is above the average water level only by half of this value (and the trough is at the same distance below the average water level). Therefore, for wind conditions corresponding to the highest design basis wind speed, the theoretical wave peak is 0.35 m above the average water level of the Meuse river along the site of Tihange.

In normal conditions, the Meuse river water level is maintained at 69.25 m along the site of Tihange. Since the stone embankments and the water intake channel's raised embankments are at least 71.35 m high, waves of a few tens of cm would not pose any problem. Should the 'reference flood' level be reached with high winds blowing down the Meuse river, the waves created could overtop the embankments. The water reaching the site would then return to the Meuse river through the sewer system and the water level at the edge of the site would not exceed a few centimeters.
Safety related equipment is not located close to the river embankments and there is no risk that it could get flooded.

The propagation of waves in the water intake channel and the risk of waves overtopping the wall along the channel have also been considered. The numerous pillars and the fact that waves are propagating down the river perpendicularly to the direction of the water intake channel significantly attenuate the waves. Consequently, it is considered that only a 'reference flood' situation combined with strong winds blowing on the Meuse river can create waves of about 10 cm in the water intake channel. These waves could overtop the wall, though on a limited scale. These small quantities of water on the site would then be collected by the sewer system or infiltrate into the soil. If necessary, mobile pumps available on site would be used.

At Doel, the ten-yearly safety review has confirmed that unfavourable wind direction combined with a high water level due to a heavy storm could result in water waves overtopping the embankment. This eventuality was already discussed in Chapter 3 (Flooding).

4.2.3. Measures that can be envisaged to increase robustness against high winds

Considering the adequacy of the design basis and the available safety margins with respect to the different scenarios, no further measure is needed in order to improve the robustness of the units at both sites.

4.3. Tornadoes

In Belgium, the strength of tornadoes is not likely to exceed level F2 on the original Fujita scale (1971). This level corresponds to wind speeds ranging from 50 m/s to 70 m/s (180 to 250 km/h).

Among the tornadoes that occurred in Belgium over the period 1880-1940, the event that led to the highest wind speed was due to a set of tornadoes moving from Holland during the storm of 10th August 1925. On this occasion, the wind speed was estimated up to 250 km/h locally.

Another high intensity tornado occurred on 20th September 1982 in the village of Léglise. The highest wind speed was estimated at 250 km/h and the tornado was about 50 m wide. There was serious damage, including blown-off roofs and destroyed buildings.

A similar event happened in Oostmalle on 25th June 1967. In general, lower intensity tornadoes are reported each year in Belgium.

There is no systematic data collection on tornadoes in Belgium (especially regarding their intensity). However, it should be noted that:

- there are 4 to 7 times less tornadoes in Europe than in the United States;
- there are each year 4 to 6 tornadoes in Belgium;
- most of the tornadoes occurring in Belgium are rated EF0 to EF2 (enhanced Fujita scale, 2007); EF3 rated tornadoes are probably uncommon from a probabilistic point of view, though the tornado that hit Haumont, in the north of France at the Belgian border, reached an intensity of EF4 in some places;
- there is no marked tendency in the evolution of the statistics;
- there is no area in Belgium where tornadoes are reported more frequently;
- half of the tornadoes in Belgium are reported during summer, but they can also occur in winter;
- the duration of a tornado in Belgium is in most cases limited to a few minutes; the diameter of whirlwinds varies from a few metres to some tens of metres, and the tornado paths range from a few tens of metres to some hundreds of metres.

4.3.1. Reassessment of tornadoes used as design basis

The design basis for the structures is based on the highest wind speed of the considered tornado.

Tihange NPP

The design basis tornado considered for Tihange 1 produces winds with a velocity of 70 m/s (250 km/h). The resistance of all the buildings to such winds was assessed during the first ten-yearly periodic safety review (1985). Some corrective actions were then taken, except for the ventilation stack that would not resist, however without having any impact on the safety equipment should it fall.
The tornado missile risk was not taken into account in the design of the electrical auxiliaries building (upper floor) and the safety diesel generators building (GDS). For the latter building, the reinforced concrete walls resisting the DBE earthquake ensure that missiles generated by the tornado will not result in the loss of safety diesel generators.

For Tihange 2 and Tihange 3, as well as for DE building, the design basis tornado considered has a wind velocity reaching 107.3 m/s (385 km/h). However this design basis tornado was considered only for "bunkered" buildings. The ventilation stacks of both units were not designed to withstand such a strong wind, but the impact of their fall was assessed and it showed that the "bunkered" buildings are preserved.

The probability that a tornado with a wind speed higher than 70 m/s reaches Tihange 1 is estimated at less than 5.8 10^{-7}/year, i.e. a return period of about 2 million years.

Yet, Tihange 2 and Tihange 3 and DE building were designed considering an even higher design basis tornado with a wind speed of 107.3 m/s (385 km/h). This design basis tornado is recommended by the USNRC Regulatory Guide 1.76 for highest risk regions in the USA.

Doel NPP

For Doel 1/2, the protection against tornadoes was based on a wind speed of 70 m/s (250 km/h). During the first ten-yearly periodic safety review (1985), it was verified whether the category 1 structures (or safety related structures) would withstand a design basis wind speed. This verification also included secondary containment, GNS, BAR, GNH, RM rooms, GEH, GMH and the stacks.
Every considered concrete building provided sufficient protection against missiles generated by a design basis tornado.

For Doel 3 and Doel 4, the protection against tornadoes was based on a wind speed of 107.3 m/s (385 km/h). The bunkered structures can resist tornadoes and potential tornado generated missiles.
This weather phenomenon was also considered for some "non bunkered" category 1 buildings such as parts of the GNH (penetration areas and radioactive gas storage tanks) and parts of the OVG2 (connecting the KVR emergency cooling pond with the BKR bunker).

The SCG building itself was not designed to withstand a tornado. However, the containers inside the SCG building can resist the impact of a missile, the impact of the collapsing building or the impact of debris from the building.

The safety related buildings of Doel 1/2 units are protected against a design basis tornado with a maximum wind speed of 70 m/s. It is very unlikely that a tornado with a wind speed exceeding 70 m/s will occur at Doel site. The associated probability is estimated at about 6.10^{-7}/year.
The probability that a tornado with a wind speed exceeding 107 m/s will occur at Doel site is even lower, at about 3.10^{-8}/year. Yet, a design basis wind speed of 107 m/s was considered for Doel 3 and Doel 4 units.

4.3.2. Evaluation of safety margins against tornadoes

The global consequences of a tornado on the facilities depend on its intensity on the Fujita scale:

- tornado with a wind speed up to 50 m/s (180 km/h): light damage (some damage to roofs, chimneys, doors and windows, uprooted trees);
- tornado with a wind speed from 50 to 70 m/s (180 to 250 km/h): significant damage (roofs torn off, cars and trucks displaced, severe damage to houses, structures with weak foundations blown away);
- tornado with a wind speed from 70 to 107 m/s (250 to 385 km/h): catastrophic damage (destroyed houses, cars and trees thrown through the air like missiles).

In general, the tornado phenomenon is not a decisive factor when designing buildings, compared to other external events like blast waves or airplane crashes. This means that the impact of missiles generated by a tornado is generally covered by the latter events. This also means that most of the buildings are designed so that they can bear tornados stronger than the design basis tornado. Obviously, all the buildings are not likely to collapse simultaneously once a specific wind speed is exceeded. Furthermore, the width of the heavily devastated zone is limited.

Tihange NPP

The global consequences of a tornado on the site of Tihange, considering its worst-case path, are described in the following table for various tornado intensities.

Table 12: Potential consequences depending on the tornado intensity

Tornado intensity	Tihange 1	Tihange 2 and Tihange 3
Wind speed up to 50 m/s	• Loss of offsite power (LOOP) → included in design basis	• Loss of offsite power (LOOP) → included in design basis
Wind speed from 50 to 70 m/s	• Loss of offsite power (LOOP) • Loss of primary ultimate heat sink → switch over to GDS or SUR	• Loss of offsite power (LOOP) • Loss of primary ultimate heat sink • Station black-out (SBO) (1st level) → switch over to BUS
Wind speed from 70 to 107 m/s	• Loss of offsite power (LOOP) • Loss of primary ultimate heat sink → switch over to GDS or SUR	• Loss of offsite power (LOOP) • Loss of primary ultimate heat sink • Station black-out (SBO) (1st level) → switch over to BUS

The following equipment – located outside the buildings – is possibly vulnerable to high-intensity tornadoes (wind speed above 50 m/s):

- a tornado across or near the site can cause the loss of external power supplies (LOOP) as it can damage either the high voltage Gramme station, the lines connecting this station with the power plant, or the high voltage station in one or several units; this situation is included in the original design basis of each unit;
- for each unit, the motors of the CEB pumps (supplying Meuse river raw water) are exposed to missiles and thus can be lost; this has no serious consequence:
    - In Tihange 1, the GDS can be cooled either by the CEB system, or by ground water (supplied by two wells that are distant from each other and located more than 100 metres away from the CEB pumps and that are both equipped with two separate pumps). It is very unlikely that a tornado will reach simultaneously all these equipment. Besides, although both wells are protected only by a corrugated iron structure that offers little resistance, it is even more unlikely that a missile will fall in the well once the corrugated iron structure is blown off.
      The available pumps (CEB or ground water) take over the water supply of the GDS, though these need to be restarted manually once connected to the ground water supplying system.
      Moreover, the emergency diesel generator (air-cooled DUR) and the emergency system (SUR) remain fully operational.
    - In Tihange 2 and Tihange 3, the loss of the CEB pumps leads to the loss of the GDS. Nonetheless, all CEU pumps (Meuse river and ground water) remain operational as they are "bunkered". As a result, the emergency building (BUS) will automatically maintain the units in a safe and stable state. In case the external power supply is lost, the diesel generators housed in the BUS take over the power supply of the equipment.
- The back-up safety diesel generator (GDR), physically located on Tihange 2 unit, is cooled by an outside air-cooling system that is vulnerable to missiles. If a unit is supplied by this GDR, only one diesel generator will be lost. This single failure is included in the design basis. Furthermore, the emergency diesel generators (DUR for Tihange 1 and GDU for Tihange 2 and Tihange 3) remain operational and maintain their respective unit in a stable state.

Doel NPP

The following table summarizes the potential consequences on Doel site units.

Table 13: Potential consequences depending on the tornado intensity

Tornado intensity	Doel 1/2	Doel 3 and Doel 4
Wind speed up to 50 m/s	• Possibility of partial or total loss of offsite power (LOOP) → included in design basis	• Possibility of partial or total loss of offsite power (LOOP) → included in design basis
Wind speed from 50 to 70 m/s	• Loss of offsite power (LOOP) • Loss of ultimate heat sink (RW) • Station black-out (SBO) (1st level) → switch over to GNS	• Loss of offsite power (LOOP) • Loss of ultimate heat sink (RN) • Station black-out (SBO) (1st level) → switch over to BKR
Wind speed from 70 to 107 m/s	• Outside of design basis → in general, a tornado is not a decisive factor when designing buildings; Doel 1/2 buildings are considered to probably resist such a tornado	• Loss of offsite power (LOOP) • Loss of ultimate heat sink (RN) • Station black-out (SBO) (1st level) → switch over to BKR

The following equipment – located outside the buildings – is possibly vulnerable to high-intensity tornadoes (wind speed above 50 m/s):

- an offsite tornado could damage the external power supplies, leading to a partial or total LOOP;
- a tornado hitting the site could damage the plant's high voltage substations, also resulting in a partial or total LOOP;
- the air-coolers of the Doel 1/2 safety diesel generators are located outside on the roof of the GMH building, and those of the Doel 3 and Doel 4 safety diesel generators are located outside on the roof of the GEH building; the cooling circuits were designed to remain operational under the highest storm winds possible at Doel site;
- the Doel 1/2 raw water system (RW) cooling towers, which are part of the first alternate ultimate heat sink, are not protected against tornadoes;
- the Doel 3 and Doel 4 raw water system (RN) cooling towers, which are part of the first alternate ultimate heat sink, are not protected against tornadoes; however, they have been designed to bear exceptional gusty winds;
- the cooling ponds (KVR), which are part of the Doel 3 and Doel 4 second alternate ultimate heat sink, are in open air; a tornado could affect the water inventory of one pond, but it is not possible that the inventory of all ponds could be lost simultaneously.

4.3.3. Measures that can be envisaged to increase robustness against tornadoes

Tihange 2 and Tihange 3 on the one hand, and Doel 3 and Doel 4 on the other hand, were designed to withstand a design basis tornado with an intensity that has never been experienced in these areas.

Tihange 1 and Doel 1/2 were assigned a design basis tornado of lower intensity. Yet such a tornado is very uncommon in Europe.

In most cases, tornado resistance is not the decisive criterion when designing buildings as most of them can bear mechanical loads much higher than the forces exerted by a design basis tornado.

In extreme conditions, a severe tornado could cause a partial or total loss of the external power supply, possibly combined or not with a station black-out (SBO) (1^{st} level) or a loss of one of the heat sinks. These scenarios are treated in chapter 5.

No measure dedicated to increase the robustness of the facilities against tornadoes is required on both sites.

4.4. Lightning

4.4.1. Reassessment of lightning used as design basis

Over the period 1901-1930, the average number of lightning days was 19.6 in the region of Tihange (data collected in Huy-Statte). Lightning strikes the surroundings of Tihange site 1.76 times per km² and per year. This value is higher than the average for Belgium (annually 1.19 strike per km²).

Close to Doel site, the weather observations over the period 1901-1930 showed 8 lightning days per year on average (data collected at Antwerp-Doel station).

4.4.2. Evaluation of safety margins against lightning

Every building on both sites is protected against lightning in compliance with the NBN C18-100 standard (edition 1985), and its addendum.

4.4.3. Measures that can be envisaged to increase robustness against lightning

From 2009, the new NBN EN (CEI) 62305 standard is applicable to every new building.

On this occasion, a lightning risk assessment has been performed for Tihange power plant in compliance with the methodology described in this new standard. The efficiency of the grounding system and the justification of the protection requirements or recommendations have been assessed.
This resulted in proposals for technical modifications initiated in 2010, culminating in a grounding system project currently in progress (spread over 2011-2012-2013).
Periodic testing of grounding devices is also scheduled in an annual program.

A similar assessment is currently in progress for Doel power plant in order to enhance lightning protection in compliance with this standard.

4.5. Snowfalls

On average, there are 15 snow days per year in lower and central Belgium, 30 snow days in upper Belgium and up to 40 snow days in the highlands.

Periods of snow-covered ground can vary significantly depending on the winter conditions. Most of the time, these periods do not exceed 3 to 5 days. The snow-cover period is slightly longer in the Ardens, especially in the highlands.

On 10^{th} February 1902, a record snow depth of 0.35 m was measured in Uccle (central Belgium). In the High Fens region, a peak snow depth of 1.15 m was recorded on 9^{th} February 1953 (highest value ever recorded in Belgium by the Royal Meteorological Institute since early 20th century).

Snowfalls are relatively scarce in lower and central Belgium, representing Tihange and Doel sites.

The safety analysis report indicates an annual average of 12 snow days nearby Doel.

4.5.1. Reassessment of snowfalls used as design basis

An average of 30 snow days per year was taken into account when the site of Tihange was designed.

Tihange 1 and Doel 1/2 units were designed in accordance with the provisions of NBN 15-1963 rule, while Tihange 2, Tihange 3, Doel 3 and Doel 4 units were designed according to NBN B 15-103 (1977) entitled "Concrete, reinforced concrete and pre-stressed concrete – Calculation".
These two standards recommend for the region of Tihange and Doel (altitude 0 to 100 m) that the overload due to snow does not exceed 0.35 kN/m² and 0.40 kN/m² respectively. In addition to this load, a point load of 2 kN over 1 m² or 1 kN over 0.2x0.2 m² at any point on the roof must be taken into account (choosing the worst of both values).

The current rules for new buildings (NBN EN 1991-1-3 ANB: 2007) are in force since 1995 and were transposed from the European construction standards (Eurocode 1) into Belgian regulation.
For the region of Tihange and Doel (altitude 0 to 100 m), this regulation recommends considering an excess snow load of 0.50 kN/m^2. These standards clearly indicate that the effects due to snowfalls and wind must not be cumulated. It should be noted that wind can create depression on roofs that is taken into account in the design of buildings (framing/cladding) and can encompass the effects due to the snow.
A code of practice issued in 1995 recommends that the roofs should be designed – when considered as necessary – so that they withstand a load of 1.20 kN/m².

4.5.2. Evaluation of safety margins against snowfalls

Snow is only a part of the roof loads that are considered in structure calculations. Besides, best practices recommend minimum values that may be increased depending on the nature of the project. That's why the excess snow load is not necessarily a design criterion. That is the case for instance with bunkered buildings that were designed to withstand much higher loads.
So, even in case of exceptional snowfalls, no problem is expected for the following buildings:

- Tihange site:
    - the reactor buildings of all three units;
    - the BUS building (W), the BAN storage pools (D and DE), and the groundwater wells and air intakes of Tihange 2 and 3 units;
- Doel site:
    - the reactor building of all four units;
    - the BAR, GNS and DGG buildings at Doel 1/2 units;
    - the BKR, GNH, SPG, GVD and OVG2 buildings at Doel 3 and Doel 4 units.

The same applies to the SCG building at Doel (spent fuel dry storage). The containers inside the SCG building can resist the impact of a missile, the impact of a collapsing building and the impact of debris from the building. As a result, snowfalls pose no threat to the safety function of the containers.

For "non bunkered" buildings, the design margins should be decreased with the extra loads on the roof that have been added over time. Since codes of practice are now applied at times and since the considered loads are wider than snow loads, some buildings on the site can withstand snow depth values that are significantly higher than the minimum value recommended by these standards.
If we consider a snow density of 100 kg/m³ (= 1 kN/m²), and an allowable overload of 0.35 to 0.40 kN/m², the roofs of "non bunkered" buildings can bear a snow layer of at least 30 cm.

Regarding the resistance of offsite power lines, a heavy snowfall could overload (mechanically) the high voltage lines or even bring them into oscillation in combination with the wind. This could induce a partial loss of offsite power supply, but this situation is included in the design basis.

4.5.3. Measures that can be envisaged to increase robustness against snowfalls

All buildings on both sites were designed to bear snow loads as set out in the relevant standards. Furthermore, when considering design margins, some buildings can actually bear loads that are much higher than the loads due to snowfalls.

For "non bunkered" buildings, the allowable overload due to snowfalls should be limited to 0.35 kN/m², namely a snow layer of 35 cm (not taking into account the overload due to the presence of personnel).
To this end, monitoring and intervention procedures will be set up on both sites to remove snow from the roofs of the "non bunkered" buildings once the snow layer is 30 cm thick.

4.6. Hail

Hail is described as a weather phenomenon localized in time and space. It was not included in the design basis as its effects are encompassed in other issues.

During a hailstorm, pellets are considered as missiles that can fall down on buildings or equipment. The missile risk for nuclear power plants is included in the design basis.

No specific measure is required to increase the robustness of the facilities against hail on both sites.

4.7. Other extreme weather conditions

The following weather conditions cannot occur in Belgium for geographical reasons, or their kinetics is so slow that appropriate actions can be taken before reaching critical stages.

Extreme temperatures

When designing nuclear power plants, extreme temperatures are considered in the design of the equipment. These values are determined using statistics and depending on the geographical location of the facilities.

The change in extreme temperatures is reassessed during periodic safety reviews. If these temperatures are modified, the design and the safe operation of the relevant systems and equipment are reassessed. Corrective actions are implemented if needed.

As periods of drought or extreme temperatures are not suddenly occurring, they can be anticipated. Nuclear power plants have specific procedures to guarantee safe operation in case of a heat or cold wave.

Tropical cyclone, typhoon, hurricane

Due to the geographical location of Tihange and Doel, these weather phenomena were not listed among extreme weather conditions.

Sand storm and dust storm

Due to the geographical location of Tihange and Doel, these weather phenomena were not listed among extreme weather conditions.

Waterspout

Due to the geographical location of Tihange and Doel, these weather phenomena were not listed among extreme weather conditions.

4.8. Synthesis of the main results presented by the licensee

Based on the information in the licensee's stress test reports and the additional information provided by the licensee during technical meetings and on-site inspections, the main results for the topic "extreme weather conditions" are as follows.

The following extreme weather conditions have been reassessed by the licensee: heavy rainfalls, high winds, tornadoes, lightning, snowfalls, and hail. Other extreme weather conditions are not applicable to Belgian NPPs (e.g. hurricanes, waterspouts, sand storms…).

For heavy rainfalls at the Doel site, detailed measurements, inspections and repairs of the on-site sewer system (five separate networks) were performed in 2007-2009. Subsequently, a hydrodynamic model of the sewer system was established and used to verify its capacity for various rain intensities and durations corresponding to return periods up to 100 years (derived from observations of rain intensities in the period 1967-1993). The sewer system capacity was found to be sufficient, except for some points of two networks (H4 and H5) where flooding in the vicinity of Doel 3 and Doel 4 buildings could not be excluded. Hence, potential improvements of the sewer system are going to be studied and an action plan will be defined if needed.
For heavy rainfalls at the Tihange site, detailed measurements, inspections and repairs of the on-site sewer system (separate networks per unit) are being performed and are near completion. Subsequently, a hydrodynamic model of the sewer system will be established and used to verify its capacity for rain intensities up to 175 l/s/ha (i.e. exceeding the intensity of 150 l/s/ha considered during design). Based on these results, potential improvements of the sewer system will be studied.

For high winds and extreme temperatures, a reassessment of meteorological conditions used in the design basis is performed during every periodic (10-yearly) safety review. If these meteorological conditions are exceeded, a reassessment of operating conditions of potentially affected SSC is carried out and modifications are implemented where needed. For extreme cold or heat waves, dedicated operating procedures have been established, in particular to avoid unavailability or degraded operating conditions of safety-related SSC.

For tornadoes, at least the second-level protection (i.e. the emergency systems) is expected to withstand tornadoes with wind speeds up to 70 m/s (250 km/h) for Doel 1/2 and Tihange 1 and up to 107 m/s (385 km/h) for Doel 3 and Doel 4, as well as Tihange 2 and Tihange 3.

For lightning, an evaluation of the protection of all units according to the new standard NBN EN 62305 is ongoing. The action plan should be implemented by the end of 2013.

For snowfalls, the thickness of the snow layers on the roofs of the "non bunkered" buildings will be monitored and the snow will be removed once the snow layer is 30 cm thick. Intervention procedures will be set up on both sites to achieve these tasks.

For hail, the hazard is covered by other types of events and no specific measure is required to increase the robustness of the facilities.

An evaluation of safety margins for extreme weather conditions is not required by the stress tests specifications. However, an evaluation of weak points and failure modes or cliff edge effects leading to unsafe plant conditions is requested. Hence, the plant robustness against extreme weather conditions within the design basis limits has been assessed. For tornadoes, some weak points are identified, leading either to a loss of off-site power (LOOP) or to a LOOP combined with the loss of the first-level protection, while the second-level protection ("bunkered" systems) would remain available.

4.9. Assessment and conclusions of the regulatory body

The approach adopted by the licensee to re-evaluate the risks associated to extreme weather conditions complies with the methodology provided by the licensee and approved by the regulatory body.

Most of the considered hazards were taken into account in the design basis of the facilities, and are hence not likely to affect the safety functions of the units.

Overall, the potential consequences of extreme weather conditions are covered by other major events (flooding, aircraft crash…) that are also reassessed as part of the stress tests program and can lead to loss of power or loss of ultimate heat sink. Thus, the actions planned to cope with these other risks will bring a higher protection level against extreme weather conditions.

However, based on the assessment of the licensee's reports and the subsequent technical meetings and on-site inspections, the regulatory body identified additional demands and recommendations in order to further improve the robustness of the facilities when faced with extreme weather conditions:

1. The reassessment of the capacity of the sewer system (five separate networks at Doel, separate networks per unit at Tihange), using a detailed hydrodynamic model must cover both short-duration heavy rains and long-lasting rains (95^{th} percentile) for return periods up to 100 years. Moreover, to define such 100-yearly rains, observations of rain intensities over a sufficiently long period of time must be used, including the latest observations (e.g. the exceptional rain of 23^{rd} August 2011). Depending on the results, potential improvements of the sewer system shall be envisaged and the licensee's action plan shall be updated accordingly where appropriate.

2. Given the fact that tornadoes of high intensities were observed in the past years in the neighbouring countries (class EF4 on the enhanced Fujita scale), the robustness of the second-level systems of Doel 1/2 and Tihange 1 should be confirmed in case of a beyond-design tornado with wind speed exceeding 70 m/s (250 km/h).

5. Loss of electrical power and loss of ultimate heat sink

In order to provide a self-standing national report for the subsequent peer review process, first the relevant information supplied by the licensee in its stress tests reports is recalled.
At the end of this chapter, a final section provides the conclusions and the assessment of the Belgian regulatory body (FANC and Bel V).

The scenarios considered in the following paragraphs describe the effects of the successive loss of electric power supplies or the various heat sinks and thus consider more and more limiting and increasingly less likely situations. They also consider the combination of loss of heat sinks and electric power supply.

It is assumed that these events might arise at any time, whatever the state of operation of the units. However, the situations in which the reactor coolant system is open or operating with reduced inventory are limited in time. The probability of an incident while a unit happens to be in one of these states is therefore low, and this regardless of the nature of the incident or combination of incidents under consideration. However, this situation is considered in the analysis of the various scenarios.

The following events are considered successively:

- loss of off-site power supply (LOOP);
- loss of off-site power supply and first-level internal power supply (station black-out);
- loss of off-site power supply and first-level and second-level internal power supplies (total station black-out);
- loss of primary ultimate heat sink;
- loss of primary ultimate heat sink and alternate ultimate heat sinks;
- loss of primary ultimate heat sink together with loss of off-site power supply and first-level internal power supply;
- loss of primary ultimate heat sink together with loss of off-site power supply, first-level and second-level internal power supplies;
- loss of primary ultimate heat sink together with loss of off-site power supply and combined with DBE earthquake.

5.1. Loss of electrical power

The electric power supply on the sites ensures at the same time the supply towards the power grid of the electricity produced by the nuclear reactors as well as the electric power supply of the auxiliary systems whether in the normal situation or in case of an incident or accident. In order to meet safety requirements, the installations of the NPP may be powered from several different and independent sources, each of which has the capacity to bring and keep the units in a stable and controlled shutdown state.

Tihange NPP

Between each unit of Tihange and the high voltage station in Gramme, the main external power supply - and supply of the produced energy - is provided by:

- two very high voltage overhead lines (380 kV) for Tihange 1;
- one very high voltage overhead line (380 kV) for Tihange 2;
- one very high voltage overhead line (380 kV) for Tihange 3.

The second external power supply for the three units is provided by a high voltage station installed on the site with three power supplies via two different (and independent) routes: a double route from the high voltage station (150 kV) in Gramme and a route (150 kV) from the station in Les Awirs. Each of these three links can individually supply power to all the auxiliary means necessary for the stable and controlled shutdown of the three units simultaneously. Each of the three lines connecting Tihange with Gramme and Les Awirs is equipped with its own independent control and protection systems. The links between the high voltage station 150 kV (installed on site) and the units are ensured by underground lines.

The most penalizing case would be the collapse by twisting of a 380 kV pylon, falling on the double power supply of the 150 kV station. In this case the 380 kV and the double 150 kV power supply would be lost. This is the rationale for the independent power supply from Les Awirs, guaranteeing power supply for the auxiliary systems of the power station even in this case.
It should be noted that Tihange 2 also has another 150 kV connection (which is not an external safety electric power supply) with the station in Avernas.

On the other hand, the most probable incident of internal origin that could affect the two independent power supplies, that is 1) the alternator output transformer (24 kV/380 kV) and the transformers powered by the 380 kV or the alternator and 2) the transformers powered via the 150 kV, is fire. To avoid the loss of the second power supply in case of fire in the first, the two are physically separated by sufficient distance and by firebreak walls.

When the unit is in normal operation (full power), the alternator supplies the electric energy to the auxiliary systems of the plant.
In the event of some failure of the main electrical power supply, the reactor unit (during power operation) automatically switches to house load operation. The reactor unit then disconnects from the external grid and the alternator will then only provide power to its auxiliary systems.

If house load operation fails, an automatic transfer from the main electric power supply to the back-up transformers (150 kV) is foreseen and the power supply to the auxiliary systems is uninterrupted.

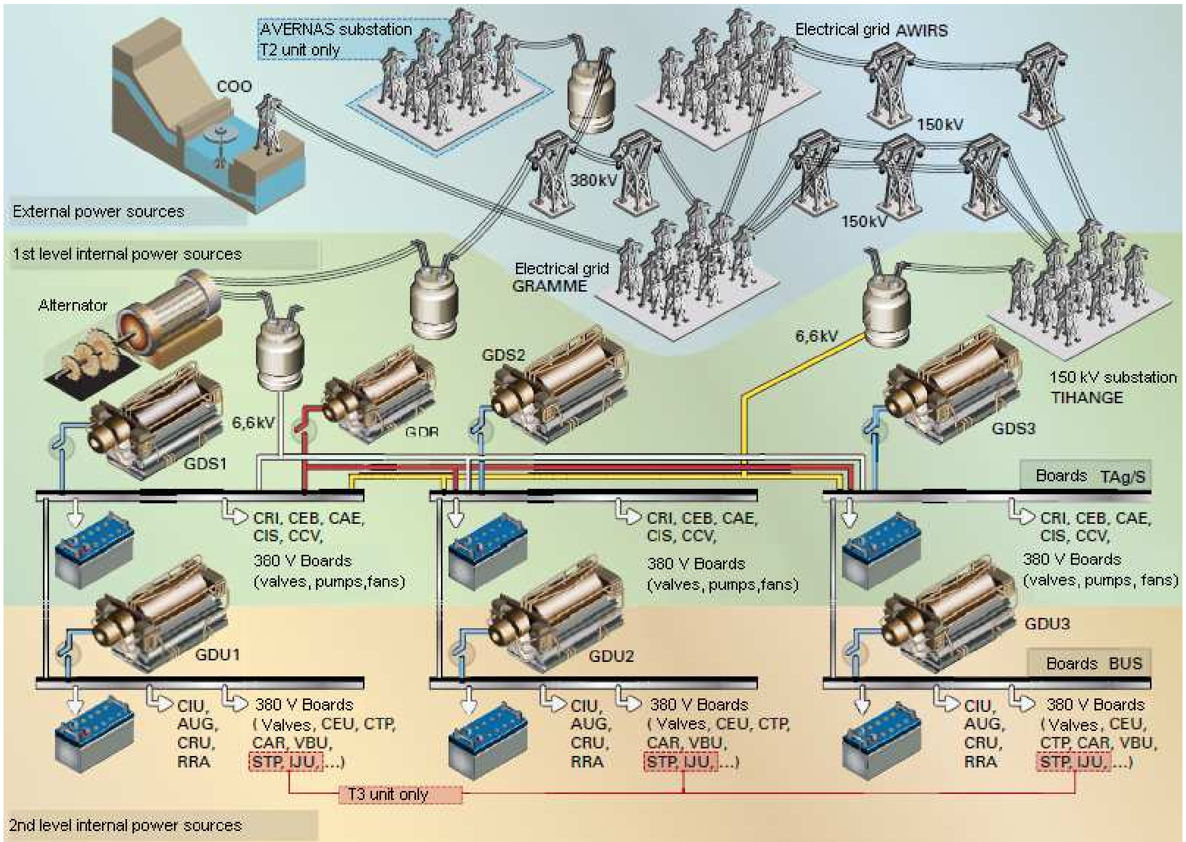

Figure 13 - Plan of the electricity power supplies in Tihange 2 and 3.

Each unit also has back-up diesel electricity generators organized in two levels of protection (first level safety diesel generators and second level emergency diesel generators). Each of these levels of protection alone can maintain the reactor in a stable and controlled state. Moreover, a back-up diesel generator common to the three units can also be used instead of any first level generator for any unit.

The first level safety systems are powered by the external grid but in the case of LOOP the first level safety diesel generators ensure the power resupply to these first level systems (2 diesel generators for Tihange 1, 3 for Tihange 2, 3 for Tihange 3).

The second level emergency systems are powered by the external grid but in the case of LOOP and loss of the first level safety diesel generators the second level emergency diesel generators ensure the power resupply to these second level systems (1 diesel generator and 1 turbo-alternator for Tihange, 3 diesel generators for Tihange 2, 3 diesel generators for Tihange 3).

Doel NPP

The main external supply of the site of Doel is assured by five 380 kV-high voltage lines (3 from the Mercator station, 1 from the Avelgem station and 1 from the Zandvliet station) which are connected to the 380 kV-station at Doel with which the 4 units are connected via different busbars.
The alternative external supply of the four units is formed by a 150 kV-high voltage station with a double busbar installed on the site of Doel and fed itself by 2 high voltage lines, one from the Kallo station and one from the Zandvliet station.

The auxiliary systems of Doel 1 and 2 take their power, at units in shutdown conditions, only from the 150 kV-grid. The auxiliary systems of Doel 3 and 4 can also be powered from the 380 kV grid.

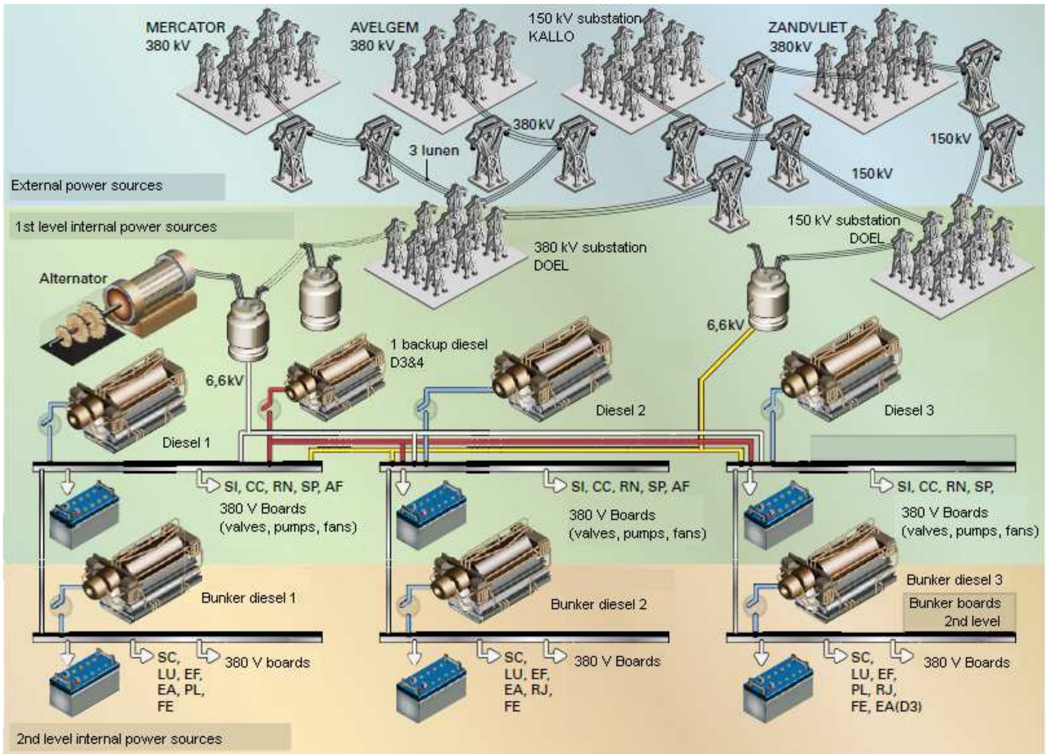

Figure 14 - Plan of the electricity power supplies in Doel 3 and 4.

When the unit is in normal operation (full power), the alternator supplies the electric energy to the auxiliary systems of the plant.
In the event of some failure of the main electrical power supply, the reactor unit (during power operation) automatically switches to house load operation. The reactor unit then disconnects from the external grid and the alternator will then only provide power to its auxiliary systems.

Each unit also has back-up diesel electricity generators organized in two levels of protection (first level safety diesel generators and second level emergency diesel generators). If house load operation fails, an emergency shutdown stops the reactor and the first and second level diesels will start.

The first level safety systems are powered by the external grid but in the case of LOOP the first level diesel generators ensure the power resupply to these first level systems (4 for Doel 1&2, 3 for Doel 3, 3 for Doel 4).

The second level emergency systems are powered by the external grid but in the case of LOOP the second level diesel generators ensure the power resupply to these second level systems (2 for Doel 1&2, 3 for Doel 3, 3 for Doel 4).

High voltage network

As manager of the Belgian high voltage network, ELIA is responsible for the operation and management of the external high voltage network.
The "Access Contract" concluded between the licensee and ELIA stipulates that, in case of an intact network, sufficient power must be available on the 380 kV and 150 kV lines of the nuclear power stations of Tihange and Doel to ensure power supply to the vital auxiliary systems of the different units.
The "Connection Contract" concluded per site between the licensee and ELIA describes, by way of information, the specific agreements that must be respected by ELIA for the operation and maintenance of the high voltage network. It also mentions the permanent availability of two independent electric supplies for powering the vital auxiliary systems in Tihange and Doel - as required by the Technical Specifications.

Moreover, the "Connection Contract" mentions the back-up and reconstruction Codes for the Belgian high voltage network. The back-up code sets out the necessary actions managed by ELIA in order to avoid a more serious deterioration of the network in case of a problem affecting it. The reconstruction code sets out the necessary actions managed by ELIA in order to reconstruct the network in case of black-out.

5.1.1. Loss of offsite power (LOOP)

The total loss of external power scenario considers the total loss of the 380 kV electric network, the failure of house-load operation and loss of the 150 kV electric network.

The LOOP is covered by the design of the units. The different automatic actions ensure the protection of the reactor and the evacuation of the residual heat: shutdown of the reactor, start-up of the auxiliary feedwater and cooling.
In case of failure of islanding of the unit and until an external power source is re-established, the auxiliaries having a nuclear safety function and ensuring a safe and controlled shutdown of the unit are powered by internal sources.

To summarize, restoring the power using internal electric power supply will allow the maintenance of the following principal functions:

- feedwater for the steam generators by the two motor-driven pumps and a turbo pump (no electric power necessary);
- injection of borated water to the primary system to compensate the contraction of water during the cooling phase, and controlling the reactivity of the core in order to keep it in a sub-critical state;
- maintaining of the primary pump seals cooling;
- maintaining of the cooling of the core by the shutdown cooling system.

The spent fuel pool cooling pumps provide the cooling of the spent fuel pools via heat exchangers.

Physical description of the scenario
After the emergency shutdown, the pumps of the primary system, too powerful to be backed up by diesel generators, will stop. The water flow rate in the core will diminish rapidly and, after complete shutdown of the primary system pumps, there will be natural circulation in the system due to convection. This natural circulation assures the removal of the residual heat from the core. It should be noted that this residual heat will diminishes progressively in time after shutdown of the reactor.
The reactor shutdown of the reactor triggers a turbine shutdown, and the closing of the inlet valves of the latter. The normal feedwater being lost, an automatic start-up signal is sent to the auxiliary feedwater system to ensure the supply of water to the steam generators. This system, consisting of two motor-driven pumps backed up by the first-level safety diesel generators and by a turbo pump driven directly by the steam produced at the steam generator outlets, provides sufficient water flow to the steam generators to remove the residual heat of the reactor. The steam is released through the relieve valves to the atmosphere.

If the loss of offsite power occurs when the unit is not in conditions allowing the removal of residual energy through the steam generators, the shutdown cooling system (Tihange: RRA, Doel: SC) takes over the cooling. The shutdown cooling system is powered by first-level safety diesel generators.

5.1.1.1. Design provisions

Tihange 1
There are **two first level safety diesel generators** (GDS) each of a power of 3552 kW (power in continuous regime), cooled by water from the river Meuse or by the groundwater via the raw water system (CEB). One GDS alone is sufficient to power the necessary auxiliary systems. This redundancy is an additional safety element. These generators are dimensioned for the safe shutdown of the unit in the worst-case scenario.

The unit also has a **second level emergency electric power supply (GUS turbo-alternator and DUR diesel generator)** that is not strictly necessary in case of loss of external electric power. However, these power sources further increase the autonomy of the site (although it would be sufficient to use only the first-level safety diesel generators). The same applies with respect to the reserve diesel generator (GDR).

Tihange 2 and 3

There are **three first level safety diesel generators (GDS)** each of a power of 5040 kW (power in continuous regime) cooled by water from the river Meuse via the raw water system (CEB). Two of the GDS are necessary to bring and maintain the unit in a stable and controlled state. Each safety diesel generator is physically independent and electrically separated from the other two so that any failure or incident in one generator will not have consequences for the two others.

The units also have a **second level emergency electric power supply (3 GDU diesel generators)** that is not strictly necessary in case of loss of external electric power. However, these power sources further increase the autonomy of the site (although it would be sufficient to use only the first-level safety diesel generators). The same applies with respect to the reserve diesel generator (GDR).

Doel 1/2

There are **four first level safety diesel generators**

- *Current situation:* four first-level diesels each with a capacity of 2100 kW, shared by both units. These diesel generators are cooled by air coolers and are designed to ensure the unit shuts down safely.
- *Future situation*: the present four first level diesel generators will be replaced during 2012 by four new first level diesel generators each with a capacity of 2500 kW. The new diesel generators are cooled by air coolers and are moreover resistant to earthquake (DBE). In addition a fifth, identical first level diesel generator is foreseen. It can replace one of the four other diesel generators in case of unavailability.

There also two second level emergency diesel generators each with a capacity of 2300 kW, shared by both units and cooled by air coolers. These diesel generators belong to the Emergency Systems Building (GNS) and are designed to assure power to all auxiliary systems required for a safe shutdown and for maintaining a safe situation in the event of the loss of all external power sources and the first level diesel generators. These second level diesel emergency generators and the systems they power are independent of the first level diesel generators. These emergency diesel generators and the systems they power are protected against external accidents.

Two additional auxiliary diesel generators each with a capacity of 1675 kW are responsible for supplying the systems intended for guaranteeing the safety of people and equipment that are not related to nuclear safety.

Doel 3&4

Each unit has **three first level diesel generators** each with a capacity of 5040 kW. They are cooled by air coolers. These generators are designed to assure the safe shutdown of the unit.

A reserve first level diesel generator (phi diesel) with a capacity of 5040 kW is shared by the units Doel 3 and Doel 4. It is located on the site of Doel 3 and is cooled by an air cooling system. This aggregate can be connected in less than 1 hour in order to replace one of the first level diesel generators of Doel 3 or Doel 4.

Each unit has **three second level diesel generators** each with a capacity of 2240 kW. These are located in the bunker of the unit and are cooled by the water from the cooling pond which belongs to the unit. These diesel generators are designed to assure power to all auxiliary systems in the bunker required for a safe shutdown and for maintaining a safe situation in the event of the loss of all external power sources and first level diesel generators. These emergency diesel generators and the systems they power are protected against external accidents.

Each unit has two additional auxiliary diesel generators available each with a capacity of 800 kW.

5.1.1.2. Autonomy

Tihange 1
The unit has a diesel fuel reservoir with a useful capacity of 80 m³ per first-level diesel generator, giving them autonomy of 3.5 days for each generator without any make-up of reservoirs and while functioning at 100% load.

Using only the systems necessary for the cooling of the unit in case of LOOP without other incident, this autonomy is 4.5 days considering the cooling of the unit and the passage from hot shutdown to cold shutdown. The use of the additional diesel fuel contained in a reserve diesel fuel tank (CVA B01Hc) gives autonomy of about 20 days.

After reduction of the load to only the systems required to maintain the unit in cold shutdown, the lubricating oil available for the GDS and the security stock present on the site (approximately 6 000 l for the three units) gives autonomy of more than two weeks.

Tihange 2 and 3
The total storage capacity of diesel fuel for the first-level safety diesel generators is:
- three tanks with a useful capacity of 170 m³ per reservoir in Tihange 2;
- three tanks with a useful capacity of 170 m³ per reservoir in Tihange 3;
- one tank with a useful capacity of 170 m³ for the common reserve diesel generator (GDR).

There is also an emergency manual link with the diesel fuel transfer pipes of the emergency diesel generators which have a main storage tank with a capacity of 185 m³.

Autonomy of 7 days is therefore available without any make-up to the diesel fuel tanks and while functioning at 100% load of the two safety diesel generators per unit in the worst-case scenario in terms of load.

Using only the systems necessary for the cooling of the unit in case of LOOP without other incident, this autonomy is about 15 days if the cooling of the site from hot shutdown to cold shutdown is included. Moreover, using the diesel fuel remaining in a reserve diesel fuel tank (CVA B08), this autonomy is extended to about 25 days.

Concerning the lubricating oil, each diesel generator is equipped with its own filling and draining system and with a storage tank holding up to 2 000 litres. Autonomy at full power is 7 days. This supposes an intervention by an operator to adjust the oil level in the diesel engine every 28 hours during operating at nominal power.

Doel 1/2
The first level diesel generators have autonomy of at least 15 days.
The tanks of the first level diesel generators have, in accordance with the Technical Specifications, a stock that allows 15 days autonomy.
If all the diesel fuel available on Doel 1/2 in the second level diesel generators and auxiliary diesel generators and in the WAB would be used, the autonomy becomes 34 days.
The lubricating oil supply available in the oil carter and the reserve tanks are more than sufficient.

Doel 3 and Doel 4
The first level diesel generators have autonomy of at least 15 days.
The diesel fuel supply in accordance with the Technical Specifications allows 23 days autonomy at Doel 3 and 20 days at Doel 4.
If the diesel fuel tanks of the first level diesel generators and the second level generators are completely full, there is autonomy of 35 days for Doel 3 and 28 days for Doel 4.
The lubricating oil supply available in the oil carter and the reserve tanks are more than sufficient.

5.1.1.3. Measures allowing prolonged use of internal electric power

To extend the autonomy of electric power supply, one essentially uses the reserves of diesel fuel and lubricating oil available in: (1) the common tanks, (2) in those of the diesel generators not available or not necessary for maintenance of a stable prolonged shutdown and (3) in the on site storehouse (transfer via internal or external means). In this situation, with the unit in stable controlled shutdown state, the energy needs are those required to maintain the unit in the stable state rather than to bring the unit to the stable state as during the first hours following the initial event. In particular, the diesel generators run at reduced load, which greatly reduces their consumption.

For Tihange, it should be noted that a common procedure for the three units applies in case of protracted problem with the external electric network, unstable power supply or black-out. The supply of diesel fuel on the site follows an internal procedure. The supply of diesel fuel is governed by a contract that provides for a delivery on site within a maximum period of 25 hours.

For Doel, a tanker truck is present on the site with which diesel fuel can be transferred from the unused diesel fuel tanks of the second level diesel generators, the reserve (phi) diesel generator, the secondary diesel generators, the WAB and between the 4 units. Both in Doel 1/2 and in Doel 3&4 transferring the diesel fuel is only necessary after 1 to 2 weeks. This is more than enough to get the required personnel on site.

5.1.1.4. Measures that may be considered to increase the robustness of the installations

A few procedures and minor organizational optimizations ensure even greater security. In case of prolonged loss of external power and impossibility of new supplies of diesel fuel and oil, it will be necessary to minimize the consumption of the safety diesel generators. For that purpose a procedure defining the non-essential loads must be provided for the units of both sites.

In Tihange 1, the make-up of lubricating oil is taken at the sump of the diesel generators from the oil barrels. The units also has a reserve tank of oil for the safety diesel generators (GDS) (approximately 2 000 l). An analysis will be conducted in order to consider a minimum reserve in this tank. Moreover, procedures shall also be amended in order to anticipate the make-up of oil for the different diesel generators (applicable for the site).

5.1.2. Loss of offsite power (LOOP) and loss of the first level on-site back-up power supplies (Station Black-out)

This paragraph considers the loss of offsite power and of the first level internal electric power.

This scenario, called station black-out, postulates, successively or simultaneously:
- the loss of external power (380 kV and 150 kV lines, see beginning of Chapter 5);
- failure of house load operation;
- loss of first-level safety diesel generator.

Note: the reserve diesel generators are also considered as unavailable for reasons of coherence of the scenario.

In these circumstances the units have a second level of protection allowing to maintain the reactor in a stable and controlled state and assuring the cooling of the spent fuel pools.

5.1.2.1. Design provisions and autonomy

In case of LOOP and loss of the first level safety diesel generators, the necessary safety equipment still need to be supplied. This can be done by:

- the reactor units on site which are not shut down;
- the second level emergency diesel generators;
- steam driven pumps;
- batteries.

The autonomies mentioned concern the situation in which each unit must use its own reserves, which represents the worst-case scenario. In case of an incident that does not affect all units on the NPP site the total reserves of the site will be used via external means for the unit(s) affected, which will increase autonomy.

Tihange 1

The emergency system (SUR) has several objectives including bringing and maintaining the unit in a stable and controlled shutdown in case of total loss of external and internal electric power supply.

The SUR includes two sources of electric power that start up automatically within less than one minute after the loss of power:

- the emergency turbo alternator (GUS) with a power of 80 kW, available if at least one of the steam generators is operational and that operates if the temperature of the water in the primary system exceeds 180 °C;
- the emergency diesel generator (DUR) with a power of 288 kW (power in continuous regime), cooled by a water/air exchanger.

These two emergency systems are situated in the Emergency Building (BUR) and power the equipment running on 380 V.

The capacity of the DUR diesel fuel tank (container holding 500 l in the BUR Building) gives autonomy of 7 and a half hours. Manual diesel fuel transfer achieved by gravity from the CVA B01Hc tank, increases autonomy to more than 200 days, which exceeds by far the time necessary for the restoration of external power - or the installation and start-up of conventional diesel generators.
This diesel fuel tank and the oil reserve (600 l) on site ensure an autonomy of several weeks.

Tihange 2 and 3

In the design basis, this type of accident challenges the second level of protection, managed by the Emergency Building (reinforced building called BUS). The role of the emergency systems (CUS) is to protect the power station and the environment from the consequences of an accident of external origin, in particular the loss of first-level protection systems.

The second level of protection has several systems the most important of which are: AUG (Emergency feedwater to steam generators), the CRU (Emergency cooling), the CIU (emergency injection) and the IJU (emergency pump seal injection, Tihange 3 only; the integrity of these pump seals is ensured by the CRU in Tihange 2).
The electric power of this equipment is provided by three emergency diesel generators each with a power of 2240 kW (power in continuous regime) situated in the BUS of the unit, cooled by water from the river Meuse or by groundwater (CEU). These generators are dimensioned to provide power supply for all the auxiliaries in the BUS necessary for bringing and maintaining the unit in stable and controlled shutdown in case of loss of all external power supply and first-level safety diesel generators.

The diesel fuel storage capacity as set by the technical specifications allows full load operation of the two emergency diesel generators (GDU) on the three sites for at least 7 days in the worst-case scenario. Using only the equipment necessary for placing and maintaining the unit in cold shutdown, autonomy is increased to 50 days. For this use is made of the remaining diesel fuel in the tank CVA B08, common to Tihange 2 and 3, and the diesel fuel in the first-level diesel generator tanks (via external means).
Oil consumption is 3.2 l/h at full power and the capacity of the tank is 1 000 l per diesel generator GDU. This gives autonomy of about 13 days. Taking account only of the equipment essential for

passage to cold shutdown, the capacity of the oil tank and the reserve stock gives autonomy of at least 4 weeks.

Doel 1/2
There also two second level emergency diesel generators each with a capacity of 2300 kW, shared by both units. These diesel generators belong to the Emergency Systems Building (GNS) and are designed to assure power to all auxiliary systems required for a safe shutdown and for maintaining a safe situation in the event of the loss of all external power sources and the first level diesel generators.
The second level emergency diesels are cooled by closed water/air heat exchangers located in the Emergency Systems Building.

Doel 3 and Doel 4
Each unit has three second level diesel generators each with a capacity of 2240 kW. These are located in the bunker of the unit. These diesel generators are designed to assure power to all auxiliary systems in the bunker required for a safe shutdown and for maintaining a safe situation in the event of the loss of all external power sources and first level diesel generators.
The second level emergency diesels are cooled by the LU-system that gets its cooling water from the LU-ponds. They are independent of the primary ultimate heat sink.

5.1.2.2. Analysis of loss of offsite power (LOOP) and loss of the first level on-site back-up power supplies

The analysis below postulates that only a single unit is affected. Different initial states of the unit will be considered:
- steam generators available: the primary circuit is closed which allows the use of the steam generators to cool the fuel;
- open primary system: the reactor coolant system is open (during outage of the unit) and the steam generators are not available to cool the fuel which is still in the open reactor vessel;
- core in spent fuel pool: the unit is in outage and all the fuel is removed from the core and put in the spent fuel pools.

Steam generators available
This scenario is part of the design of all the units. For the recent units, the second-level of protection systems allow the reactor to be placed and maintained in cold shutdown.
The design of the oldest units (Tihange 1, Doel 1/2) differ significantly from the recent units.

Tihange 1
The unit is brought and maintained in a stable and controlled intermediate shutdown, known as the fall-back state.
The residual heat of the core is cooled by the steam generators which are fed by the auxiliary feedwater turbopomp EAS. The autonomy of the auxiliary feedwater tank (EAS) is sufficient to allow a manual alignment with the groundwater system.
Moving to cold shutdown is not possible. The GUS and the DUR, not being electrical sources of 6 kV, cannot power the shutdown cooling pumps (RRA). It is therefore necessary to stay on the steam generators - which supposes a primary system temperature of about 180 °C in order to allow the functioning of the turbopomp – as long as the 6 kV power supply is not recovered for these pumps.

There is no cliff-edge effect for this scenario. The groundwater system has autonomy of at least 30 days considering a single affected unit. This autonomy largely exceeds the time needed until arrival of equipment or water from another unit or from outside the site.
The available capacities of diesel fuel and oil in the unit allow autonomy of several weeks, which largely covers the time until arrival of equipment or consumables from another unit or from outside the site.

Doel 1/2

For the removal of the residual heat, one can rely:

- in first instance on the Auxiliary Feedwater (AFW) Turbo pump for feeding the steam generators. The pump gets its water from the higher located AFW tank and MW tank. These 180 m³ are sufficient to keep the power station at hot shutdown for 7 hours.
- furthermore, on the second level feedwater supply of the steam generators: the Emergency Feedwater system (EF). This has a stock of 400 m³ per unit, sufficient for autonomy of 20 hours. Refilling of the EF-tank is realized by the fire protection system (FE).

After cooling down with the EF, the shutdown cooling system (SC) may be taken into service 7 days after the reactor shutdown for the removal of the residual heat. The SC-coolers and pumps are cooled by the second level emergency cooling system (EC). This cools the EC water by air coolers. A water supply is then no longer necessary.

There are two second level diesel generators available but only one diesel generator is needed for supplying the consumers of both units. With a realistic consumption and if less essential consumers are stopped (heating, ventilation at half strength), the diesel fuel stock is sufficient for approximately 5 days.

There are no cliff edge effects for this scenario. There is enough water storage available on site to achieve conditions where a switch to the EC for cooling of the SC is possible. After 5 days the second level diesel generators must be resupplied with diesel fuel. That is more than enough time to get diesel fuel from other places on or off the site.

Tihange 2 and 3

The residual heat of the core is removed by the steam generators which are fed by the auxiliary feedwater turbopomp EAA. One may further use the second level supply of the steam generators, the emergency feedwater-system (AUG).
The second-level of protection systems allow the reactor to be placed and maintained in cold shutdown. There is therefore no cliff-edge effect for this scenario.

The only problem that might arise is the exhaustion of diesel fuel or oil for the second-level diesel generators, which will happen after a minimum of one week. This autonomy covers the time before the arrival of equipment or consumables from another unit or from outside the site.

Doel 3 , Doel 4

For the removal of the residual heat, one can rely in first instance on the Auxiliary Feedwater (AF) turbo pump for feeding the steam generators. The pump gets its water from two higher located AF-tanks. These each contain at least 700 m³ water. This is sufficient to cool the unit to shutdown conditions and then cool it for at least an additional 16 hours using the steam generators. For the removal of the residual heat one may further use the second level feedwater supply of the steam generators, the Emergency Feedwater system (EF).
All pumps and heat exchangers necessary during the stabilization and cooling down are cooled by the second level cooling system LU. The autonomy of the water supply from the LU ponds is at least 26 days.
All electrical supplies come from the second level diesel generators in the Bunker. Two of the three diesel generators are sufficient to power the consumers of the unit. There is sufficient diesel fuel stock present for at least 10 days. That is more than enough time to get diesel fuel from other places on or off the site.

The second-level of protection systems allow the reactor to be brought and maintained in cold shutdown state. There is therefore no cliff-edge effect for this scenario.

Open primary system

Tihange 1

In this case the shutdown cooling system of the reactor (RRA) remains connected but not operational since it requires a power supply of 6 kV.

If it is possible to close the primary system, the accident management procedure foresees restoring the use of the steam generators by allowing the primary system to heat up until restoration of function of the EAS turbopump. The rest of the sequence is described above (Steam generators available).

If it is not possible to close the primary system it is still possible to execute a feed and bleed operation. In this case cold water from the B01Bi tank is fed to the primary system and steam is extracted by a VBP ventilator to the chimney and filtration systems of the VBP.

There is no cliff-edge effect for this scenario. The make-up from tank B01Bi is in fact sufficient for functioning for at least 72 hours. This autonomy covers the time until arrival of equipment or water from another unit or from outside the site. An exterior link allows connection of a tanker truck containing borated water for make-up in tank B01Bi.

Diesel fuel and oil autonomies given above allow amply to wait for the arrival of equipment or consumables from another unit or from outside the site.

Doel 1/2

The removal of the residual heat from the open reactor cooling system is realized by SC-pumps which are powered by the second level diesel generators. The cooling of the SC-pumps and coolers is taken over by the EC-system. No water supply needs to be provided for the unit with the open RC-system.

If account is taken for 1 unit with an open primary system and 1 unit with steam generators available, the fuel capacity of the second level diesel generators is sufficient for more than 5 days. Furthermore if the stock of the first level diesel generators is used to supply the second level diesel generators, then the fuel stock is sufficient for 1 month.

The unit of which the primary system is open, is cooled from the beginning by both EC-coolers. It is not necessary to add water. Without cooling a fully loaded open reactor will start to boil under the most conservative circumstances after 20 minutes (half leg, full core, 5 days after shutdown). The manual alignment of the EC-system takes 45 minutes. In that case the core would boil for a short time but the inventory is maintained by the RJ-system and the RWST.

After a little more than 5 days the second level diesel generators must be resupplied with diesel fuel. That is more than enough time to get diesel fuel from other places on or off the site.

Tihange 2 and 3

The second-level systems, powered by the emergency diesel generators GDU, can maintain the reactor in cold shutdown (and cool the CTP spent fuel pools).

The only problem that might arise is the exhaustion of diesel fuel and oil for the second-level diesel generators, which will happen after a time (minimum one week) compatible with the time before the arrival of equipment or consumables from another unit or from outside the site.

Doel 3 , Doel 4

The removal of the residual heat from the reactor is realized by the SC-system and the LU-system, both powered by the second level diesel generators.

Diesel fuel consumption is lower than in the ‘steam generators available’ scenario. The Bunker can continue for more than two months with the diesel fuel stock from the first level tanks.

There are no cliff edge effects for this scenario.

Core in spent fuel pool

Tihange 1

In this scenario the spent fuel pool is not cooled by the CTP exchangers (the pumps of the normal pool treatment system CTP-P01Bd 1 and 2 are not backed up by the SUR). An analysis of the possibility of emergency repowering of the CTP pumps by the SUR will be conducted.

The fuel assemblies in the pool remain cooled by the water present in the pool. Evaporation begins approximately 40 hours after the loss of normal cooling. In these conditions the

situation to avoid is the uncovering of the fuel assemblies (period of at least two weeks without water make-up). Water make-up in the spent fuel pool, carried out within few hours by conventional or non-conventional systems, allow the fuel to be kept under water. The make-up water comes from tank B01Bi, either by gravity or by pump P04Bd (powered by the DUR).
The current SUR procedures will be amended in order to provide make-up and steam evacuation.

Doel 1/2
During a full core unloading, the core is stored in the PL-pools of the Nuclear Auxiliary Services Building (GNH). The cooling of the PL-pools is taken over after the loss of the first level systems by the second level PL-air cooler, via 2 PL-pumps powered by the second level diesel generators.
If account is taken of 1 unit in hot shutdown and 1 unit of which the whole core is unloaded, then the fuel stock in the Emergency Systems Building is sufficient for 7 days.
If one uses the stock of the first level diesel generators in addition to this to supply the second level diesel generators, then the fuel stock is sufficient for approximately 40 days.
An uncooled spent fuel pool will only start to boil after 15 hours. The PL-system is aligned manually within 1.5 hours. This is much less than the 15 hours available.
The PL-system is moreover a closed system for which no additional water is required.
After 7 days the second level diesel generators must be resupplied with diesel fuel. That is more than enough time to get diesel fuel from other locations on or off the site.

Tihange 2 and 3
The second-level systems allow the reactor to be placed and maintained in cold shutdown and cool the CTP pools. The spent fuel pools in the DE building can be cooled by a CEU well in Tihange 2 or Tihange 3. The autonomy of the groundwater is at least 30 days. There is therefore no cliff-edge effect.
The only problem that might arise is the exhaustion of diesel fuel and oil for the second-level diesel generators, which will happen after a time (minimum one week) compatible with the time before the arrival of equipment or water from another unit or from outside the site.

Doel 3, Doel 4
The cooling of the spent fuel pools in the Spent Fuel Building remains assured. The removal of the residual heat from the spent fuel pools is realized using the PL-system and the LU-system, both powered by the second level diesel generators.
Diesel fuel consumption is lower than in the 'steam generators available' scenario. The Bunker can continue for more than two months with the diesel fuel stock from the first level tanks.
There are no cliff edge effects for this scenario.

Several units of the Tihange site affected
The management of the accident for this scenario will be identical to that for the case in which a single unit of the site is affected, since only the equipment and reserves proper to each unit are used in the short term (at least 72 hours in Tihange 1 and one week in Tihange 2-3).

The main difference is the use of groundwater by several units, which is discussed later on (loss of primary ultimate heat sink).
However, in case of loss of external electric power combined with the loss of the first-level diesel generators, the units Tihange 2 and 3 can use water from the river Meuse except for the cooling of the DE pools. Tihange 1 is therefore the only unit that will use the groundwater over the medium term as a heat sink (autonomy of 30 days if a single unit is affected). It will also be necessary to provide for the medium term the use of wells for the cooling of the DE. Even in these cases the site will always have autonomy of several weeks. There is therefore no cliff-edge effect.

Several units of the Doel site affected
Doel 3&4 do not use the systems from Doel 1/2, so that this additional loss has no effect. If the entire site is affected, Doel 3&4 must however share the water stock available from the LU-ponds with all units. However this stock is sufficient.
The diesel fuel tank of the WAB always remains available.

Other units affected will not cause additional cliff edge effects.

5.1.2.3. Battery capacity and autonomy

Tihange 1

The panels necessary for the functioning of the SUR (including those backed up by batteries) will be repowered by the DUR and the GUS, thus giving them autonomy at least equal to that of the SUR (up to several weeks). The autonomy of the batteries of the SUR is not limiting in this case.

Tihange 2 and 3

The panels necessary for the functioning of the BUS (including those repowered by back-up batteries) will be repowered by GDU, giving them autonomy at least equal to that of the GDU (up to several weeks). The autonomy of the batteries of the BUS is not limiting in this cases.

Doel 1/2

In the case of the loss of all external and internal first level power sources, the batteries of the first level diesel generators may still be relied on. The batteries of the first level systems are able to ensure power for the instrumentation and control and the signalization for 4 to 16 hours.
The second level systems, including their diesel generators, are entirely operational in this case. The batteries of the second level diesel generators are therefore continuously recharged using rectifiers. As long as the second level emergency diesel generators are operational, the autonomy of those batteries is unlimited and the power supply of instrumentation and control is assured.

Doel 3, Doel 4

In the case of the loss of all external and internal first level power sources, the batteries of the first level diesel generators may still be relied on. The batteries of the first level systems are able to ensure power for the instrumentation and control and the signalization for 3 to 27 hours.
The second level systems, including their diesel generators, are entirely operational in this case. The batteries of the second level diesel generators are therefore continuously recharged using rectifiers. As long as the second level emergency diesel generators are operational, the autonomy of those batteries is unlimited and the power supply of instrumentation and control is assured.

5.1.2.4. Autonomy of the site before degradation of the nuclear fuel

Tihange NPP

This incident is a part of the design of the power stations. A series of equipment and reserves available on site allows running for more than 72 hours without equipment or consumables from outside the site. The incident will be managed according to the procedures in force by the shift crew and on-call teams.

Doel NPP

This incident is a part of the design of the power stations. There is sufficient water and diesel fuel present on the site for several weeks. Standard operating procedures are available so that the shift personnel can handle this situation.

5.1.2.5. (External) actions provided to avoid degradation of the nuclear fuel

Tihange 1

Because this scenario is part of the present design of Tihange 1 (at power), it is therefore not necessary (in the short term) to use external means.
The unit has equipment powered by the SUR that is sufficient to handle this type of incident, as described previously, and therefore to preserve the integrity of the fuel. In this scenario priority will therefore be given to retrieve a source of electric power (external, GDS or GDR).

Moreover, water make-up may also be carried out from the reserve in B01Bi to the pools, other emergency system allow a supply of fire protection water to the spent fuel pool either indirectly by a hydrant supplying the pool filling tank, or directly from a hydrant filling the pool. In both cases the fire system is pressurized by its diesel motor pump (approximately 450 m^3/h) or by a mobile motor pump. The fire protection system of the three units may also be interconnected.

These solutions may be implemented well before the temperature of the water makes it difficult to access the building, if necessary. The minimum time before boiling is about 10 hours.

Tihange 2 and 3

Because this scenario was considered as part of the design of the units, it is therefore not necessary (in the short term) to use external means. The second-level protection systems allow the cooling of the fuel storage pool and of the DE pool for Tihange 3.
In this scenario priority will be given to retrieve an external source of electric power.

Doel NPP

Because this scenario was considered as part of the design of the units Doel 1/2 (at power), Doel 3 and Doel 4, it is not necessary under those circumstances to use external means.
In this scenario priority will be given to retrieve an external source of electric power.

5.1.2.6. Measures that may be considered to increase the robustness of the plant

Tihange NPP

In Tihange 1 the management of this accident uses as a source of electric power the emergency diesel generator DUR and the GUS. A make-up of diesel fuel for the emergency diesel generator is necessary three times a day. This make-up is manual. The implementation of an automatic system will be analyzed.
Studies will be conducted to analyze the possibility of repowering the pumps (CTP, RRA) in Tihange 1 in order to maintain closed-loop cooling for the pools and the primary system (in conditions in which the steam generators are not available) in this type of scenario.
The current procedures for modification of the SUR will be amended in order to ensure a make-up and steam release for the scenario with the core in the BAN D spent fuel pool.

A procedure defining the non-essential loads in emergency situation should be provided in order to limit consumption of diesel fuel for all the Tihange units.
Moreover procedures should be amended in order to ensure regular make-up of oil for the various diesel generators.

Doel NPP

If there is no prospect of enduring recovery of the external grid or delivery of new diesel fuel after 72 hours, all non-essential consumers are stopped. The applicable procedures are amended for this.
In the event of the long-term loss of the external grid and the inability to supply new diesel fuel from outside the site, the provision is made to pump the diesel fuel stock available on site to the most essential diesel generators still available. This is necessary at the earliest after 15 days at Doel 1/2 and 20 days at Doel 3&4. Maintenance staff is relied upon for this, and will certainly be available in that time period. This measure and the elaboration, with reference to those executing it, must be described in an organizational memo. Training of the involved staff is provided.

5.1.3. Loss of external power (LOOP) and loss of all on-site back-up power provisions (total Station Blackout)

This paragraph considers the loss of all sources of electric power, external or internal, first-level and second-level.

5.1.3.1. Design provisions

In these circumstances the NPP site only has batteries, turbo pumps and water reserves that can be moved by gravity or by non-conventional mobile means. In this exceptional case, the site has an autonomy varying from few hours to several days. The scenario is therefore used for the definition of additional non-conventional means allowing ensuring that the unit stays in a stable and controlled state over the long term.
In all cases the complete loss of external and internal electric power is managed initially by accident procedures (high priority to rapid restoration of a diesel generator or of an external source of electric power) and then according to predefined criteria laid down in the SAMG.

It should also be noted that Tihange 1 has the particularity of a emergency turbo alternator (GUS). This latter, which will be available as long as the steam generator produces sufficient steam pressure, is an important asset. In fact, the GUS allows the repowering of certain equipment such as the TPA-EAS batteries, the primary system pump seal injection pump and one of the emergency air compressors.

5.1.3.2. Battery capacity and autonomy

Tihange NPP

In case of loss of all external and internal electric power, the last elements that can be deployed are the batteries that are designed to guarantee power for the instrumentation and control/command for a minimum of 3 hours for Tihange 1 (3 hours for Tihange 2 or Tihange 3) according to the technical specifications.
On the basis of real consumption measurements (estimation of real capacity) the progressive loss of power supply in connection with first-level batteries starts after 4 hours of running in Tihange 1 (5 hours in Tihange 2 or Tihange 3) and can span more than 17 hours in Tihange 1 (more than 15 hours in Tihange 2 or Tihange 3).
Similarly the emergency equipment has an estimated battery autonomy of more than 7 hours running for Tihange 1 (more than 7 hours in Tihange 2 or Tihange 3) in case of total loss of external and internal electric power supply.

Doel NPP

In the event of the simultaneous loss of all external and internal power sources, the batteries can still be relied on:

- In Doel 1/2 the batteries of the 1st level systems and 2nd level systems will ensure the supply of the instrumentation and control and the signalization for 4 to 16 hours.
- In Doel 3&4 the batteries of the 1st level systems and 2nd level systems will ensure the supply of the instrumentation and control and the signalization for 3 to 27 hours.

5.1.3.3. Autonomy of the site before degradation of the nuclear fuel becomes inevitable

Different initial states of the unit will be considered:

- steam generators available: the primary circuit is closed which allows the use of the steam generators to cool the fuel;
- open primary system: the reactor coolant system is open (during outage of the unit) and the steam generators are not available to cool the fuel which is still in the open reactor vessel;
- core in spent fuel pool: the unit is in outage and all the fuel is removed from the core and placed in the spent fuel pools.

Steam generators available

Using the AFW turbo pumps, the unit can be cooled down and kept at hot shutdown. The regulating AFW-valves can be manually actuated. Steam from the steam generators is vented using steam relief valves.

The main limitation encountered (cliff-edge effect) is the exhaustion of the water contained in the auxiliary feedwater tank and then the loss of instrumentation with the loss of the batteries.

Specific features and values are presented below:

Tihange 1

The volume of the auxiliary feedwater tank is 120 m³; this allows no more than 3 hours cooling (until complete emptying of the steam generators) if the SBO is sudden. Non-conventional means are available to restore the supply of water to this tank via the fire protection system. The fire protection diesel motor pump and the fitting of hoses will allow supplying of this tank within a very short time (30 minutes). These non-conventional means allow avoiding this cliff-edge effect.

However, to increase the robustness of the installations, feasibility studies will be conducted in order to examine the possibilities of increasing the capacity of the auxiliary feedwater tank and for the addition of a back-up feedwater pump.

When the batteries of the instrumentation and control panels are empty (cliff-edge effect), approximately 7 hours after the accident initiation, the turbo pump cuts off and the feedwater to the steam generators is lost. The steam generators dry out is expected to occur more than 12 hours after the loss of electric power supply. Alternative means of restoration of control and command are under consideration to avoid loss of cooling of the core. The same applies for maintaining a minimum instrumentation. Maintaining of the functioning of the turbo pump will allow the eventual use of the CMU in order to provide supply for the steam generators at low pressure.

Doel 1/2

The AFW-tank has a 90 m³ capacity. The normal refilling of this tank is not possible in the absence of power, but it is possible to switch to tank MW1/2R2 which has the same volume. The unit can be kept at hot shutdown for 7 hours this way. If the unit is cooled faster using these stocks, the autonomy is 1.5 hours.

It is possible to inject FE-water using fire hoses in the MW-safety collector and directly to the AFW-tank via this route. If the fire service diesel pump is still available it will be used to pump water from the TW-tank (1300 m³) to the AFW-tanks. As a back-up for the aforementioned refilling options there is a diesel pump present on site which can be used to pump water directly from the large MW tank (1500 m³) to the AFW tank. As an ultimate back-up the mobile diesel pumps on site can be used to pump water from any available water stock directly to the AFW-tank. It is also possible to fill the stocks with the FE-system from the LU-ponds of Doel 3&4 (3 x 30000 m³).

In the first 10 hours there is enough battery supply to monitor all parameters. Within this period an alternative supply must be provided to make it possible to continue to monitor all parameters in order to avoid overfilling or boiling dry of the steam generators.

Tihange 2 and 3

The removal of residual heat by the SG, fed by the EAA turbo pump, is limited by the available volume in the EAA tank (680 m³ in Tihange 2 and 800 m³ in Tihange 3) if make-up is not performed at the latest within approximately 17 hours in Tihange 2 (23 hours in Tihange 3) after accident initiation. Maintaining the functioning of the turbo pump will eventually allow the use of the CMU to guarantee feedwater to the steam generators when these are running under low pressure.

When the batteries of the instrumentation and control panels are empty, after a period estimated to be between 6 to 12 hours in case of Tihange 2 (14 hours in Tihange 3) after the accident initiation, the regulation of the speed of the turbo pump and the generated flow rates to the steam generator must be performed manually. At this point the reading of the steam generator water level is also lost. The operator must first have set a correct water flow rate to the steam generators, otherwise this could eventually result in the drying out or, in the opposite case, an excess of water in the SG. Maintaining a minimum instrumentation is provided by non-conventional means.

Doel 3, Doel 4

There is 2 x 700 m^3 water available in the AF-tanks, which is enough for more than 8 hours. Afterwards, the MW-tanks (2000 m^3) can be aligned manually. And finally the LU-ponds (3 X 30000 m^3) are aligned manually towards the AF-collector. This way there is enough water supply for dozens of days. As an ultimate back-up the mobile diesel pumps on site can be used to pump water from any available water stock to the LU-ponds.

If there is no power at all, the batteries will ensure power to the instrumentation and control systems for at least 4 to 6 hours.

In the first 3 hours there is enough battery supply to monitor all parameters. Within this period an alternative supply must be provided to make it possible to continue to monitor all parameters in order to avoid overfilling or boiling dry of the steam generators.

Primary system open

This case covers a considerable number of configurations of the primary system that differ markedly by the amount of residual heat and by the water inventory in the primary system (including the volume in the reactor building pools). The worst-case scenario is the first step referred to as "mid-loop or reduced inventory" of a unit outage.

After total loss of electric power the water in the primary system heats up to boiling within an interval of less than half an hour to an hour followed by release of the produced steam in the reactor building. This release of steam would have the potential effect of triggering a progressive increase of pressure inside the containment and blocking the gravity feed if nothing is initiated to depressurize the containment.

Specific features and values are presented below:

Tihange 1

In Tihange 1 the gravity feed from tank B01Bi is effective and can delay the core uncovering for one day. If no action is taken the fuel will be damaged after more than one day.

A VBP ventilation (backed up by first-level generators GDS and by the DUR) avoids pressurization of the containment by removal of the generated heat. In case of emergency, the partial opening of the containment also allows this pressurization to be avoided. Additional management strategies of containment overpressure will be examined.

Doel 1/2

The evaporated water is replenished by gravitationally emptying the RWST into the primary system. If make-up to the primary system is performed, the pressure in the reactor building will have risen to failure pressure at the earliest after 3 days. By then the spray system in the reactor building must be taken into service or the reactor building must be vented in a controlled way.

Tihange 2

In Tihange 2, the gravity feed from the CTP tanks is effective and can delay the core uncovering by eight hours. The refilling of the CTP tanks from various sources of water (partial drainage of the pools or any other alternative means) allows extension of their autonomy until restoration of a conventional source of cooling.

Tihange 3

In Tihange 3, the gravity feed from the CTP tanks cannot be performed due the position of the tanks (lower than the primary system). If no action is taken the fuel will be damaged after 3 hours. A feasibility study is foreseen for an alternative make-up.

The refilling of the CTP tanks from various sources of water (partial drainage of the pools or any other alternative means) allows extension of their autonomy until restoration of a conventional source of cooling.

Doel 3, Doel 4

The evaporated water is replenished by gravitationally emptying the RWST into the primary system. At the earliest after 3 days, the pressure in the reactor building will have risen to failure pressure. By then the spray system in the reactor building must be taken into service.

Core in spent fuel pools

In case of complete loss of all external and internal electric power the spent fuel pool is not cooled by the spent fuel pool exchangers.

The cooling of the fuel is maintained by evaporation and water make-up, implemented within few hours. In theory, without cold water make-up to the pool, evaporation will start after several hours, and the time before uncovering of fuel assemblies (cliff edge effect) is a few days if the transfer tube is closed and no action is taken to remedy the situation.

Access to the building will eventually become difficult by the presence of steam. Any operations inside the building will therefore have to be executed as quickly as possible. The opening of a steam relieve (doors, stairs etc.) will allow avoiding overpressure inside the building.

The time required for water make-ups is compatible with the periods mentioned above. Given the numerous means that can be used in the unit for water make-up, this cliff-edge effect is very unlikely.

Several units of the Tihange site affected

The above analysis was conducted for each of the Tihange units independently. If several units are affected at the same time, there will not be any additional constraints since, in the short term, each unit uses its own means and its own reserves.

Several units of the Doel site affected

For Doel, if the entire site is affected, there is an impact on some evaluations of the autonomy.

For Doel 1/2 the FE-system cannot be kept under pressure by the systems from Doel 3&4. As a result the autonomy of the Doel 1/2 systems is shortened from quasi unlimited to shorter, but still sufficiently long periods.

For Doel 3& 4, the FE-system cannot be kept under pressure by the systems from Doel 1/2 and other (non-conventional) means are to be used to compensate for the evaporated water for the spent fuel scenarios.

5.1.3.4. (External) actions foreseen to avoid degradation of nuclear fuel

The complete loss of external and internal electric power is managed initially by accident procedures (high priority for rapid restoration of a diesel generator or an external source of electric power) then by the severe accident guides SAMG following predefined sets of criteria. In case of complete loss of first-level and second-level electric power, only equipment running on battery (until empty) and the back-up feedwater turbo pump remain available.

The actions planned to prevent damage to the fuel and the time before the onset of damage in this scenario are described previously.

At present no additional equipment from outside the site in the case of complete loss of external and internal electric power are considered by the site licensee.

For the Tihange NPP, as part of the periodic safety reviews a flooding that causes complete loss of electric power was studied which led to the setting up of additional measures (CMU equipment). In line with a defined strategy, the setting up and use of CMU equipment is implemented in this case.

5.1.3.5. Measures that may be considered to increase the robustness of the plant

Tihange NPP

The complete loss of first-level and second-level electric power is not considered in the design basis accidents of the power stations Tihange 1, 2 or 3. The autonomy of the batteries and tanks will allow the temporary preservation of certain functions (core cooling).

A series of non-conventional systems has been introduced to respond to an exceptional flood (eventually resulting in a total station black-out), but this supposes an alert period compatible with the time necessary for the implementation of these resources and passage to an emergency situation.

The more limiting analysis conducted for this scenario has identified certain concerns in the management of complete and simultaneous loss of all electric power sources (external and internal). This scenario is used as the envelope case for determination of additional emergency means. The following points summarize the solutions considered. Unless otherwise indicated they apply to all units of the site.

Commitment for implementation

- Provision of an additional 380 V electric power supply in order to be able to restore elementary functions in case of loss of first-level and second-level electric power supply
- Use of the CMU generator to repower control command allowing the functioning of the TPS in Tihange 1;
- Introduction of additional pool level measures on the basis of the following constraints: loss of all electric power and information gathering outside the building;
- Implementation of provisions to allow isolation of SI accumulators during depressurization of the primary system.

Commitment for feasibility studies

- Feasibility study for the addition of a flanged connection from outside the BAN in order to be able to spray the reactor building using a mobile pump to avoid overpressure in the building;
- Feasibility study in order to increase the capacity of the EAS and to add an emergency feed-water motor (Tihange 1);
- Feasibility study for the provision of non-conventional means in order to ensure make-up for the primary system in case of open primary circuit (for Tihange 2 and 3);
- Feasibility study for reliable manual actions on the SG atmospheric discharge valves (Tihange 1 and 3);
- Feasibility study for adding mobile compressors to be connected to the emergency compressed air system.

Procedures must be foreseen to respond to this type of event, integrating the necessary non-conventional means and action strategies (for example: rapid depressurization to limit damage to the pump seals, coordination with non-conventional means present on site, removal of non-essential loads, steering of the local TPA, water make-up and removal of steam from the pools and prioritization of local actions in case of loss of normal cooling of the pools, etc.).
It will also be necessary to modify the existing "accident procedures" to take account of this scenario. Procedures describing the repowering of required equipment by non-conventional means must also be provided.
The organization of the response to this type of non-conventional accident must also be implemented (management of equipment, documents, etc.) without affecting the management of design basis incidents/accidents.

Doel NPP

Steam generators available

The following hardware solutions are planned:

- The diesel generators required (10 x 30 kVA, 4 x 350 kVA) are already available on site, and can be used as emergency power for the instrumentation and control systems and measurement systems.
- For Doel 1/2 , the turbo pump is fed from the small AFW-tank. Mobile diesel powered pumps are available on site to refill this tank.
- To prevent nitrogen from the SI-accumulators ending up in the primary system an alternative power source is foreseen to power the isolation valves of the SI-accumulators with the mobile diesel generators.

The following procedural amendments are planned:

- Updating an operating procedure in the case of total SBO or LUHS (e.g. fast cooling down using steam generators).
- The necessary procedures are foreseen to use the aforementioned resources.

Primary system open

The following hardware amendments are planned:

- For Doel 1/2, the cooling of the reactor will be realized initially through boiling and gravitational refilling of the inventory. After 12 hours the SP-pump will take this over. A connection is foreseen to be able to power the SP pumps from the available mobile diesel generators.
- For Doel 1/2, if there is pressure in the RC-system, the spray piping to the reactor building has to be isolated. Whether another manual valve can be installed for this purpose is being investigated.
- For Doel 3 and 4, studying whether the necessary connections may be provided on the suction and discharge side of the SP-pump and buying a mobile pump (250 m^3/h at 13 bar) to realize alternative SP-flow rate.

The necessary procedures are foreseen to use the equipment mentioned above.

Core in spent fuel pools

The following hardware solutions are investigated:

- To make it possible to refill the PL-pools in the GNH or SPG more easily, it is being investigated whether permanent pipes and connections could be provided to allow this from the outside using mobile pumps. The necessary procedures are foreseen to use the equipment mentioned above.

5.2. Loss of heat sink

5.2.1. Loss of the primary ultimate heat sink (LUHS)

Tihange NPP

The Tihange NPP, situated beside the river Meuse, has several heat sinks. In normal situation, the three units in Tihange use water from the Meuse, drawn from a water intake channel forming an artificial stretch of the river, as a heat sink for the cooling systems. Besides the possibility of pumping from the intake channel, the units in Tihange 2 and 3 also have a deep water intake in the river bed, allowing the cooling system of these units to be fed in case of significant drop in the level of the Meuse.

In case of loss of water from the river Meuse all the units also have wells fed by the groundwater. The site also has several water reservoirs.

It should also be noted that, since 2011, access to an independent groundwater source deeper than the groundwater table constitutes an additional resource.

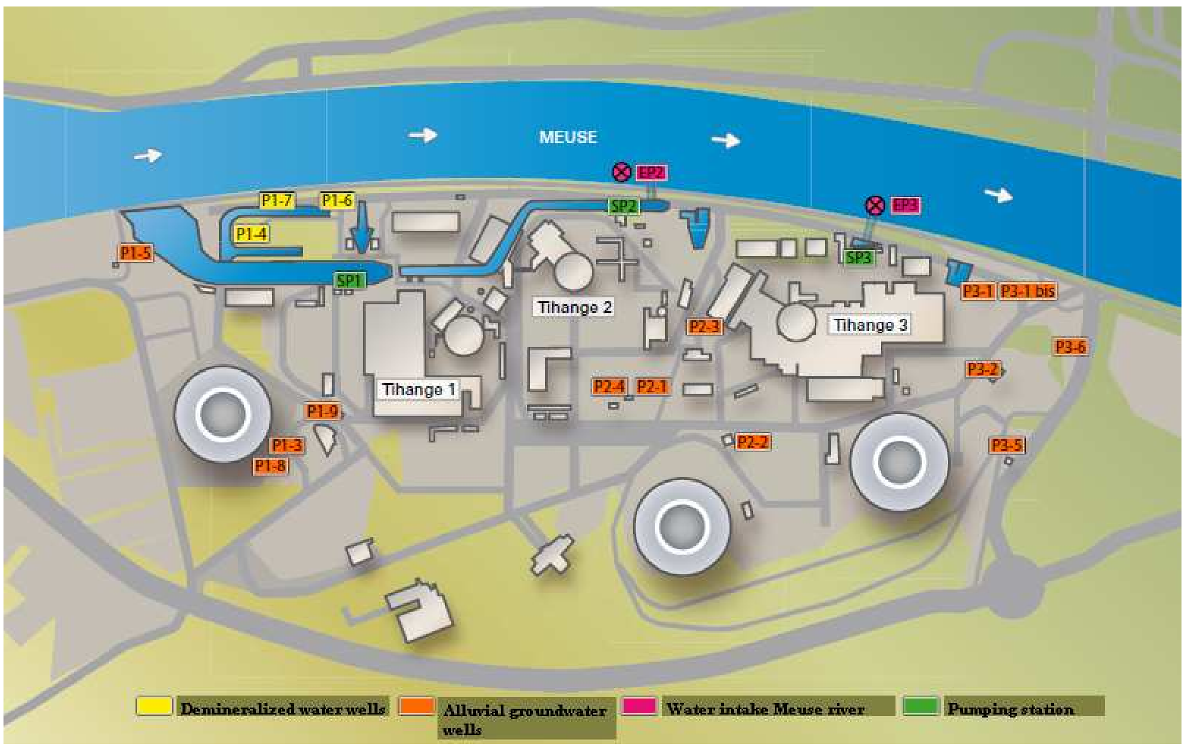

Figure 15 - Plan of heat sinks in Tihange.

Doel NPP

Under normal operation the units use the Scheldt for cooling. Water from the Scheldt is continuously pumped through the CW-system. At Doel 1/2 a part of the CW-flow is used to cool the CC-system. At Doel 3&4 a part of the CW-flow is used to refill the cooling towers of the RN-system. In the case of the loss of all connections with the Scheldt the units must be cooled by alternative cooling systems.
For Doel 1/2 and Doel 3&4 the loss of the primary ultimate heat sink is the loss of the supply of cooling water (CW, Cooling Water) from the Scheldt.

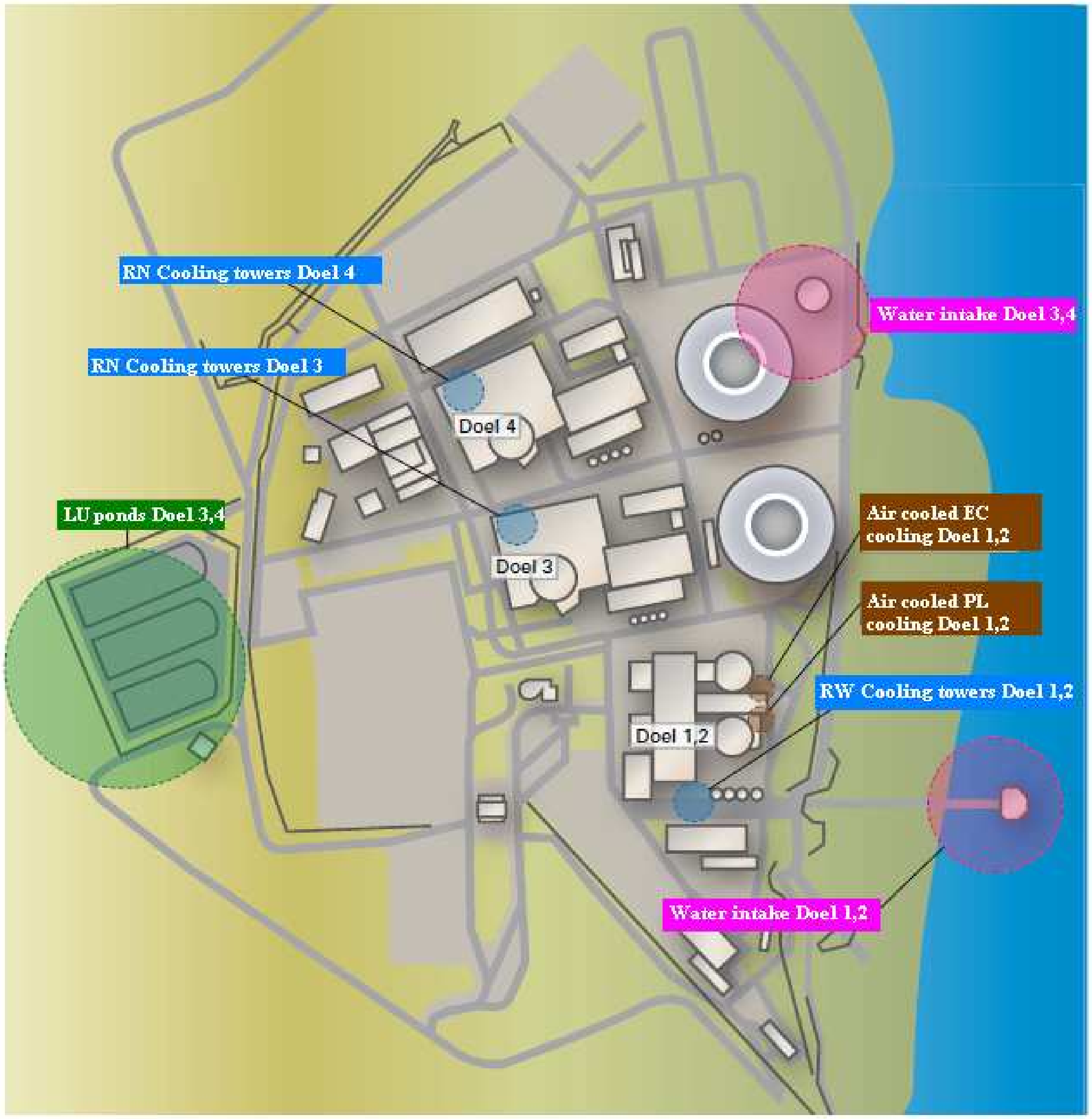

Figure 16 - Plan of heat sinks in Doel.

5.2.1.1. Design provisions

Tihange NPP

The three units of the site in Tihange use the Meuse as their primary ultimate heat sink. The level of the river is maintained at a constant value by the dam at Ampsin-Neuville, situated 2 km downstream of the water intake point of the power station.
The water intake for the pumps of the raw water system (CEB) is situated in a water intake channel which is an artificial branch of the river.
All systems mentioned in this scenario are classified as resisting to a DBE earthquake.

Tihange 1

The scenario considered below takes account of an accident occurring in Tihange 1 only.

a) Design measures of Tihange 1

The raw water system (CEB) of the unit includes two complete pumping trains - plus a third reserve pump - and may be powered electrically by the safety diesel generators (GDS). One CEB train is sufficient to bring and maintain the unit in the cold shutdown state.
If the level of water in the Meuse falls too low for the CEB pumps, the groundwater system (which is part of the CEB) will be aligned manually. In the event of break of a large lock gate in the dam at Ampsin-Neuville, situated downstream of the site, the personnel on site should have 30 minutes, according to the safety analysis report, to realign the systems in such a way. This time limit may be increased up to 1 to 2 hours depending on the considered flow rate of the Meuse.

The groundwater system can of course be connected manually in case of total loss of suction of the CEB in the intake channel for any other reason, such as plugging of the water intake filters. However, the filters situated upstream of the CEB pumps are equipped with a bypass check valve that opens under hydraulic pressure in case of high load loss (50 mbar) on the filter.
Measures are also taken to monitor the filters and the screen rakes: regular inspections of the water intake stations to check the fouling of the filters, switch to recirculation of the unit in case of exceptional high water to avoid mass inrush of leaves, etc.

The groundwater system, which is a safety water supply, may be powered electrically by the safety diesel generators (GDS). This system has two wells, each equipped with two pumps. Only one pump runs at a time. The second pump is activated only in case of failure of the first. These different wells are placed geographically distant from each other and from the water intake station.

Moreover, a hose link between the groundwater system in Tihange 1 and one of the CEU Meuse pumps in Tihange 2 could also be established.

The groundwater system has an autonomy of at least 30 days if only one unit is affected. In the scenario of a break in the dam at Ampsin-Neuville, only Tihange 1 would draw from the groundwater while Tihange 2 and 3 would continue to draw water via the deep water intakes in the Meuse river bed.

b) Autonomy of Tihange 1 before fuel damage

In case of loss of normal suction of the CEB pumps in the water intake channel, the alternate ultimate heat sink, that is, the groundwater system, must be realigned manually. In the hypothetical case - not being part of the design base - of an instant loss of the CEB pumps, there will no longer be any available heat sink until the realignment of the groundwater system is completed. In case of gradual loss of suction of the CEB pumps, for example, in case of break of a lock gate in the dam at Ampsin-Neuville, the shift crew have enough time to connect the groundwater system before loss of the CEB pumps.

For the reasons just explained, the loss of heat sink is separated into two scenarios:
1. Instant loss of suction by the CEB pumps from the water intake channel.
2. Gradual loss of suction by the CEB pumps from the water intake channel (included in design basis).

SCENARIO 1: Instant loss of suction by the CEB pumps from the water intake channel

Steam generators available

The steam generators are supplied with water by the EAS pumps that draw from the EAS tank (120 m³). Without make-up the autonomy of the EAS tank would be limited to 60 minutes. However, make-up is triggered automatically by a floating valve once the water reaches a preset level (from the demineralised water tanks). This automatic make-up increases the autonomy to at least 4 hours.

Primary system open

Cooling by the RRA exchangers is not possible before realignment of the groundwater system. If the primary system has a reduced water inventory (situation of outage with reduced inventory, etc.) at the time of the accident, make-up to the primary system is possible from tank B01Bi via one of the low-pressure injection lines. Use of this make-up allows sufficient time to line up the groundwater system. This leads to scenario 2.

Core in spent fuel pools

The pool is not cooled before realignment of the groundwater system, but its temperature evolves slowly and does not pose a problem during this time.
After line-up of the groundwater system the scenario becomes scenario 2.

SCENARIO 2: Gradual loss of suction by the CEB pumps from the water intake channel

In case of gradual loss of normal suction of Meuse river water from the intake channel, the groundwater wells are realigned manually to the essential users before total loss of the CEB pumps.
A hose link between the groundwater system in Tihange 1 and one of the CEB Meuse pumps in Tihange 2 could also be provided.
The capacity of the CEU wells gives them autonomy of at least 30 days if only one unit is affected.

Steam generators available

Groundwater make-up for the steam generators is provided from the EAS tank and pumps. The groundwater system could eventually add water into the tank and allow maintaining the reactor in a stable and controlled state. The groundwater will also be used for the cooling of the reactor by the RRA exchangers.

Primary system open

Cooling by the RRA exchangers is possible using the groundwater system. The groundwater system is able to maintain the reactor in stable and controlled shutdown.

Core in spent fuel pools

The CTP pools can be cooled by the groundwater system.

c) General conclusions for Tihange 1

There is no cliff-edge effect in case of instant or gradual loss of the primary ultimate heat sink. In fact, in Tihange 1, this accident is managed by use of the groundwater system after manual realignment. Autonomy of the groundwater is at least 30 days if only one unit is affected. This largely covers the time for deployment of additional means from the site or from outside the site.

Tihange 2 and 3

The scenario considered below considers an accident occurring in one of the two units (Tihange 2 or 3). The principle is the same for both units.

a) Design measures of Tihange 2 and 3

The raw water system (CEB) of each unit includes three complete pumping trains and may be powered electrically by the safety diesel generators (GDS). Two CEB trains are sufficient to place and maintain the unit in the cold shutdown state.
There are two deep water intakes in the Meuse river bed, each having a sufficient capacity to cover all requirements and able to feed the CEB pumps. These deep water intakes are normally closed. If the level of the Meuse falls below that of the bed of the water intake channel one of these connections with the river bed is opened manually.
In the event of break of a large lock gate in the dam at Ampsin-Neuville, situated downstream of the site, the personnel on site should have 2 hours 20 minutes, according to the safety analysis report, to realign the systems in such a way. This time limit may be increased up to more than 6 hours depending on the considered flow rate of the Meuse.
The deep water intakes in the Meuse could also be used in the event that the normal suction of the CEB pumps from the intake channel becomes impossible for other reasons, for example, plugging of the screen rakes. However, the filters situated upstream of the CEB pumps are equipped with a bypass check valve that opens (under hydraulic pressure) in case of high load loss (50 mbar) on the filter.
Measures are also taken to monitor the filters and screen rakes: regular inspections of the water intake station to check the fouling of the filters, switch to recirculation of the unit in case of exceptional high water to avoid massive inrush of leaves, verification of correct functioning of the screen rakes, etc.

In case of total loss of the raw water system (CEB), the emergency water system (CEU) can supply the water necessary to bringing and maintaining the unit in a state of stable and controlled shutdown. The CEU consists of three trains and is powered by the second level emergency diesel generators (GDU). Each CEU train has a pump that draws from the intake channel (Meuse water) and a well (groundwater) pump. Normally, the two pumps do not function simultaneously since, depending on the situation, one of the two could be lost following an accident of external origin. These different wells are placed geographically distant from each other and from the water intake station.

In case of loss of the CEB function from the intake channel but the Meuse remains available, the CEU Meuse pumps could still be used by opening the deep water intakes from the river bed (see above), allowing water supply to the pumps.

The spent fuel pools of the DE building are cooled indirectly by the CEB in Tihange 3. In case of total loss of the CEB function of Tihange 3, a supply of groundwater is available from a CEB well pump in Tihange 2 or 3.

b) Autonomy of the Tihange 2 and 3 units before fuel damage
If normal water intake from the channel is lost, the CEB pumps in Tihange 2 and 3 can draw water directly from the deep water intakes in the river bed of the Meuse. This requires manual opening of the connection, which can be achieved within a period of time compatible with the time of loss of normal water intake. Even in case of break in the dam at Ampsin-Neuville, the level of the Meuse would remain sufficiently high to be able to be draw water via that route.

For the reasons that have just been explained, the loss of heat sink is separated into two scenarios:
1. Loss of normal intake of Meuse river water from the intake channel (included in design basis);
2. Total loss of intake of Meuse river water (included in design basis).

SCENARIO 1: Loss of normal intake of Meuse river water from the intake channel (included in design basis)
As already mentioned, it is possible to establish a manual connection between the suction of the CEB pumps and the deep river water intake on the bed of the Meuse, which keeps the CEB system available. Autonomy is then unlimited.

Steam generators available
Initially the core is cooled by the steam generators supplied with water by the EAA system. In case the EAA tank runs empty it is possible to supply the steam generators using reserves of demineralised water and then, if necessary, raw water. This can be achieved by the normal CEB via the EAA pumps or by the AUG second level system. However, the autonomy of the EAA allows reaching conditions which allows use of the RRA shutdown cooling system. This

system is itself cooled by the intermediate cooling system (CRI) which is in turn cooled by the CEB.

Primary system open
The CRI (cooled by the CEB) cools down the core via the RRA exchangers and the CTP pools via the CTP exchangers.

Core in spent fuel pools
The CRI (cooled by the CEB) cools down the CTP pools via the CTP exchangers.

DE spent fuel pools
The spent fuel pools in the DE building are cooled indirectly by the CEB of Tihange 3. Since the deep river water intake and the external electric power sources are still available, autonomy is unlimited.

In this scenario the heat sink is still the Meuse. There is no cliff-edge effect.

SCENARIO 2: Total loss of intake of Meuse river water (included in design basis)
The situation of total loss of water intake from the Meuse is included in the design basis of the second-level protection systems of Tihange 2 and Tihange 3.
The heat sink in this case is the groundwater. The capacity of the wells of the CEU drawing from the groundwater gives autonomy of at least 30 days if only one unit is affected. This autonomy is largely sufficient before the arrival of equipment or water from another unit or from outside the site.

Steam generators available
The second-level systems (supplied with water from the CEU wells) described previously can place and maintain the reactor in stable and controlled shutdown.

Primary system open
The second-level systems (supplied with water from the CEU wells) can maintain the reactor in stable and controlled shutdown.

Core in spent fuel pools
The CTP pools can be cooled by the second-level protection systems (CTP exchangers supplied with well water via the CRU).

DE spent fuel pools
The spent fuel pools in the DE building are cooled via the STP exchangers by the SEU system supplied with water from the CEU wells.

c) General conclusions for Tihange 2 and 3
There is no cliff-edge effect in case of instant or gradual loss of the heat sink. In fact, this accident is managed, in Tihange 2 and 3, by use of the CEB system (deep water intakes from the river bed of the Meuse) or the CEU system (groundwater). The groundwater autonomy is at least 30 days if only one unit is affected. This largely covers the time for deployment of additional means from the site or from outside the site.

Several units of the Tihange site affected
The management of a loss of heat sink in the three units depends essentially on the possibility of use or not of the deep river water intake in the Meuse for the units Tihange 2 and 3.
If the deep river water intake in the Meuse is still available, Tihange 1 uses groundwater and Tihange 2 and 3 use Meuse river water. Autonomy is then at least 30 days for Tihange 1 and unlimited for Tihange 2 and 3. If the deep river water intakes are all lost, the three units resupply from the groundwater table. Autonomy is then three weeks.

The design bases of the units consider the use of groundwater by only one unit. The autonomy of use of groundwater was determined considering such hypothesis. In case of an event affecting more than

one unit, the realistic case of two units with steam generators available and one unit cooled by the RRA is considered.
New procedures will be issued in order to take into account loss of the primary ultimate heat sink affecting more than one unit.
In that case the control of the temperature of the primary system must be achieved by the steam generators for those reactor units where the steam generators are available, in order to limit groundwater consumption by avoiding passage of these units to RRA.

If Tihange 3 is one of the units affected by a total loss of river water intake from the Meuse, the pool in the DE building is no longer cooled by the conventional systems. To limit groundwater consumption, the cooling will then achieved by water make-up provided by various non-conventional means present on site. They can be deployed within few hours, this is long before damage of the fuel assemblies start, which is more than 20 days.

Doel NPP

The probability of the entire site being affected by the loss of the primary ultimate heat sink is very unlikely for Doel. The water intake areas of Doel 1/2 and Doel 3&4 are significantly separated from each other and their operating principle is different. The pumping station of Doel 1/2 is situated in the Scheldt. The pumping station of Doel 3&4 is situated on the site itself but is connected via underground pipes to a suction well in the Scheldt.

In the case where Doel 3&4 is affected and Doel 1/2 is not affected by the loss of the primary ultimate heat sink, the cooling water can be pumped from Doel 1/2 to Doel 3&4. This alignment requires local manual actions and takes a few hours.

Doel 1/2

The units are designed to keep the safety equipment and the reactor cooled in the case of the loss of the primary ultimate heat sink. We first describe below the available back-up systems of the first and second level and then the scenarios in the three operating conditions.

a) Design measures of Doel 1/2 : Back-up from the first level systems

In the case of the loss of the primary ultimate heat sink, the cooling of the CC-system is assured by the RW-system (Raw Water system). The RW system is a safety system comprising four trains and can be powered by the first level safety diesel generators. The RW system comprises 4 closed loops cooled by cooling towers with forced draft. To compensate for the loss of water in the cooling towers, the cooling tower tanks can be refilled in a diversified way:

- Gravitational refilling from the city water reservoir.
- Gravitational refilling from the common demineralised water tank.
- Refilling with Scheldt water.
- In addition to the previous refilling options, there is also the possibility to refill the RW-cooling towers directly via the FE-system.

Refilling is assured automatically during approximately 12 hours by a gravitational refilling from the TW- and RW- tanks. Manual actions are needed for the other refilling options.

b) Design measures of Doel 1/2 : Back-up from the second level systems

If the CC/RW-system becomes unavailable in addition to the primary ultimate heat sink (CW system), then the cooling of the SC-system (Shutdown Cooling) and of the PL-pools for the storage of spent nuclear fuel is assured by the second level systems.

- As a replacement of the CC-system on the SC, there is the second level cooling system EC (Emergency Cooling). The EC-system is common to both units. It comprises 2 pumps and 2 air coolers that are placed in parallel on a single loop and that can cool the four heat exchangers of the SC and the six SC pumps. The equipment of the system is located in the GNS Emergency Systems Building (pumps and expansion tank), and on the roof of the GNS (air coolers). The SC-pumps and coolers are located in the Nuclear Auxiliary Services Building and get their electrical supply from both the first and second levels.
- As replacement of the PL-coolers the cooling of the pools of the Nuclear Auxiliary Services Building may be switched to an air cooler (belonging to the PL-system) on the roof of the GNS Emergency Systems Building. Two of the three PL-pumps can be powered by the second level

diesel generators to assure this function. The third PL-pump is powered by the first level diesel generators.

As long as the first level systems are operational, the second level systems are not needed. The diesel generators of both levels are cooled by air coolers and therefore remain available without the primary ultimate heat sink, without CC/RW and without EC.

c) Autonomy of Doel 1/2 before fuel damage

Steam generators available

The first level RW-cooling towers ensure that all safety related first level systems remain cooled via the CC-system.
The cooling of the core is assured by cooling via the steam generators and the subsequent transition to SC-cooling. The cooling via the steam generators is guaranteed at the first level by the AFW-system (Auxiliary Feedwater). At the second level the EF-system (Emergency Feedwater) in the GNS Emergency Systems Building may be used.
There are no cliff edge effects for this scenario. There is more than sufficient water supply available at Doel 1/2 for refilling the RW-cooling towers. Furthermore refilling is possible via the FE-system from the ponds (3 x 30000 m^3) at Doel 3&4.
If the water supply is exhausted then the second level systems of Doel 1/2 will be used and the EC-system in the Emergency Systems Building will take over the function of the CC-system.

Primary system open

The first level RW-cooling towers ensure that all safety related first level systems remain cooled.
The core is cooled via the SC-system and the CC-system which is cooled in turn by the alternate ultimate heat sink (RW).
There are no cliff edge effects for this scenario. There is more than sufficient water supply available at Doel 1/2 for refilling the RW-cooling towers. Furthermore refilling is possible via the FE-system from the ponds (3 x 30000 m^3) at Doel 3&4.
If the water supply of the ponds is exhausted then the EC-system in the Emergency Systems Building will take over the function of the CC-system.

Core in spent fuel pools

The first level RW-cooling towers ensure that the spent fuel storage pools remain cooled.
The core is cooled via the PL-system and the CC-system which is cooled in turn by the alternate ultimate heat sink (RW).
There are no cliff edge effects for this scenario. There is more than sufficient water supply available at Doel 1/2 for refilling the RW-cooling towers. Furthermore refilling is possible via the FE-system from the ponds (3 x 30000 m^3) at Doel 3&4.
If the water supply of the ponds is exhausted then the PL-coolers in the Emergency Systems Building will take over the function of the CC-system.

Doel 3&4

Each unit is designed to keep the safety equipment and the reactor cooled in the case of the loss of the primary ultimate heat sink. The CC-system is always cooled via the RN-system (RN-cooling towers), which recieves make-up water from the CW-system. If the CW-system is lost, the RN system automatically switches to the CD-system to compensate the loss of water inventory. The CD system takes its water from the LU-ponds of Doel 3&4 (3 x 30000 m^3).

a) Design measures of Doel 3&4: Back-up from first level systems

The RN-system is a closed system that cools the CC-system and that releases the heat to the atmosphere via cooling towers. The RN-system comprises three cooling loops for cooling the heat exchangers of the intermediate cooling system CC. Each RN-loop has a set of 2 cooling towers with forced draft. To compensate for the loss of water of the cooling towers, water has to be added to the RN-system. There are different alternatives for this water supply:

- The additional water of these towers is usually supplied by the water intake area of Doel 3&4 via CW pumps from Doel 3&4.
- From the LU-ponds refilling of the RN is provided via the CD-system.

- In addition to the previous refilling options there is also the possibility to fill the RN cooling towers by the FE-system.

b) Design measures of Doel 3&4:Back-up from second level systems

If the CC/RN system also becomes unavailable in addition to the primary ultimate heat sink, the emergency cooling system (LU-system) can provide the cooling needed to bring the units to a cold shutdown state and to maintain it in this state. The LU-system comprises three independent trains that are automatically powered by the second level diesel generators (KE) if the external power sources are lost.

In each unit the cooling water is pumped up from the corresponding LU-pond, directly sent to the coolers (PL, SC, …) and sent back to the LU-pond.

Three independent artificial LU-ponds are provided. The ponds are far enough away from the reactor units so that the units´ power station and the cooling ponds cannot be affected simultaneously by an external accident. Both Doel 3 and Doel 4 have their own LU-pond with a water reserve of 30,000 m³. The third cooling pond serves as an industrial water reserve (IW) and, if necessary, as a common reserve for the cooling ponds of Doel 3&4.

Taking account of a capacity reserved for the FE-system (fire fighting) and different possible losses, for a few weeks there remains sufficient water in the LU-ponds to guarantee the proper functioning of the LU-pumps. The temperature of the pond remains also limited to 50°C due to thermal inertia and spray system.

As long as the first level systems are operational, the second level systems are not necessary. The first level diesels are cooled by air coolers and remain thus available without primary ultimate heat sink, without CC/RN and without LU. The second level diesels are cooled by the LU-system and remain thus available without primary ultimate heat sink and without CC/RN.

c) Autonomy of Doel 3&4 before fuel damage

Steam generators available

The first level RN-cooling towers ensure that all safety related first level systems remain cooled.

The cooling of the core is assured by cooling via the steam generators and the subsequent transition to SC-cooling. The cooling via the steam generators is guaranteed at the first level by the AF-system (Auxiliary Feedwater). At the second level the EF-system (Emergency Feedwater) in the GNS Emergency Systems Building may be used.

There are no cliff edge effects for this scenario. The LU-ponds contain sufficient water for an autonomy of at least 26 days. That is more than enough to be able to refill the LU-ponds.

Primary system open

The first level RN-cooling towers ensure that all safety related first level systems remain cooled.

The core is cooled via the SC-system and the CC-system which is cooled in turn by the RN-cooling towers.

There are no cliff edge effects for this scenario. The LU-ponds contain sufficient water for an autonomy of at least 26 days. That is more than enough to be able to refill the LU-ponds.

Core in spent fuel pools

The first level RN-cooling towers ensure that the spent fuel storage pools remain cooled.

The pools remain cooled via the PL-system and the CC-system which is cooled in turn by the RN-cooling towers.

There are no cliff edge effects for this scenario. The LU-ponds contain sufficient water for an autonomy of at least 26 days. That is more than enough to be able to refill the LU-ponds.

Several units of the Doel site affected

If the entire site is affected and the water reserves of Doel 1/2 become exhausted, then Doel 3&4 has to share the ponds with Doel 1/2. The water reserve in the ponds is sufficient to provide Doel 1/2 with water as well. Furthermore one disposes of several weeks to refill the ponds. But before this happens the second level systems at Doel 1/2 can be taken into service. These rely entirely on air coolers that do not require any refilling.

5.2.1.2. (External) actions foreseen to prevent fuel damage

Tihange NPP

As described in the previous paragraph the loss of the Meuse water river is managed in various ways according to the units.

The shift crew teams are trained to respond to this type of accident. The Internal Emergency Plan (PIU) is started and no equipment from outside the site is necessary over the medium term. It should however be noted that, in case of break of a lock gate in the downstream dam at Ampsin-Neuville, the period needed for an obstruction of the breach by reserve cofferdams (two cofferdams) permanently available on site is estimated by the "Service des Voies Hydrauliques" at a maximum of two days. If the structure of the dam is intact, this allows quite rapid restoration of the correct level of the Meuse.

Doel NPP

This incident is a part of the design basis of the units and is countered perfectly by the available installations, the standard operating procedures and the shift crew.

5.2.1.3. Measures that may be considered to increase the robustness of the plant

Tihange NPP

The loss of water from the Meuse river is considered in the design basis of each of the three units - in the three possible configuration: steam generators available, primary system open and core in spent fuel pools - if only one unit draws from the groundwater. This type of accident does not require additional measures.

However, if all three units have to draw from the groundwater, it is necessary to optimize water consumption. Methods to limit water drawing from the groundwater and determining which well(s) to use preferentially must be included in procedures and/or in the strategy for management of a "multi-unit" accident.

Doel NPP

This incident is a part of the design basis of the units and can be countered perfectly with the available systems, the standard operating procedures and the shift crew. No modifications to the hardware, no new procedures and no organisational measures are required.

5.2.2. Loss of the primary ultimate heat sink and alternate ultimate heat sink(s)

Tihange NPP

The simultaneous loss of primary and alternate ultimate heat sink is not part of the design bases of Tihange units. However, the analysis given below shows that the site has emergency means and sufficient autonomy for the management of this type of accident compatible with the time for deployment of non-conventional means from outside the site in addition of those available on site.

Doel NPP

In Doel there are two alternate ultimate heat sinks in each unit. It is shown that the units are designed to withstand the loss of one of the two systems. The loss of both systems simultaneously is highly unlikely and is therefore not a part of the design basis. In a few specific cases this means that one will have rely on non-conventional means.

5.2.2.1. Autonomy of the site before fuel damage

Tihange NPP

By design the site has diversified its heat sinks in order to reduce the risk of their simultaneous loss. As a result, the total loss of the primary ultimate heat sink (the river Meuse) and the alternate ultimate heat sink (the groundwater table) is not included in the design basis of the units.
This scenario considers the successive or simultaneous loss of:

- water from the intake channel flowing from the Meuse;
- deep water intakes on the river bed of the Meuse, installed for Tihange 2 and 3, to compensate a possible fall in the water level of the river;
- water from the groundwater wells (each of the three units has several wells situated in different places on the site).

The analyses below consider the worst-case - and highly unlikely - scenario of immediate and simultaneous loss of all these heat sinks with the external electric power still available. In case of gradual and successive loss of these sources (more realistic situation), the autonomies would be greater than those indicated in the paragraphs below. The cases described below are therefore extremely conservative.
These analyses suppose that each unit uses its own reserves of water and equipment. In case of an accident affecting less than three units, transfers of water are always possible, after connection of one unit to the other units in order to increase the autonomy of the affected unit(s).

The total loss of the heat sinks will prevent the continuous functioning of the various first-level and second-level safety systems (in particular the diesel generators) in the absence of cooling - apart from those not requiring water cooling (such as GDR for example, which is air-cooled), or those that are self-cooled.
The construction of a new demineralized water production circuit for the whole site is in progress. For this operation investigations have revealed the existence of a deep groundwater table at the Tihange site. Three wells have been dug into this water table; they are equipped with pumps. It is already possible to use this source of water by means of hoses. The autonomies estimated below do not take account of this new source of water.

Tihange 1

Steam generators available

The steam generators are supplied with water by the self-cooled EAS pumps drawing from the EAS tank (120 m³). Without make-up, the autonomy of the EAS tank would be limited to 60 minutes. However, a make-up is triggered automatically, thanks to a floating valve, as the water reaches a preset level.

The available volumes of water (1120 m³) and the inertia of the water present in the steam generators allow a cooling via the steam generators for at least 1.5 days. An additional reserve of water available in the two condensers could also be used (approximately 320m³). In case of emergency, this water could be sent to the steam generators.

In the event that cooling by the steam generators is lost and no alternative supply to the steam generators is found, it is possible to place the primary system in a "feed and bleed" configuration by direct injection of borated water and by discharging through the SEBIM valves of the pressuriser.

Given the loss of all heat sinks the cliff-edge effect occurs upon loss of water for the steam generator cooling (after approximately 1.5 days). This period allows sufficient time to deploy alternative make-up means available on site.
In fact it is possible to add make-up water via the fire water system using non-conventional means, in this case a mobile motor pump unit drawing water directly from the Meuse. Using such means, this cliff-edge effect can therefore be avoided.

Primary system open

The "feed and bleed" principle is used for the primary system. The steam is released through a VBP vent to the chimney and its filtration systems.
The required reaction time depends on the water inventory in the primary system including the reactor pool. Without additional water make-up or reactivation of the cooling, the water from B01Bi injected into the primary system is evaporated in slightly more than 5 days. A steam release route is foreseen in order to avoid the reactor building overpressure. In case the steam in the reactor building is not released, and without use of containment spray, the overpressure risks to damage the containment structure after 3 to 4 days.
The unit also has a reserve of water in its CIS accumulators that could be used depending on their content of water at the time of loss of the heat sinks. Finally, the reserves of water in the CAB tanks could also be used.

The cliff-edge effect occurs when all the borated water tanks are empty. The B01Bi tank gives autonomy well beyond 72 hours. This autonomy covers the time until arrival of equipment or water from another unit or from outside the site. Besides the available reserves in other borated water tanks, an external link is foreseen for a tanker truck containing boron to ensure make-up of B01Bi. Using these means, this cliff-edge effect can therefore be avoided.

Core in spent fuel pools

The spent fuel pool is no longer cooled by the normal systems. Evaporation starts approximately 10 hours after the loss of the normal cooling systems.

Non-conventional means may be deployed to ensure a water make-up in a few hours, that is, well before the assemblies begin to uncover which, in theory, occurs at least 4 days after loss of normal cooling (fuel transfer tube closed).

The cooling of the fuel is maintained by evaporation and water make-up, which can be deployed in a few hours. Over time, access will be rendered difficult by the presence of steam in the reactor building. Thus, any eventual operations in the building must be executed as soon as possible. Procedures will be issued for the management of the pools in this type of scenario. The introduction of additional level measurements in the spent fuel pools is also considered.

The situation to avoid is the uncovering of the fuel assemblies (cliff-edge effect).The time for installing water make-up is compatible with the time periods mentioned before. There is therefore no cliff-edge effect.

Tihange 2 and 3

Steam generators available

The steam generators can be supplied by the self-cooled EAA pumps that draw from the EAA tank (total capacity 690 m³ for Tihange 2 and 800 m³ in Tihange 3).

When this tank is empty the contents of the following tanks can be routed to the steam generators:

- EDN B06: capacity 800 m³in Tihange 2 and EDN B05: capacity 800 m³in Tihange 3;
- EDN B07: capacity 300 m³ in Tihange 2 and EDN B07: capacity 500 m³in Tihange 3;
- Condenser: average content 170 m³ in Tihange 2 and 350 m³ in Tihange 3;
- PED B01: average content 110 m³ in Tihange 2 and PED B03: average content 110 m³ in Tihange 3.

The available volumes of water (2166 m³ for Tihange 2 and 2523 m³ in Tihange 3) and the inertia of the water present in the steam generators allow a cooling via the steam generators for at least 3.5 days in Tihange 2 and 5 days in Tihange 3.
In the event that cooling by the steam generators is lost and no alternative supply to the steam generators is found, it is possible to place the primary system in a "feed and bleed " configuration by direct injection of borated water and by discharging through the pressurizer relieve valves.

Given the loss of all heat sinks the cliff-edge effect occurs upon loss of water for the steam generator cooling (after approximately 3.5 days in Tihange 2 and 5 days in Tihange 3). This period allows sufficient time to deploy alternative make-up means available on site. This cliff-edge effect can therefore be avoided.

Primary system open

The content of the CTP tanks can be injected in the primary system in case of reduced water inventory. Without additional water make-up or reactivation of the cooling, the water from CTP injected into the primary system is evaporated in slightly more than 6 days either in Tihange 2 or in Tihange 3. A steam release route is foreseen in order to avoid the reactor building overpressure. In case the steam in the reactor building is not released, and without use of containment spray, the overpressure risks to damage the containment structure after 3 to 4 days either in Tihange 2 or in Tihange 3.

The unit also has a reserve of water in its CIS accumulators that could be used depending on their content of water at the time of loss of the heat sinks. Finally, the reserves of water in the CAB and CUS tanks (around 450 m^3) could also be used.

The cliff-edge effect occurs when all the borated water tanks are empty. Just the CTP tanks give autonomy well beyond 72 hours either in Tihange 2 or in Tihange 3. This autonomy covers the time until arrival of equipment or water from another unit or from outside the site. This cliff-edge effect can therefore be avoided.

Core in spent fuel pools

The spent fuel pool is no longer cooled by the normal systems. Evaporation starts approximately 8 hours after the loss of the normal cooling systems.

Non-conventional means may be deployed to ensure a water make-up in a few hours, that is, well before the assemblies begin to uncover which, in theory, occurs at least 2 days in Tihange 2 (3 days in Tihange 3) after loss of normal cooling (fuel transfer tube closed).

The cooling of the fuel is maintained by evaporation and water make-up, which can be deployed in a few hours. Over time, access will be rendered difficult by the presence of steam in the reactor building. Thus, any eventual operations in the building must be executed as soon as possible. Procedures will be issued for the management of the pools in this type of scenario. The introduction of additional level measurements in the spent fuel pools is also considered.

The situation to avoid is the uncovering of the fuel assemblies (cliff-edge effect).The time for affecting water make-ups is compatible with the time periods mentioned before. There is therefore no cliff-edge effect.

DE spent fuel pools

In this scenario the used fuel pools in the DE building are not cooled by the normal systems. Evaporation begins about 4 days after loss of cooling of the pools. Non-conventional means, deployed in a matter of hours, are foreseen to achieve make-up of water before the uncovering of the fuel assemblies (at least 3 weeks). Provision is also made for the evacuation of steam.

There is therefore no cliff-edge effect.

Several Tihange units affected

The above analysis was conducted for each of the Tihange units independently. If several units are affected at the same time, there will not be any additional constraints since, in the short term, each unit uses its own means and its own reserves.

Doel NPP

At Doel 1/2 and Doel 3&4 two alternate ultimate heat sinks are available. Therefore the scenario is split into two steps.

<u>Doel 1/2: Step 1: loss of CW (primary ultimate heat sink) + RW (first alternate ultimate heat sink)</u>

The Doel 1/2 power station is designed to independently withstand a total loss of the first alternate ultimate heat sink (RW cooling towers) because of the availability of the second level systems in the Emergency Systems Building.

In the event of the loss of the RW-cooling tower (first level cooling towers) the CC-system will become unavailable. As a result multiple first level safety systems will lose their cooling.

Total loss of the refilling to the RW cooling towers is highly improbable as multiple redundant refilling options are available.

Steam generators available

The AFW-pumps and the second level systems (GNS Emergency Systems Building) ensure that the unit is cooled and maintained in cold shutdown.
In this scenario the (self-cooling) AFW-pumps (2 motor pumps & 1 turbo pump) remain available to feed the steam generators from the AFW-tank and MW-tanks. The steam generators can also be fed by the EF-pumps.
There are no cliff edge effects for this scenario.

Primary system open

The second level systems (GNS Emergency Systems Building) ensure that the unit is maintained in cold shutdown.
With an open primary system the core is cooled with the SC-system, which in turn is cooled by the CC-system. In the event of the loss of the CC-system, the EC-system is aligned to take over this function.
Aligning the EC-system to the SC-system takes 45 minutes at most. However, if no water is added, the water in the reactor will start to boil within the hour. This period depends on the time interval between the shutdown and the initiating event, the level of water in the reactor and the possibility of increasing the water level. As long as the EC-system is not aligned to the SC-system the water level is maintained by injection of borated water via two RJ-pumps.
Within an hour the water in the reactor will start to boil. That water will continue to boil until the cooling via the EC system is recovered. There are sufficient resources to compensate for the evaporated water. The EC-system can continue to run without restriction.

Core in spent fuel pools

The second level systems (GNS Emergency Systems Building) ensure that the PL-pools remain cooled.
The nuclear fuel is cooled via the PL-system. In this scenario the PL-system of the first level is realigned to the PL-air coolers of the Emergency Systems Building. The nuclear fuel will remain cooled in the meantime by the water in the PL-pools. That water will only start to boil after 15 hours. Once the PL-system has been aligned to the Emergency Systems Building it can be operated without limit in this way.
The PL system is aligned manually within 1.5 hours. This is much shorter than the 15 hours available. Furthermore the PL system is a closed system where no water has to be added.

<u>Doel 1/2 Step 2: loss of CW (primary ultimate heat sink) + RW (first alternate ultimate heat sink) + air coolers Emergency Systems Building (second alternate ultimate heat sink)</u>

The Doel 1/2 unit is not designed to independently withstand the total loss of both alternate ultimate heat sinks. Simultaneous total loss of the first and second alternate ultimate heat sink (CW+RW and the air coolers Emergency Systems Buildings) is highly improbable.
Cooling of the nuclear fuel and maintaining the sub-criticality can still be guaranteed however.

Steam generators available

The reactors are cooled by the first and second level systems via the steam generators. In this scenario the (self-cooled) AFW-pumps (2 motor pumps & 1 turbo pump) are available to feed the steam generators.
Because the SC-system cannot be taken into service, this condition must be maintained for an unlimited period. Therefore water must be continuously supplied to the steam generators.
The water reserves of Doel 1/2 give an autonomy of more than ten days per unit. With the volume in the LU-ponds of Doel 3&4 the steam generators of Doel 1 and Doel 2 can in principle be supplied for a few months.
There are no cliff edge effects for this scenario.

Primary system open

In this scenario the water in the reactors starts to boil and the evaporated water is compensated by fresh water. Water in the reactor will start to boil within an hour. The water level in the reactor is kept at a sufficient level by adding borated water via the 2 RJ-pumps. As a back-up the RWST may also be drained gravitationally to feed the reactor via the SC-system.
After a loss of all heat sinks the reactor building is hermetically sealed to avoid that the steam formed would be released into the environment. As a result the pressure in the reactor building will rise. The pressure rise can be delayed by spraying cold water in the reactor building via the SP-system.
The failure pressure of the reactor building will be reached after 3 days at the earliest. By that time the first level (CC) or the second level (EC) heat sink should have been restored. If that does not succeed then the reactor building must be vented in a controlled way.
As a result of the presence of steam, access to the reactor building will become difficult in due course.

Core in spent fuel pools

In this scenario the water in the spent fuel pool starts to boil and the evaporated water is compensated by fresh water. Boiling the water in the pools is an efficient way to remove the heat from the nuclear fuel elements.
Within 15 hours at the earliest the water in the spent fuel pool will start boiling. As a result of the presence of steam, access to the pools becomes more difficult in due course. For that reason it is necessary to make the water supply available before boiling starts. The time available is more than enough to refill the spent fuel pools.
There are sufficient means and there is sufficient time available to keep the PL-pools filled. Without this filling it will take another 4.8 days before the water level has dropped to the top of the nuclear fuel elements.

Entire site affected

If the units Doel 3, Doel 4 and WAB are also affected, the cooling of the reactors of Doel 1&2 remains assured. In that case Doel 1&2 share the water of the LU-ponds with Doel 3&4. As a result the autonomy offered by these ponds decreases a little.
However this does not introduce additional cliff edge effects.

- Doel 1&2 has sufficient water reserves (AFW, MW, EF) to cover 10 days. That is sufficient time to provide an alternative water supply for the steam generators or to fill the LU-ponds shared with Doel 3&4 by external means.
- If the entire site is affected, the available borated water has to be shared. However borated water is only necessary in the scenario 'primary system open' and two outages never occur simultaneously on the site.

Doel 3&4 Step 1: loss of CW (primary ultimate heat sink)+ RN (first alternate ultimate heat sink)

The units Doel 3 and Doel 4 are designed to independently withstand a total loss of the first alternate ultimate heat sink (RN-cooling towers) with the help of the second level systems in the Bunker and the corresponding water supply from the LU-ponds.
If the RN-cooling towers are lost the CC-system becomes unavailable. As a result multiple first level safety safety systems will have no cooling.
Total loss of the refilling of the RN-cooling towers is highly improbable, as there are multiple redundant refilling options.

Steam generators available

The AF-pumps and the second level systems in the Bunker ensure that the unit is cooled and kept in a cold shutdown state.

In this scenario the primary system is cooled with the steam generators to a temperature and pressure that have dropped sufficiently to take into service the shutdown cooling (SC). The self-cooled AF-pumps (motor & turbo) remain available to feed the steam generators.

There are no cliff edge effects for this scenario. The autonomy of the LU-ponds is at least 26 days. This is more than enough to refill the pond by external means.

Primary system open

The second level systems (bunker) ensure that the unit is kept in a cold shutdown state. The core is cooled via the SC-system. After the loss of the CC-system the SC-system is cooled by the LU-system.

Cooling via the LU-system is restored within a maximum of ½ an hour. If the cooling cannot be restored the water in the reactor will start to boil within an hour.

Operation on LU-system can continue to run for 26 days. This is more than enough to refill the ponds by external means.

Core in spent fuel pools

The second level systems in the Bunker ensure that the PL-pools remain cooled.

The spent fuel pool is cooled with the PL-system. After loss of the CC-system the PL-system is cooled by the LU-system.

The cooling of the pools via the LU system is restored within the hour. That is much shorter than the 8 to 10 hours available. A non-cooled spent fuel pool will only start to boil after 8 to 10 hours. The operation on LU-system can continue to run for 26 days. That is more than enough to refill the ponds by external means.

Entire site affected

If the other units are also affected, the cooling of the units Doel 3 and Doel 4 remains assured. Doel 3 and Doel 4 do not use the Doel 1/2 systems, except a back-up option in the scenario 'core in spent fuel pools'. If the LU-system would also supply a few systems of Doel 1/2 via the FE-system, the autonomy of the cooling ponds also decreases by a few days. Considering the very high level of autonomy there is more than enough time to refill the ponds.

Other units affected do not provide any additional cliff edge effects.

Doel 3&4 Step 2: loss of CW (primary ultimate heat sink)+ RN (first alternate ultimate heat sink)+ water supply from LU-ponds (second alternate ultimate heat sink)

The units Doel 3 and Doel 4 are not designed to independently withstand the total loss of both alternate ultimate heat sinks.

Simultaneous total loss of the first and second alternate ultimate heat sink is highly improbable.

Cooling of the nuclear fuel and maintaining the sub-criticality can still be guaranteed however.

Steam generators available

The reactors are cooled by the first and second level systems via the steam generators. In this scenario the (self-cooled) AF-pumps (2 motor & 1 turbo pump) are available to feed the steam generators.

Because the SC-system cannot be taken into service, this condition must be maintained for an unlimited period. Therefore water must be continuously supplied to the steam generators in order to guarantee the safety functions.

The normal total water inventory (5280 m^3) gives an autonomy of more than 2 weeks. This is more than enough to provide extra water via external means.

There are no cliff edge effects for this scenario.

Primary system open

In this scenario the water in the reactors starts to boil and the evaporated water is compensated by fresh water.The water level in the reactor is kept at a sufficient level by adding borated water via the air cooled CV-pump or 2 RJ-pumps.

As a back-up the RWST may also be drained gravitationally to feed the reactor via the SC-system.
After a loss of all heat sinks the reactor building is hermetically sealed to avoid that the steam formed would be released into the environment. As a result the pressure in the reactor building will rise. The pressure rise can be delayed by spraying cold water in the reactor building via the SP-system. After 24 hours the maximum pressure is 2.4 bar, which is far below the design pressure of 4.5 bar. The failure pressure of the reactor building will be reached after 3 days at the earliest. By that time the first level (CC) or the second level (LU) heat sink should have been restored. If that does not succeed then the reactor building must be vented in a controlled way.
As a result of the presence of steam, access to the reactor building will become difficult in due course.

Core in spent fuel pools
In this scenario the water in the spent fuel pool starts to boil and the evaporated water is compensated by fresh water. Boiling the water in the pools is an efficient way to remove the heat from the nuclear fuel elements.
Within 8 hours (Doel 3) or 10 hours (Doel 4) at the earliest the water in the spent fuel pool will start boiling. As a result of the presence of steam, access to the pools becomes more difficult in due course. For that reason it is necessary to make the water supply available before boiling starts.
There are sufficient means and there is sufficient time available to keep the PL-pools filled. Without this filling it will take another 4 days before the water level has dropped to the top of the nuclear fuel elements.

Entire site affected
If the other units are also affected, the cooling of the reactors of Doel 3 and Doel 4 remains assured. Doel 3 and Doel 4 do not need systems from Doel 1/2 for this scenario's, except to increase the already large autonomy.

5.2.2.2. (External) actions foreseen to prevent fuel damage

Tihange NPP
As explained above, the total loss of heat sink will prevent the continuous functioning of the various first-level safety and second-level systems (in particular the diesel generators) in the absence of cooling - apart from those not requiring water-cooling or those that are self cooled.

The Internal Emergency Plan will be started and, if necessary (by decision of the emergency director), the Engineering Department could also be mobilized.

The accident will be managed in accordance with the "accident" and "critical function monitoring" procedures. In the particular case of open primary system, the "accident" procedures in their present version do not fully describe the management of this beyond-design accident - typically, steam evacuation routes were provided, but the procedures do not take account of this type of scenario. The various procedures will be amended to take account of the different aspects revealed for this type of accident. Moreover, an integrated strategy will also be introduced for the management of this type of beyond-design accident.

Cooling of the spent fuel pools
The cooling of used fuel is achieved by boiling of water in these pools. Make-up is possible by the conventional systems (CTP, EDN, CAB) or non-conventional, and can be deployed in a time period (less than an hour for the conventional means and in a matter of a few hours for non-conventional means) shorter than the period until the uncovering of fuel assemblies (several days).

Cooling of the long-term storage pools (DE building)
The spent fuel in the DE is cooled by the boiling of water contained in these pools, giving a time limit before damage to the fuel of at least 3 weeks without water make-up. Make-up is possible within this time limit from the conventional systems (STP, SDN, SAB, etc.) or from the non-conventional systems

and can be deployed in a time period of less than an hour for the conventional means and in a matter of a few hours for non-conventional means (time for guidance only).

Non conventional means
Ultimate (non-conventional) means are available on site which can be deployed to maintain the cooling of the pools (CTP and DE).

For Tihange 1 it consists of the fire water supply to the spent fuel pool. This can be done either indirectly through a fire hydrant supplying the pool fill tank or directly from a fire hydrant supplying the pool. The pressurization of the fire water system can be achieved in the Meuse by an immersed mobile pump (available on site) and make-up by tanker truck via the CMU system.

For Tihange 2 it also consists of a water supply from the fire water system that can be pressurized by the fire pump of another non-affected unit or by a motor-driven pump installed in the river bed of the Meuse. This can be done from any fire hydrant in the system to refill the spent fuel pools.

For Tihange 3 it consists of a resupply of the pools spent fuel pools and the long-term storage (DE) pools from the effluent tanks of the primary system.

Doel NPP
At the water intake of Doel 1/2 in the Scheldt a loading quay is foreseen to supply water from a ship via the 'Polaris pipeline' to the power station at Doel 1/2. There are no contracts to deliver water as there are sufficient water supplies on site.
Because the improbability of this scenario, the use of external off site means is not considered,

5.2.2.3. Measures that may be considered to increase the robustness of the plant

Tihange NPP

Diversification of sources
The construction of a new demineralized water production circuit for the whole site is in progress. Investigations have revealed the existence of a deep groundwater table at the Tihange site. Three wells have been dug into this water table; they are equipped with pumps. The construction of a new demineralised water production circuit for the whole site is in progress.
Three deep wells dug in these zones allow a global flow of approximately 105m^3/h. Long-duration pumping tests have confirmed the capacity of this limestone water table and demonstrated its independence from the ground water table.
Branching has already been installed on this new system for the non conventional means. Its capacity exceeds the long-term water requirements of the steam generators.

Modification or creation of procedures
It is necessary to create or modify procedures in order to:
- define an integrated strategy for this accident (loss of all heat sinks) not taken into account at design (management of pressure in the building in "feed and bleed" configuration, optimum use of available means, etc.);
- integrate these new scenarios in the existing procedures;
- integrate use of the new demineralised water installation for unit resupply by non-conventional or conventional systems.

Doel NPP
The units are able to respond to this scenario. No hardware changes are needed.
The required procedures are provided for and may be executed with the shift crew teams present.

5.3. Loss of the primary ultimate heat sink combined with loss of off-site power and loss of first level on-site back-up power supply

Tihange NPP

The loss of primary ultimate heat sink combined with loss of off-site and first-level electric power is considered in the design bases of the site.
The primary ultimate heat sink of the Tihange NPP is an artificial branch of the Meuse. In case of loss of access to the river the units in Tihange use an alternate ultimate heat sink. The loss of off-site power and the loss of the first-back-up power supply (safety diesel generators) will prevent the use of first-level pumps drawing water from the primary ultimate heat sink. The loss of first-level and off-site electric power thus implicitly results in loss of access to the Meuse for the first-level pumps. The analysis given below shows that the site has sufficient emergency systems and autonomy compatible with the time required for restoration of an external electric power supply or for resupply from outside the site.

Doel NPP

The loss of primary ultimate heat sink combined with loss of off-site and first-level electric power is considered in the design bases of the site.
In the event of a loss of off-site power together with the loss of the first level safety diesel generators, the CW-pumps of Doel 1/2 and the make-up pumps of the RN-cooling towers of Doel 3&4 will not be powered. The loss of the external electricity grid together with the loss of the first level diesel generators therefore always automatically implies the loss of the primary ultimate heat sink.
The conclusions of the previous scenario 'Loss of off-site power (LOOP) and loss of first level on-site back-up power supply' (§ 5.1.2) therefore remain valid in this new scenario.

5.3.1. Autonomy of the site before fuel damage

Tihange NPP

This scenario supposes the loss of external electric power (very high voltage lines) and first-level safety diesel generators (GDS and GDR generators) combined with the impossibility of accessing water from the river Meuse. When the first level of protection is lost (except TPA-EAA) it will be necessary to go over the second-level emergency systems.

Tihange 1

The alternate ultimate heat sink will be the water from the groundwater table. This point has been discussed previously and the reserves available on the unit will allow covering the period until start-up of the groundwater.
The situation of loss of water from the Meuse combined with a station black-out is considered in the design of Tihange 1. Recourse will there be taken to the Emergency System (SUR) using procedures known as "beyond H3 dimensioning" and "ground well use".
Management of this accident and SUR autonomy are identical to what is described in the paragraph 5.1.2.1.

Core in spent fuel pools

In this scenario the spent fuel pool is not cooled by a closed-loop system. It is however possible to add make-up water by simple gravity, either by pump P04Bd via tank B01Bi, or using non-conventional means within a few hours period, or well before the uncovering of the spent fuel assemblies (a few days).
If a single unit is affected the groundwater autonomy is at least 30 days. Recourse to the SUR allows an autonomy beyond 72 hours by using only equipment and reserves available on site. These time periods allows arrival of equipment or water make-up from another unit or from outside the unit.
There is therefore no cliff-edge effect in this case.

Tihange 2 et 3
In the first case the heat sink may be either the groundwater wells (limited autonomy) or the Meuse via the deep river water intakes (unlimited autonomy).
The accident results in the loss of the first level safety systems - except the TPA-EAA, which runs until the water reserves run out or the batteries run empty (without external action). In the design, recourse is taken to the second level emergency systems, which use the primary ultimate heat sink (the Meuse) or the alternate (well drilled into the groundwater table) and emergency diesel generators (GDU). These systems allow placing and maintaining the reactor in a stable and controlled shutdown and the cooling of the CTP spent fuel pools (see paragraphs 5.1.2.3 and 5.1.2.4).

Core in spent fuel pools
The cooling of the CTP pools (Tihange 2 and 3) and DE pools (Tihange 3) is achieved by the conventional means via the exchangers of the respective systems cooled by groundwater (or by river water from the Meuse).
In case of total loss of intake of river water from the Meuse (that is, including deep intake), groundwater autonomy is at least 30 days if only one unit is affected.
If the unit affected is Tihange 3, the spent fuel pools of the DE building can be cooled from the CEU wells in Tihange 2 or Tihange 3. The pools are cooled by the CTP exchangers supplied from the groundwater.
The second level protection systems, powered by the GDU diesel generators, can place and maintain the reactor in a stable and controlled shutdown and cool the CTP and DE pools (Tihange 3). There is therefore no cliff-edge effect for this scenario.
The only possible problem is the running dry of the diesel fuel for the emergency diesel generators GDU, which occurs after a minimum of one week. This autonomy allows the deployment of compensatory means. The water autonomy of the alternate ultimate heat sink is unlimited if deep water intakes from the bed of the Meuse remains available, and last for at least 30 days (only one unit affected) if lost (groundwater autonomy). This autonomy allows the deployment of compensatory means.

Several units of the site affected
The management for Tihange 1 is similar to the case "Only Tihange 1 affected". The particularity would be the shared use of the groundwater.
The management for Tihange 2 or 3 is similar to that for the case "Only Tihange 2 or Tihange 3 affected". The particularity would be the shared use of the groundwater if the water intake from the bed of the Meuse for unit 2 and/or 3 is (are) unavailable .
A hose link between the groundwater system in Tihange 1 and one of the Meuse CEU pumps in Tihange 2 could also be installed.

Core in spent fuel pools
In the worst case the pools could be cooled by water make-up using non-conventional means (mobile pumps, hoses, diesel generators) present on the site. They can be deployed within few hours, that is, before expiry of the period of time before damage to the fuel, which is several days. It will then be necessary to arrange steam release routes.

DE spent fuel pool
If several units including Tihange 3 are affected by total loss of intake of river water from the Meuse, the spent fuel pools in the DE building can no longer be cooled by the conventional systems (limitation of heat sink) in the short term. Non-conventional means (pumps, hoses, diesel generators), deployed in a few hours, can deliver make-up water before the uncovering of the spent fuel assemblies (which occurs after at least 3 weeks). Provision is also made for release of this steam.

Doel NPP
The autonomy for this scenario is identical to the autonomy described in paragraph 5.1.2.4. The description of the autonomy of the site does not refer to means which use river water from the Scheldt.

5.3.2. (External) actions provided to prevent fuel damage

Tihange NPP

The loss of primary ultimate heat sink combined with loss of off-site and first-level electric power is considered in the design bases of the site.
The personnel involved in the management of this type of accident receives adequate training for use of the Emergency System SUR (in Tihange 1) or the second level emergency systems (Tihange 2 and 3). The Internal Emergency Plan will be started with call-out of the standby teams as described in Chapter 6.
No action or equipment from outside the site is necessary in the short term.

Doel NPP

The (external) actions for this scenario are identical to the autonomy described in paragraph 5.1.2.5. The description of the (external) actions does not refer to means which use river water from the Scheldt.

5.3.3. Measures that can be considered to improve the robustness of the installations

Tihange NPP

The measures that can be considered to improve the robustness are identical to those described in paragraph 5.1.2.6.

Doel NPP

The measures that can be considered to improve the robustness are identical to the measures described in paragraph 5.1.2.6. The description of the measures does not refer to a measure to restore the primary ultimate heat sink.

5.4. Loss of the primary ultimate heat sink combined with a total Station Black-out

Tihange NPP

The primary ultimate heat sink of the Tihange NPP is an artificial branch of the Meuse. In case of loss of access to the Meuse, the units in Tihange use an alternate ultimate heat sink. This most unlikely scenario combines total station black-out with loss of the primary ultimate heat sink. Such a scenario is not part of the design bases of Tihange units. The units still have water from the groundwater or deep water intakes but can no longer use it due to lack of electric power.

The conclusions of the scenario 'Loss off-site power (LOOP) and loss of all onsite back-up power (Total Station Black-out)' (paragraph 5.1.3) therefore also remain valid in this scenario.

Doel NPP

In the event of a total station black-out, the CW-pumps of Doel 1/2 and the make-up pumps of the RN-cooling towers of Doel 3&4 will not be powered. For that reason a total Station Black-out automatically implies the loss of the primary ultimate heat sink.

The conclusions of the scenario 'Loss of off-site power (LOOP) and loss of all onsite back-up power (Total Station Black-out)' (paragraph 5.1.3) also remain valid in this scenario.

5.5. Loss of the primary ultimate heat sink combined with the loss of off-site power and Design Basis Earthquake

In this scenario it is assumed that after the Design Basis Earthquake (DBE) the external electricity grid and the primary ultimate heat sink are no longer available.
In the event of the loss of off-site power all safety systems must be powered by the reactor units on site that have not been shutdown, the diesel generators present on site, batteries and steam driven pumps.
In this scenario the only available equipment is that which has been designed to resist a DBE
The analysis given below shows that the sites have emergency means and sufficient autonomy to manage this type of accident within the time period required for restoration of an off-site power supply or resupply from outside the site.

5.5.1. Autonomy of the site before fuel damage

Tihange NPP

The resistance of the dam at Ampsin-Neuville (situated downstream of the site) in case of design basis earthquake (DBE) was analyzed. The main conclusion is that its function of water containment would be preserved. Therefore, the worst case to consider is a slow reduction of level of the Meuse following a possible deterioration of the systems regulating the dam at Ampsin-Neuville. The study has been completed up to the review level earthquake (RLE).
If the level of the Meuse is maintained, which corresponds to the most likely case, the accident corresponds to a LOOP as described in paragraph 5.1.1.
The case of progressive reduction is examined below.

Tihange 1

The gradual loss of suction by the CEB pumps (part of the design bases) is considered. The simultaneous loss of off-site power will lead to use of the first-level safety diesel generators (which are seismically qualified).
After realignment, the groundwater system will supply the raw water system (CEB), normally drawing from the water of the Meuse. This safety water supply from the CEB allows coping with the consequences of the event, this regardless of the state of operation of the unit at the time of accident (steam generators available, primary system open or core in spent fuel pools). In fact, this system can ensure cooling of the safety diesel generators, water supply the steam generators, cooling the core by the RRA system and cooling the pools.

The autonomy of the first-level safety diesel generators is at least 3.5 days. The groundwater autonomy is at least 30 days. In this scenario Tihange 2 and 3 use the deep river water intake in the Meuse and therefore do not require their CEB wells. Tihange 1 then has two wells at its disposal for at least 30 days. These periods allow covering the time until arrival of equipment from another unit or from outside the site. There is therefore no cliff-edge effect.

Tihange 2 and 3

This scenario corresponds to the gradual loss of suction in the CEB pumps. This problem is handled by switching to deep water intakes from the Meuse. The simultaneous loss of off-site power will lead to use of the first-level safety diesel generators.
The deep water intakes from the Meuse, which remains available in case of failure of the dam at Ampsin-Neuville, can be connected to the raw water system (CEB). This safety water supply of CEB allows the management of the consequences of the event, and this regardless of the state of operation of the unit at the time of accident (steam generators available, primary system open or core in spent fuel pools). In fact, this system can ensure the functioning of the first-level safety systems: the cooling of the safety diesel generators, supply to the steam generators, the cooling of the core by the RRA system and the cooling of the pools.

Spent fuel pools

The cooling of the CTP pools and the pools in the DE building (Tihange 3) is then provided by the CEB and the CRI, which requires the repowering of the CTP and STP pumps (Tihange 3) from back-up panels. This repowering involves an electric realignment, executed well before the boiling of the pools, and therefore largely before expiry of the period until damage to the fuel (several days).

The autonomy of the first-level safety diesel generators is at least one week, and the use of the deep river water intake in the Meuse gives unlimited water autonomy. These periods of time allow covering the time until arrival of equipment from another unit or from outside the site. There is therefore no cliff-edge effect.

Several units of the site affected

The fact that several units are affected does not involve any additional constraint compared to the previous situation since Tihange 2 and 3 do not use groundwater.

Doel NPP

Doel 1/2

The units 1/2 are designed to independently withstand a total loss of off-site power together with the loss of the primary ultimate heat sink (at power). This is realized with the second level emergency systems. All second level emergency systems at Doel 1/2 are completely designed to resist the Design Basis Earthquake (DBE).

At Doel 1/2, the following systems are designed to withstand the DBE:

- All second level systems in the Emergency Systems Building
- The primary system (RC)
- The shutdown cooling system (SC)
- The secondary system up to the first isolation valve (FW/MS)
- The storage tank for demineralised water of 1500 m^3 (MW)

After the Fukushima accident, seismic upgrade of the AFW-turbo pumps and their tanks (small storage tank – 100 m^3) were done.

In the event of the loss of external power, the first level and second level diesel generators remain ready for deployment.

The current four first level safety diesel generators are not designed for the DBE.

Steam generators available

The earthquake resistant second level systems in the Emergency Systems Building ensure that the unit is cooled down and maintained in a cold shutdown.

All safety functions remain guaranteed.

The residual heat is removed using the second level EF-system.

Furthermore, when the first level diesel generators are no longer available, the AFW-turbo pump remains available for refilling the steam generators from the AFW-tank.

There are no cliff edge effects for this scenario.

There is sufficient water supply present on site to cool down until one can switch to the EC-system for cooling the SC-system. After this switch the primary system is cooled by the SC-system and no further water supply is needed.

After approximately 5 days the second level diesel generators must be refuelled. That is more than enough time to get diesel fuel from other places either on or off the site.

Primary system open

The second level systems ensure that the unit is maintained in a cold shutdown state.

The removal of the residual heat of the open reactor is realized using SC-pumps that are powered by the second level diesel generators. The cooling of the SC-pumps and coolers is taken over by the EC-system.

If the cooling cannot be restored, the water in the reactor will start to boil within an hour. This period depends on the time interval between the shutdown and the initiating event, the water level in the reactor and the possibility to increase the water level.

That water will continue to boil until the cooling via the EC-system is restored (after a maximum of 45 minutes). The water inventory is kept at a sufficient level by filling with the RJ-system or by gravitationally emptying the RWST to the primary system. The operation on the EC-system may continue indefinitly. No water needs to be supplied.
After 5.5 days the second level diesel generators must be refuelled. That is more than enough time to get fuel from other places on or off the site.

Core in spent fuel pools

The second level systems ensure that the spent fuel pools remain cooled.
The PL-system is aligned to the Emergency Systems Building within 1.5 hours. This is faster than the time available of 15 hours, before boiling starts.
The PL-system is a closed system. No water needs to be added.
After 7 days the second level diesel generators have to be refuelled. That is more than enough time to get fuel from other places on or off the site.

The entire site is affected

If the other units are also affected the cooling of the reactors at Doel 1/2 remains assured.
The supply from the LU-ponds must be shared with the other affected units. The supply (3 x 30,000 m³) is sufficiently large.
Other affected units do not induce any additional cliff edge effects.

Doel 3&4

The units Doel 3 and Doel 4 are designed to independently withstand a total loss of off-site power together with the loss of the primary ultimate heat sink. The first level safety systems and second level emergency systems at Doel 3 and Doel 4 are all fully designed to withstand the SSE.
The conclusions of the scenario 'Loss of off-site power (LOOP) also remain valid in this scenario.
The loss of the external grid always goes together with the loss of the primary ultimate heat sink.

5.5.2. (External) actions foreseen to prevent fuel damage

Tihange NPP

The loss of heat sink and off-site power following an earthquake of intensity comparable to the DBE is considered in the design of the site.
This type of accident is managed by the shift crew teams in the control room and by the standby teams. The Internal Emergency Plan described in Chapter 6 will be started (with call-out of the various standby teams). The site has sufficient reserves of diesel fuel and oil. It is therefore not necessary to consider external actions in the short term.

Doel NPP

Elia is expected to provide the NPP with power as quickly as possible. See paragraph 5.1 above for the description of the methods available for this and the corresponding repair times.
At the water intake of Doel 1/2 in the Scheldt a loading quay is foreseen to supply water from a ship via the 'Polaris pipeline' to the power station at Doel 1/2. There are no contracts to deliver water as there are sufficient water supplies on site.

5.6. Spent nuclear fuel storage

Tihange NPP - DE building

As already mentioned, the various systems and systems involved in the pools are linked to the operation of the unit Tihange 3 and therefore to the state of the unit at the time of occurrence of a possible accident. Therefore, and for comprehension sake, the analyses concerning the spent fuel pools were described in the paragraphs on the units (specifically Tihange 3).

Doel NPP - SCG building

The storage of spent nuclear fuel in the containers situated in the nuclear fuel container building SCG is entirely passive. No electricity or active heat sink is required to cool the containers.
The nuclear fuel is stored in transport containers that are resistant against external circumstances that might occur as a result of road accidents on the road. The storage building together with the container provides shielding and an improved heat removal under normal conditions.
Loss of off-site power, loss of the first level diesel generators, loss of the second level diesel generators, loss of the primary ultimate heat sink and loss of the alternate ultimate heat sinks have no impact whatsoever on the cooling or integrity of the containers situated in the SCG.

5.7. Synthesis of the main results presented by the licensee

Based on the information in the licensee's stress test reports and the additional information provided by the licensee during technical meetings and on-site inspections, the main results for the topic "loss of electrical power and loss of ultimate heat sink" are as follows.

Scenarios

The definition of the selected scenarios as well as the various states of the reactor mentioned in these scenarios (steam generators available, primary circuit open and connected to the shutdown cooling system, core fully unloaded in the spent fuel pools) are in agreement with the stress test specifications.

Taking into account the

- different levels of safety systems (first level safety systems and second level emergency systems) in the Belgian NPPs,
- multiple ultimate heat sinks, with several means to draw water: river by the site (Scheldt river at Doel, Meuse river at Tihange), artificial cooling pond (Doel), and ground water wells (Tihange),

the following different scenarios were assessed:

1. loss of off-site power supply (LOOP);
2. loss of off-site power supply and first-level internal power supply (station black-out);
3. loss of off-site power supply and first-level and second-level internal power supplies (total station black-out);
4. loss of primary ultimate heat sink;
5. loss of primary ultimate heat sink and alternate ultimate heat sinks;
6. loss of primary ultimate heat sink together with loss of off-site power supply and first-level internal power supply;
7. loss of primary ultimate heat sink together with loss of off-site power supply, first-level and second-level internal power supplies;
8. loss of primary ultimate heat sink together with loss of off-site power supply and combined with DBE earthquake.

Initiating events (for example earthquake) and their consequences on the safety functions are not systematically considered in the management of the first 7 scenarios and in the determination of the autonomy of the equipment needed to cope with these scenarios. For example non seismic tanks (water, diesel fuel/oil) are used as supplementary reserves in each scenario.

However, the impact of the initating events flooding and earthquake has already been assessed in detail in the previous chapters.
In addition, the last scenario (scenario 8) assumes that after a Design Basis Earthquake (DBE) the external electricity grid and the primary ultimate heat sink are no longer available. In this scenario the only equipment that is credited in the assessment is the one that has been designed to resist a DBE.

Several units affected on the site

For each scenario, the licensee first assessed the impact separately on each reactor unit on the site. The simultaneous impact on all units on a NPP site was also addressed systematically by the licensee for the various scenarios (with specific regard to the autonomy of the different resources in this case).

Safety functions

The stress tests specifications demand that the licensee shall identify the means to maintain the three fundamental safety functions (fuel cooling, control of reactivity, confinement of radioactivity) and support functions (power supply, cooling through ultimate heat sink).

Concerning the three safety functions, the "fuel cooling" is the safety function that is most relevant when dealing with loss of electrical power and loss of heat sink scenarios and was assessed in detail.

The safety function "control of reactivity" poses no major problem as long as there is no extra pure water supplied to the primary circuit. The safety function "confinement of radioactivity" has been addressed by focusing on the aspect of maintaining the containment building integrity.

The re-assessment allowed the licensee to identify for some scenarios areas for improvement. A number of additional hard-ware improvements (for example non conventional means) or improvements to procedures have been proposed by the licensee, some of which have already been implemented.

Design basis

The different scenarios either are part of the initial design basis, or were reassessed during the first periodic safety review, or are "beyond design basis" scenarios.

- Initial Design Basis

The scenarios of "Loss of offsite power (LOOP)" and "Loss of primary ultimate heat sink (LUHS)" are part of the initial design basis of all the Belgian units. The scenario "Loss of primary UHS, LOOP and earthquake DBE" is part of the initial design for all the Belgian units except for the Doel 1/2 units.
For the four most recent units (Tihange 2-3 and Doel 3-4), the scenarios "Station Black out (SBO)" and "Loss of primary UHS and SBO" are also considered in the initial design basis of these units. A second level of protection called the "Bunker" allows facing these situations. All the systems which are part of the second level of protection (classified electrical and I&C systems, fluids systems, etc.) are physically and electrically independent from the first level of protection. Furthermore, these classified systems meet safety requirements such as redundancy, independency, qualification (e.g. earthquake, aircraft crash), testing, etc.

- Design reassessed during the first periodic safety review

For the oldest units (Tihange 1 and Doel 1/2), the scenarios "Station Black out (SBO)" and "Loss of primary UHS and SBO", "Loss of primary UHS, LOOP and earthquake DBE" (only for Doel 1/2 because of the DBE aspects) were not taken into account during the initial design.
During the first periodic safety review of these units, a new building with a second level of protection was added for the cooling sources and the electrical power supply. This second level of emergency systems, called "SUR" ("Systèmes d'Ultime Repli") for Tihange 1 and "GNS" ("Gebouw NoodSystemen") for Doel 1/2, is able to cope with the above mentioned scenarios.

However, the improvements implemented in that framework include some limitations, of which the main ones are:

- For Doel 1/2: the second level only covers the power operation states (and the removal of the residual heat in the spent fuel pools in normal conditions). This situation was regarded as acceptable at the time considering that the shutdown states duration was limited. Consequently, the second level systems are not required in shutdown states. However, it is clear that the diesel generators are physically present on the site and they would be used if they are not under maintenance. Likewise, the system for residual heat removal was designed for a heat load corresponding to 7 days after the reactor shutdown (including conservatism), the unit being first cooled down by the steam generators for a period of time. Since then, procedures and hardware modifications were set up to better manage that scenario.
  This point was identified in the framework of the "Long Term Operation" ("LTO") project of these two units and is subject to an improvement project.
- For Tihange 1: the second level is not entirely seismically qualified as this hazard was handled by the first level; the second level allows to deal with an SBO and some external hazards. Similarly, for the shutdown states, the RRA and CTP pumps are not re-supplied by the second level.

- Beyond Design Basis

The scenarios "Total SBO", "Loss of primary and alternate UHS", "Loss of primary UHS and total SBO" are considered as beyond design situations for all the Belgian units.

Due to the presence of a second level of protection independent from the first level of protection, the installations in the Belgian units are robust to face different scenarios like "SBO", "Loss of primary

UHS", "Loss of primary UHS and SBO", "Loss of primary UHS, LOOP and earthquake DBE". The oldest units are less robust but the utilities have defined actions to improve the situation.

5.7.1. Scenario "Loss of offsite power (LOOP)"

This scenario was studied in the original design basis of all the Belgian units. This accident is managed by the first level safety systems (and in case of failure, by the second level emergency systems – cf. SBO scenario). The licensee assessed the autonomy for diesel fuel and lubricating oil for the diesel generators needed by these safety and emergency systems.

There is no cliff edge effect, the autonomy being sufficient for at least 72 hours. This autonomy covers the time until arrival of equipment or water from another unit or from outside the site.

The licensee envisages the modification or writing of procedures in order to further improve the autonomy of the diesels:

- a procedure will be adapted for anticipating manually the oil and fuel supplement to the diesel generators;
- a procedure will be drawn up for defining the non essential loads to be disconnected from the diesel generators in order to minimize the fuel consumption.

5.7.2. Scenario "Station Black Out (SBO)"

This scenario was studied in the original design basis of the four most recent Belgian units (Tihange 2 and 3, Doel 3 and 4) and during the first periodic safety review for the oldest ones (Tihange 1 and Doel 1/2). There is no cliff edge effect. For Tihange 1, a reinforcement of the robustness of the installations is foreseen in the second level of protection (to avoid feed-and-bleed) (see second bullet hereafter).

The licensee's reassessment evokes rightly for Tihange 1 a limitation linked with the current design of the unit, namely the impossibility to connect the RRA system to the emergency power supplies – penalizing situation for the "Open primary circuit" configurations. The envisaged response is the "feed-and-bleed" to prevent the situation to worsen into a severe accident.
For Doel 1/2, as explained previously, the second level can deal fully with that scenario only when the unit is initially in power operation. This aspect is not clearly presented inn the licensee's evaluation. However, procedure and hardware modifications were progressively implemented and improve the management of this scenario. Other improvements are expected as part of the "Long Term Operation" ("LTO") project.

The licensee plans analyses of hardware modifications. Revision and writing of procedures are also foreseen:

- the implementation of an automatic fuel supplement to the diesel DUR fuel tank from the CVA fuel tank will be studied (Tihange 1);
- in the framework of the LTO project of Tihange 1, studies will be carried out for analyzing the possibility of supplying the spent fuel cooling pumps and the shutdown cooling pumps by the SUR system (6 kV);
- the existing SUR procedures will be revised in order to ensure a water supplement and a steam evacuation in the spent fuel pools (Tihange 1);
- A procedure will be drawn up for defining the non essential loads to be disconnected from the diesel generators in order to minimize the fuel consumption.

5.7.3. Scenario "Total SBO"

This scenario is a beyond design basis scenario for all the Belgian units. In order to avoid the cliff edge effects the licensee has proposed a set of additional measures.

For the states in which the steam generators are available, the management of this scenario relies on the removal of the residual heat via the auxiliary feedwater turbopump and steam generator discharge to the atmosphere. If this process is physically feasible, the following aspects shall be pointed out:

- if the unit is not initially in a power operation state, the start of the turbopump requires a sufficient pressure in the primary circuit. For example at Doel 1/2, this pressure is relatively high (24 bars). A rise of the pressure and temperature is not planned in the management actions, consisting in a depressurization and a fast decrease of the temperature to protect the primary pumps seals in case of loss of injection to those seals. The licensee has confirmed its strategy in that case, namely a temporary rise of the pressure and temperature to allow the turbopump to start. Indeed, the primary pumps seals are supposed to survive a temporary solicitation (engineering judgement based on tests results).
- the control valves for the auxiliary feedwater and the discharge to the atmosphere can be manually actuated locally, after the loss of control compressed air and/or batteries. Nevertheless, those operations are performed in difficult access conditions and with no visibility on the results (no indication of the steam generator level). Hence there is a risk of overfilling (or drying) the steam generator.

The main commitments of the licensee are described hereafter:

- use of non conventional means:
    - to refill the steam generators and the spent fuel pools,
    - to ensure make-up for the primary circuit in open configuration (for Tihange 2 and 3),
    - to avoid the overpressure in the reactor building,
    - to restore the electrical power supply to instrumentation and control panels, motors, valves,
    - to make operable the emergency compressed air circuit;
- feasibility study in order to increase the capacity of the auxiliary feed water (EAS) system and to add an emergency feed-water motor (Tihange 1);
- feasibility study for reliable manual actions on the steam generators atmospheric discharge valves (Tihange 1 and 3);
- drawing up of a specific "Total SBO" procedure.

5.7.4. Scenario "Loss of the primary ultimate heat sink"

This scenario was studied in the original design basis of all the Belgian units when one unit of a site is affected by this accident.

There is no cliff edge effect. This accident is managed by the second level of protection systems (ground water wells for Tihange and cooling pond water for Doel). For Tihange 2 and 3, emergency deep water intakes (2 per unit) draw water directly in the bed of the Meuse river. According to the safety analysis reports, these emergency water intakes are considered as an additional line of defence in depth for these units.
The ground water wells or cooling ponds allow an autonomy of 30 days (Tihange) or 26 days (Doel) when one unit of the site is affected by the loss of primary UHS in accordance with the design basis. If all units of Doel are affected by the loss of the primary UHS (beyond design scenario) the licensee confirmed that the autonomy of the ponds is sufficient. If all units of Tihange are affected by the loss of the primary UHS the autonomy of the well water is 3 weeks without the use of the emergency water intakes (Tihange 2 and 3). If these intakes are available the autonomy is unlimited for Tihange 2 and 3 and of 30 days for Tihange 1.

The licensee plans to write a new procedure to manage a multi-unit accident and to optimize the water consumption of the second level of protection (wells or ponds).

5.7.5. Scenario "Loss of primary and alternate ultimate heat sinks"

The scenario "Loss of primary and alternate ultimate heat sink" was not studied in the original design basis of the Belgian units.

For Tihange, there exist cliff edge effects at the time of the loss of cooling of the steam generators when the steam generators are available, and at the time all borated water tanks are empty when the primary circuit is open. In these cases, the times for lining up the NCM equipment (mobile pump in Meuse to refill the steam generators and tanker with borated water to refill the refueling water storage tanks) are estimated to be sufficient by the licensee.
The licensee indicates also that in the short term the water autonomy will be increased by a new deep water ground well independent from the existing well systems. This new water source has been recently discovered and will be used for the production of demineralized water.

For Doel, similar cliff edge effects can be prevented by relying on site systems.

The main commitments of the licensee are described hereafter:

- use of non conventional means:
    - to refill the steam generators and the spent fuel pools,
    - to ensure make-up for the primary circuit in open configuration (for Tihange 2 and 3),
    - to avoid the overpressure in the reactor building;
- drawing up of a specific "Loss of primary and alternate UHS" procedure;
- in the short term the robustness of the installation will be reinforced by a new deep ground water well. This new well independent from the existing ground water wells, could constitute an additional source of water for the 3 units of Tihange.

5.7.6. Scenario "Loss of the primary UHS with SBO"

This scenario was considered in the design basis of the Belgian units. There is no cliff edge effect. This scenario is managed by the second level emergency systems.

5.7.7. Scenario "Loss of the primary UHS with total SBO"

This scenario is a beyond design basis situation for all the Belgian units. In order to avoid the cliff edge effects the licensee has proposed a set of additional measures.

5.7.8. Scenario "Loss of the primary UHS, LOOP and earthquake DBE"

This scenario was considered in the design basis of the Belgian units. There is no cliff edge effect. This scenario is managed by the second level of protection systems for the units of Tihange and Doel 1/2, and by the first and second levels of protections systems for Doel 3 and 4.
For Doel 1/2, the licensee takes credit of the auxiliary feedwater pumps ant the associated tanks. By design these equipment are non seismically qualified. Shortly after the Fukushima accident, the utilities decided to upgrade these equipment and make improvements to assure their availability after an earthquake.

5.7.9. Spent Fuel Pools

For the evaluation of the robustness of the spent fuel pools, the most conservative scenario is a total SBO at the end of the core unloading (core fully discharged and spent fuel pools filled).

The spent fuel pools can be gravity-refilled from tanks permanently connected to the fuel pools (refueling water storage tanks, borated water, and demineralized water) of the unit. The various water supplies on site are sufficient to ensure the required make up in the long term. The licensee confirms that non conventional means (tanker or mobile pumps with their own power supply taking water from the primary or the alternate UHS, fire protection system…) can be lined up in less than one hour. Hardware modifications are envisaged for the site of Doel (points of connection and hard pipes) to increase the robustness of the installations.

The autonomies mentioned in the final reports are not very detailed. Complementary information was given by the licensee during specific inspections which leads to the conclusion that these autonomies are compatible with the internal backup facilities or the external facilities (non conventional means) that will be installed to refill the spent fuel pools.

5.8. Assessment and conclusions of the regulatory body

The approach adopted by the licensee to re-assess the management of the loss of electrical power and loss of ultimate heat sink complies with the methodology provided by the licensee and approved by the regulatory body.

Due to the presence of a second level of protection (emergency systems) fully independent from the first level of protection (safety systems), the installations in the Belgian units are very robust to face the different scenarios. Furthermore, these different safety and emergency systems are diversified and meet safety requirements such as redundancy, independency, qualification, testing, etc.

Generally speaking, the licensee must guarantee the availability and proper functioning of the various devices evoked in the framework of the stress tests program, including the beyond design scenarios:

- through the technical specifications that indicate the requirements in terms of availability, testing and allowed outage time, for all safety related equipment. The licensee should review the plants technical specifications in order to further improve the availability of the second level emergency equipment. In particular, the maximum allowed downtimes and the time limits for return to service should be re-evaluated and justified, given the risks involved (see also requirement 7 in paragraph 6.7).
- through the consideration of adverse weather conditions. Some weather conditions (extreme cold or heat waves) were not considered in the stress tests specifications. However, if these events might not be regarded as initiating events, the licensee shall verify that the various means implemented for the management of accidental scenarios are effectively usable in practice, be it in winter (freeze and snow periods are not exceptional in Belgium), or in summer (periods of relatively high temperatures for several days or weeks).

Based on the assessment of the licensee's reports and the supporting documents, the subsequent technical meetings and the on-site inspections, the regulatory body considers that the resulting action plan is adequate.

However, the regulatory body identified additional demands and recommendations to further improve the robustness of all the Belgian units:

1. The operability of the non conventional means should be justified on the basis of technical data (design, operation, alignment and connections, periodic testing, preventive maintenance, etc.).

2. The technical characteristics of the non-conventional means (NCM) should account for the adverse (weather) conditions they may be subject to during the whole period of operation.

3. The licensee should, in collaboration with ELIA, manager of the high voltage network, make a feasibility study to ensure a better geographical separation of the high voltage lines (380 and 150 kV) to further improve the reliability of the external power supply to the NPPs. In addition, the licensee should, in agreement with ELIA, ensure that in case of LOOP the NPPs have the highest priority for reconstruction of the external power supply to the NPPs. The regulatory body shall take the necessary steps, in collaboration with other competent authorities, to ensure the fulfilment of this recommandation.

4. In relation to the "total SBO" scenario, the potential overfilling or drying of the steam generators due to the loss of ultimate compressed air should be examined.

5. In relation to the "total SBO" scenario, the operability of the AFW turbine-driven pump due to the loss of ventilation in the turbine-driven pump room should be examined.

6. In case of (total) station black-out, the licensee should assess whether all containment penetrations can be closed in due time and whether the relevant containment isolation systems remain functional, in particular during outage situations. The feasability of closing the

personnel and material hatches should be assessed. These topics should be addressed in the "total station black-out" procedure.

7. The licensee shall justify that the water capacity (quantity and flow of cooling water for the consumers) of the second level of protection is sufficient when all the units of the site are affected by the loss of primary UHS. If needed a strategy to optimize the water consumption should be developed.

8. For Tihange, the licensee should reinforce the emergency lighting in the different rooms and places where the operators should intervene during the different scenarios.

9. In relation to the "loss of primary UHS" scenario, the licensee shall carry out alignment and operating tests of the emergency deep water intakes from the Meuse river bed in 2012 (for Tihange 2 and 3).

10. In relation to the "loss of primary UHS" scenario, the licensee should justify the availability (accessibility, operability and alignment) of the emergency water intakes of Tihange 2 and 3 in accordance with the requirements of US NRC RG 1.27.

11. Two configurations should be evaluated by the licensee for the spent fuel pools:
    a. Configuration with a fuel assembly handled in the reactor pool during a "Total SBO". The fuel assembly should manually be handled in a safe position. The licensee should investigate the provisions (hardware installations, procedures, lighting, etc.) to be implemented for this configuration.
    b. Configuration with the loss of water inventory in the spent fuel pools. The international experience feedback has already pointed out potential problems with the design of the siphon breakers in the spent fuel pools. In case of piping rupture, an insufficient capacity of the siphon breakers may lead to a fast uncovering of spent fuel assemblies. The licensee should examine this safety concern.

6. Severe accident management

In order to provide a self-standing national report for the subsequent peer review process, first the relevant information supplied by the licensee in its stress tests reports is recalled.
At the end of this chapter, a final section provides the conclusions and the assessment of the Belgian regulatory body (FANC and Bel V).

6.1. Organisation and arrangements of the licensee to manage accidents

6.1.1. Organisation of the licensee to manage the accident

6.1.1.1. Staffing and shift management in normal operation

Shift crew ensure a continuous presence on site and are always composed as described in the table below and according to the minimum requirements of the safety analysis report.

Table 14: Minimum composition of shift crew according to the state of the units

Unit	Status of the unit	Number of personnel in the shift crew
Tihange 1	In operation, hot shutdown or intermediate shudown	7
	Cold shutdown	6
Tihange 2	In operation, hot shutdown or intermediate shudown	8
	Cold shutdown	6
Tihange 3	In operation, hot shutdown or intermediate shudown	7
	Cold shutdown	6
Doel 1/2	Doel 1 and Doel 2 in operation	9
	Doel 1 or Doel 2 in cold shutdown	9
	Doel 1 and Doel 2 in cold shutdown	7
Doel 3 and Doel 4	Doel 3 and Doel 4 in conditions 1 (operation) to 4 (intermediate shutdown)	13
	Doel 3 or Doel 4 not in conditions 1 (operation) to 4 (intermediate shutdown)	9
	Doel 3 and Doel 4 not in conditions 1 (operation) to 4 (intermediate shutdown)	7

The shift crew are assisted by the radiation protection agents, the fire brigade and the site security.

The mission of the shift crew consists in taking – 24 hours a day, 7 days a week – the first appropriate actions should any event occur. In normal operating conditions or in case of a problem, they can rely at any time upon a team of on-call technicians and staff. In case of an emergency at a unit, the internal emergency plan is activated. It ensures mobilization of the necessary internal and external resources to manage the event.

6.1.1.2. Measures taken to enable optimum intervention by personnel

In case of a nuclear accident, the shift crew, supported by the radiation protection agents, the fire brigade and the site security personnel, all present on site, is to deal with the accident. The shift crew is in the control room where they will call in the on-call personnel.

The roles of the on-call personnel are defined in the emergency planning organization.
There are at least five members per on-call team, who remain on duty for 12 hours.
The on-call personnel will be present within a time span planned in advance. In addition, availability tests have shown that 80 % of the other on-call personnel (not on duty at that moment) can be present within a delay of 2 hours.
The on-call personnel will then occupy the different emergency response centres.

Tihange NPP

At Tihange, the management of an emergency is ensured from three separate places:

- from the unit control room where shift crew operators are working in normal and accidental conditions;
- from the "unit operation centre", called "COT" at Tihange (located next to the control room and designed with the same resistance features as the control room), where the first part of the emergency management team meets and from which the technical management of the event takes place;
- from the "site operation centre" called "COS" at Tihange (physically distant from the control room) where the second part of the emergency management team gathers and from which communication and external relations with the outside world are managed.

Initially, the emergency is managed from the control room of the concerned unit. As soon as the internal emergency plan is activated, an emergency management team is set up. It includes a local team, which meets in the unit operation centre (COT) located next to the control room of the concerned unit. The rest of the emergency management team meets in the site operation centre (COS) located in the administrative building. The team that meets in the COT deals with technical aspects, while the team gathered in the COS focuses on organization and communication (in particular with public authorities) as well as on strategic decisions for emergency management.

In addition, an off-site reception and fall-back centre called "CARA" is located in Les Awirs, at 12 km from the Tihange NPP. In the event of an emergency, the CARA will fulfil the following functions:

- it can function as an off-site fall-back emergency centre in situations where the normal on-site operation centre (COS) is inaccessible; the on-call emergency team can manage the emergency in a safe and continuous manner from the CARA centre;
- it can be used as a gathering and briefing room for shift crew and response teams just before they go to the plant; information about technical aspects and protective measures to take are provided to the personnel of the licensee and contractors;
- it can be used as a decontamination facility for the personnel, in case of a severe contamination of the Tihange NPP making personnel decontamination impossible on site; after their work and before going home, the members of shift crew and response teams must return to the CARA centre for debriefing;
- there is an infrastructure for the reception of the families of injured personnel; information intended only for these families is given at the CARA centre.

Doel NPP

At Doel, the management of an emergency is performed from four separate places:

- in the unit control room, shift crew operators are working in normal and accidental conditions;
- the unit annex control room ("BK"), located in the same place as the control room, is the nerve centre of the severe accident management ("SAM"); from this centre, actions affecting the installations are performed;
- in the on-site technical support centre ("OTSC"), interventions and operations in the installations and long-term actions are prepared. The Doel 1/2 OTSC is part of the Doel 1/2 machine room; in this place, the most important operational parameters are monitored. The

Doel 3 and Doel 4 OTSC is part of the Electrical Services Building ("GEH") of Doel 4; in this place, the most important core status parameters are monitored. The Doel 3 and Doel 4 OTSC can function as a back-up for the Doel 1/2 OTSC;
- in the site emergency operations facility ("NPK"), the data are consolidated, the communication with the authorities is coordinated, and the possible dissemination of radioactivity in the environment is calculated.

For both sites, the preparedness of the complete emergency planning infrastructure is followed up with maintenance plans.

Among the resources involved in the internal emergency plan are the NPP's own personnel.
The whole NPP's personnel are gradually involved:
- shift crew teams,
- on-call managers,
- on-call technicians (mechanics, electricians, radiation protection officers, ICT),
- first response teams,
- the security guard service and the medical aid service,
- the whole personnel of the NPP on request, depending on individual skills.

Further resources can also be mobilized, including response units sent from the other NPP (Doel or Tihange) and members of the Electrabel corporate emergency organisation.
Contractor employees that are usually working on the site of the NPP as well as other people that are not linked with the licensee can also be called upon. In this respect, assistance conventions and cooperation agreements have been concluded with some companies or bodies.

Technical resources available on the sites include:
- fire brigade garages equipped with equipment and consumables for the suppression of a wide range of events (fire, explosion, flooding, release of products with dangerous characteristics);
- logistic equipment: sandbags, compressors…
- fully equipped monitoring vehicles to perform radiological measurements on site and off site;
- stocks of packages of personal protection equipment;
- medical posts with equipped nursing and doctors' practice and triage zones;
- helicopter landing places;
- guards for the protection against unauthorized access to the site.

6.1.1.3. Use of off-site technical support for accident management

When an internal emergency plan is activated, the on-call management officially informs the public authorities in compliance with the emergency notification process. This information is automatically directed to the call centre of:
- the Governmental coordination and crisis management centre ("CGCCR"),
- Bel V,
- the Federal Agency for Nuclear Control (FANC).

Depending on the nature of the event, other authorities such as the local mayor, the governor of the Province, the local fire brigade or the Ministry of Employment, Labour and Social Dialogue may also be informed.

<u>Electrabel corporate emergency organisation</u>

In order to bring support to a unit or a NPP in emergency, Electrabel created the emergency management centre production Belgium ("CMCPB"), located in Brussels and headed by a member of the Electrabel executive board.

The mission of this emergency management centre consists in:
- supporting the NPP with strategic decisions;

- ensuring the availability of extra financial, material and human resources;
- ensuring external communication and guaranteeing consistency with communication actions taken by the NPP;
- providing experts in specific fields (insurance, law, human resources management, maintenance, safety, etc.) to the NPP.

This centre is informed by the NPP's emergency director during the notification process. Depending on the nature of the event, the CMCPB will do its utmost to provide the support needed by the NPP. The NPP can also submit specific questions or requests (e.g. need for equipment or skilled staff) to the emergency management centre in order to lighten the management on site.

<u>Agreements with hospitals</u>

The Tihange NPP signed agreements with 5 hospitals:
- regional hospital centre in Huy;
- university hospital in Liège;
- cancer institute in Brussels;
- burn care centre in Loverval;
- French military hospital in Paris (Percy).

Those agreements cover the medical care of injured people (contaminated or not), should an incident at Tihange NPP happen.

The Doel NPP signed agreements with 2 hospitals:
- Middelheim hospital in Antwerp, in which 8 beds are permanently available and there is the possibility to evacuate the hospital so that its full capacity can be used;
- French military hospital in Paris (Percy).

<u>Technical assistance convention with Tractebel Engineering</u>

Tractebel Engineering provides technical support to the licensee in order to:
- help achieve a diagnostic;
- predict how the event will develop;
- give recommendations and propose actions;
- answer its questions.

A minimum cell is set up within 4 hours after the licensee's call.

<u>Support by contractors and other companies</u>

Many external companies are working every day on the NPP sites. Their personnel have specific skills and knowledge of the facilities that can prove useful in case of an incident or accident. Therefore, the emergency management team relies firstly on those professionals who know how to intervene on the site before calling upon companies without knowledge of the facilities.
Moreover, the licensee has concluded contracts with external companies for intervention or equipment supply, including responsiveness terms for urgent requests from the NPP. Some of these services include:
- supply and intervention on electrical wiring within 24 hours;
- fuel supply for diesel generators within 25 hours;
- decontamination of structures: 18 persons within 2 hours and 45 within 48 hours;
- scaffolding: 12 persons (per 2 hour-shift) within 24 hours;
- mechanical tasks and repairs: about 100 mechanics and 20 milling operators available within 2 hours;
- cranes supplied within 4 hours;
- boric acid supply within 15 working days;
- instrumentation repairs within 24 hours;
- chemical products supply within 12 to 48 hours (depending on the product);
- electrical motor repairs within 5 hours;
- ventilation repairs within 4 hours (1 technician);

- industrial gas supply within 6 to 12 hours (depending on the gas);
- power generators and cooling groups hiring: standard equipment within 24 hours (less if available in Benelux), reactor building ventilation equipment within 3 days;
- hiring of rapid deployment clearance equipment parked close to the NPP in order to guarantee access to the necessary means in emergency situation.

The licensee and ELIA (the operator of the high and very high voltage networks), are working in effective cooperation in case of problems affecting the external electrical grid.

<u>Support by public institutions</u>

The Royal Decree of 17th October 2003 sets forth that the Minister of Internal Affairs, with the licensee's cooperation, may mobilize and deploy all the civil and military resources to control or mitigate an emergency situation and take action to fight against the effects of the emergency situation inside the facility. In this respect, the institutions listed hereafter can provide technical support to the Tihange and/or Doel NPPs:

- the Scientific Institute for Public Health ("WIV-ISP");
- the Royal Meteorological Institute ("RMI");
- the Belgian Nuclear Research Centre ("SCK-CEN");
- the National Institute for Radioelements ("IRE");
- the Civil Protection;
- the police;
- the Army (the Amay military barracks are 8 km away from the Tihange NPP);
- the Hydrology Service of the Wallonia Public Services (for Tihange NPP);
- the Royal Observatory of Belgium;
- the University of Liege (ULg) and the University of Ghent;
- the regional fire brigade of Huy (Tihange) and the fire brigade of Beveren (Doel), located close to the NPPs; the licensee has signed specific conventions with these fire brigades, defining the modalities regarding training, communication, commanding of interventions and dosimetric aspects.

<u>Other resources</u>

The Transnubel company can charter a bus with driver within a short period of time and can provide transportation means for material and staff members.

If some of the abovementioned external services are unavailable, the NPP has some capabilities within its structure, such as vehicles and trailers with radiation protection measuring devices and fire fighting equipment.

An external care/decontamination centre in Wachtebeke (located at 45 km from the Doel NPP) provides the infrastructure for the detection and decontamination of people and vehicles, for food supply and for sleeping places.

6.1.1.4. Procedures, training and exercises

<u>Internal emergency plan procedures</u>

The internal emergency plan procedure describes the structure and organisation of the internal emergency plan for each NPP.
For the Tihange NPP, this procedure and its 58 associated procedures constitute the whole internal emergency plan. The Doel NPP disposes of 28 emergency planning procedures directly linked to the emergency plan and supplemented with several other procedures and documents (practical guidelines).
All of these procedures related to nuclear accidents are regularly updated.

Internal emergency plan training programs and exercises

Every person involved in the internal emergency plan receives initial training and periodic refresher training depending on his/her role. Training procedures define for each function or role which training program must be provided with regard to emergency responsiveness.
This training also includes periodic exercises.

NPP operating procedures

Shift crew can rely on specific incident and accident management procedures. When an anomaly occurs in the installations, the operating team first applies a set of incident management procedures to respond to the event. If these prove insufficient, accident management procedures are then implemented. Finally, if some criteria are fulfilled, these accident management procedures are replaced by severe accident management guidelines ("SAMG").

NPP operation training programs and exercises

Procedures describe job training programs for each department (operation shift crew, maintenance). Every staff member involved in the operation of the facilities (executives, shift crew teams) receives initial training and periodic refresher training depending on his/her role. Exercises are performed annually for each job.
In particular, licensed control room operators, shift supervisors and executives train on the simulator in the training centre during an annual two-week period for control room operators and shift supervisors and during an annual one-week period for licensed executives. This simulates virtual incidents or accidents to help them with the implementation of the relevant procedures.
For Tihange NPP, a two-day training period dedicated to the SAMG is provided to the operating shift crew, licensed executives and on-call executives. A refresher course must be completed every three years.
For Doel NPP, a one-day training period dedicated to the BK-procedures is provided to the operating shift crew, licensed executives and on-call executives. A refresher course must be completed every five years.

6.1.1.5. Plans for strengthening the site organisation for accident management

Among the resources involved in the internal emergency plan are the NPP's own personnel.
A solution is currently set up to ensure sufficient supervisory staff management in case of a multi-unit event, which in essence requires an ongoing mobilization of many engineers on the site.

6.1.2. Possibility to use existing equipment

In the event of a severe accident, the following means are essential:

- unborated water for injection into the steam generators;
- borated water for injection into the primary circuit of the reactor building;
- electricity to supply the vital pumps.

All the existing equipment on site can be used in order to restore potential failures, through particular equipment connexions where required. The SAMG guides describe how to use the existing equipment.

In case of unavailability or failure of this equipment, non-conventional means can be implemented. These devices were not considered when designing the units but are available on site.

6.1.2.1. Provisions to use mobile devices (availability of such devices, time to bring them on site and put them in operation)

Existing mobile equipment

If a beyond-design event occurs on the site of Tihange, non-conventional stationary or mobile equipment (CMU equipment), which is independent of the design basis equipment and facilities, can be used to fulfil the following functions:

- water supply for spent fuel storage pools in building D at all three units and in Building DE at Tihange 3;
- low-pressure feedwater supply for steam generators;
- emergency lighting;
- deployment of diesel generators to power the necessary equipment.

There are also mobile power generators available on the Doel site in order to feed the rectifiers alternatively using adapted connectors and cables. They will form a back up 380 V network. This way a longer period of "station blackout" can be covered while the measurements, signalization and control can be maintained. The electricity supply to the safety-related components (compressors, valves…) will be operated in the same way.
Doel 1/2 also has power generators to give an alternative power supply to the containment spray pumps.

Most of these mobile devices are already available in the installations and require only gas/power/water connection – using flexible hoses stored nearby the places where they are used – to be started.

Future (non-conventional) mobile resources

In the aftermath of Fukushima, a systematic analysis was performed to assess the needs for extra equipment. This analysis assumed a total loss of AC power and considered the different possible initial conditions of the units.
As a result, the equipment/devices that can be implemented to mitigate the consequences of such an extreme situation have been identified.
This analysis resulted for each unit in a timeline indicating in chronological order when an essential function is not guaranteed anymore without deploying extra resources. Considering this timeline, the licensee defined stopgap measures to compensate for the lost functions. It also determined when these stopgap measures shall be operational and which features are necessary to restore the functions.

For each device, the time between the occurrence of the event and the start of the device, as well as its necessary capacity, determine whether it must be installed permanently and ready to start, or if an on-site storage is sufficient or even if an external assistance can be considered to fulfil this function. In this last assumption, it is considered that an external assistance is only credible after 72 hours (period of time considered as sufficient to arrange access to the site and bring heavy machinery if necessary). Furthermore, non-conventional devices must be able to work, irrespective of the state of the other units on the site. The analysis included issues such as power supply or water and fuel stocks needed to guarantee this period of autonomy and independence.

These non conventional means will be compared to the ones defined in the extensive damage mitigation guidelines ("EDMG") developed by the Nuclear Energy Institute in order to take into account situations that would not have been included in the assumption of a total loss of AC power sources.
Some of the devices that have been identified and that are not available on site yet are being implemented. Other devices require a justification/feasibility study. They will be implemented in conditions ensuring optimal robustness against extreme external hazards (natural or not). An appropriate storing place for mobile devices will be sought. Stationary devices that have already been installed will be protected against hazards. If they are not sufficiently protected in the place where they are stored or installed, the devices shall be made inherently resistant to the hazards considered.

Once fully implemented, these devices will be integrated in accident management procedures and in SAMG guides so that they can be used correctly by the emergency response teams.

For the Doel NPP, the current emergency lighting units will be replaced by emergency lighting units with long autonomy (LEDs). Extra mobile lighting towers will also be bought.

6.1.2.2. Provisions for and management of supplies (fuel for diesel generators, water…)

The technical specifications mention the minimum supplies of gas oil and boric acid required to keep safety-related equipment operational in case of an accident (excluding severe accidents). As far as the emergency management related equipment is concerned, minimum supplies and availability requirements are specified in and verified through the relevant procedures.

At the Doel NPP site, a study is performed in order to provide the necessary connection points on the fuel storage tanks of the different reactor units, so that fuel can be transferred between the different tanks. There is a tanker truck on the site intended for the transportation of fuel throughout the site.

6.1.2.3. Management of radioactive releases, provisions to limit them

In case of a nuclear accident, all attention needs to be focused on:

- the leak tightness of the reactor building;
- the pressure decrease in the reactor building in case the reactor building is no longer leak tight;
- the deposit of iodine and aerosols by means of sufficient spraying;
- the water inventory in the reactor building;
- the water inventory in the spent fuel pools.

Potential radioactive releases in the environment are limited by:

- the highest specific activity allowed in the primary system in normal operation;
- the leak rates allowed for the primary system and the steam generator tubes;
- the containment leak rates.

Reactor containment design

If radioactivity is released into the reactor building, the containment and associated systems will ensure that the radioactive gases remain within the reactor building, so that no radioactive materials are released into the environment. As long as the radioactivity remains within the containment, radioactive decay plays an important role. Depending on the isotopes involved, the source term can already be reduced down to 5 to 25 % after half a day of retention.

All reactor units at Tihange and Doel have a double containment structure.
For all three Tihange units as well as for Doel 3 and Doel 4 units, the internal containment is made of pre-stressed reinforced concrete to bear pressure, with a metal liner on its inner surface to ensure leak tightness. For Doel 1/2 units, the internal containment is made of steel ensuring leak tightness.
For all units, an independent outer containment is made of reinforced concrete and is intended to collect and filter potential leaks from the internal containment.

The pressure level in the containment is monitored by several safety rated instruments (with back-up) measuring the absolute pressure. Some of them are used for measuring pressure levels corresponding to normal operation levels while others can monitor the pressure evolution up to 10 bars.

A containment spray system is used to limit the pressure peak in the containment resulting from a loss of coolant accident ("LOCA") or a leakage in the emergency cooling system and, in turn, to minimize the leak rate from the containment into the annulus space.
The internal ventilation will also help in decreasing the pressure in the reactor building.

The leak rate from the containment into the annulus space is measured at each refuelling outage. The leak rate for all the penetrations through the containment is verified in the same way.
Radioactivity measuring systems are installed in the different buildings, including the reactor building, and allow prompt detection of any leakage problem. Measuring systems also monitor activity releases at the ventilation stack of the nuclear auxiliary buildings. Procedures have also been set up to identify inter-system loss-of-coolant accidents ("ISLOCA").

A potential leak from the reactor building would flow into the annulus space. The annulus is kept under negative pressure (compared to the atmosphere) by ventilation systems equipped with filtration systems (absolute filters and carbon filters). Heating elements fitted on the exhaust branch of the ventilation keep gas humidity below a specific level in order to guarantee the efficiency of the filter banks.

In addition, Doel 1/2 units dispose of compressors in the annulus space designed to force the return of the gases back to the internal containment, and, by doing so, to keep the inventory – in the short term – as much as possible inside the reactor building.

Containment isolation

Each penetration through the containment is equipped with two leak-tight isolation systems in series that can be operated from the control room. They shut automatically if an anomaly is detected which requires the containment to be isolated from the outside environment. In case of a failure of these isolation systems, procedures require corrective actions to restore the situation.

Reduction of airborne contamination inside the reactor building

The filtration system of the reactor building consists of filters and carbon filters and is located inside the internal containment. It is intended to capture airborne radioactive products and iodine released in the containment building in case of an accident.
By spraying inside the containment building, the radioactive particles and the iodine are also captured in the water.
For all three Tihange units as well as for Doel 3 and Doel 4 units, it is possible to add a soda solution to the spray fluid in order to transfer airborne iodine into solution more efficiently, and then keep it in the reactor building sump water. In 24 hours, the containment spray system can dissolve and capture up to 99 % of iodine products that are present in the primary system and could be released in the containment.

Internal containment leakage monitoring

The containment's tightness is monitored periodically by pressure tests. These tests are performed at reduced pressure during each refuelling outage and at design pressure every ten years.

Other provisions

If any release of activity resulting from a fuel handling accident during core refuelling/unloading operations is detected by the radiation protection measuring systems installed in the reactor building or at the ventilation stack, the exhaust ventilation system of the pool building is switched into post-accidental configuration and the containment ventilation system is isolated.

In case of an accident in the nuclear fuel pools – with a 10 m water layer – the release of iodine and aerosols can be limited to 0.2 % of the source term.

The nuclear auxiliary buildings' basements dispose of a large storage capacity for potential liquid effluents so that a possible release to the environment can be postponed as much as possible.
Furthermore, all units are equipped with tanks for collecting and storing effluents and with processing systems intended to limit their volumes and activity.

Release calculation and assessment programs

A specific program can be used to calculate and predict the dispersion of potential radioactive releases in the environment. The correct management of potential releases is described in SAMG procedures.

6.1.2.4. Communication and information systems (internal and external)

There is a whole range of various and independent communication equipment and systems available at both sites to ensure minimum communication required in emergency situations.

Tihange NPP

Internal communication

a) The phone network includes normal phone lines connected to the Tihange NPP telephone exchange (4 hour autonomy, battery supplied) as well as an internal paging system via normal phone network. 16 emergency "genephones" – which do not require electricity – are also installed in the main staff gathering places, in the COS and in every COT. They are used in the event of a failure of the other communication media, in particular the telephone exchange.

b) A video line connecting the operation centre of each unit (COT) with the on-site operation centre (COS). This line is not connected to the telephone exchange.

c) The NPP is also equipped with a network of loudspeakers and an emergency siren, both with backed up power supply.

External communication

a) The phone network includes:

- normal phone network: a telephone exchange with 2 x 30 external lines towards Huy and Amay;
- 2 Electrabel private lines connecting the NPP with both Electrabel centres in Linkebeek and Schaerbeek. These lines are connected to the telephone exchange.
- direct lines connecting each of the three control rooms with the regional fire brigade. These lines are not connected to the telephone exchange.
- 17 Belgacom direct lines for emergency situations: 14 for the COS/COTs and 3 for the control rooms. These lines are not connected to the telephone exchange.
- Some extra lines, connected to the Belgacom network without being connected to the telephone exchange. The NPP's Manager, each of the Department Heads, and the shift supervisors on each unit dispose of one of these phone lines.

Possibilities for the emergency management team to make calls to the outside world include:

- automatic recall system for on-call managers (emergency call out system "ECOS");
- these on-call managers can be called in via two redundant systems that are not connected to the telephone exchange: through ASTRID pagers (messages can be sent via an Astrid radio using a governmental secured network) and individual mobile phones (Proximus network).

The installation of the REGETEL priority communication system connecting the external organisations involved in the emergency plan is currently in progress in Tihange (COS).

Furthermore, other wireless phones and radios are also available on site for internal and external communication. 13 wireless phones on another mobile operator (currently Mobistar) are available in the COS (4) and in each COT (3 per COT). 7 Astrid radios are installed in the COS (1), in the radiation protection vehicles (2), in the rooms of the first response teams (3) and in the CARA centre (1). Astrid mobile phones are compatible with the regional fire brigade communication network and with Astrid pagers.

Lastly, the Tihange NPP can also make use of 5 satellite phones in ultimate circumstances (unavailability of all the above mentioned communication media).

b) The video network includes:

- a normal line located in the COS and connected to the telephone exchange;
- a channel connecting the COS to the Governmental coordination and crisis management centre (CGCCR).

Doel NPP

Internal communication

a) Doel NPP has its own telephone network which is completely separate from the public Belgacom network. The network part situated on the nuclear power plant is fully battery supplied and has six-hour autonomy.
For the information of the site workers, the following devices are available:

- important messages from the emergency operations facility ("NPK") can be projected onto the tv screens of the meeting rooms;
- emergency planning interphones can also be used to connect the emergency operations facility and meeting rooms, operating rooms and radiation protection rooms on all four units, and the access building and guard's locations. There is also a connection with the medical services. The power supply of this system is guaranteed;
- public address is an internal speaker broadcasting system equipped with a siren.

In the Doel 3 and Doel 4 technical buildings, there is an autonomous telephone system ("genephones" which don't rely on electrical power supply or batteries). In the Doel 1/2 technical buildings, a GNS telephone system is available.

b) In the emergency operations facility and in the monitoring vehicles, cell phones are available for certain specific guard duty role members and for the emergency services.

c) There are also high-powered walkie-talkies.

External communication

a) There are several public and direct telephone lines – using the Belgacom network – for contact with the outside world. In order to guarantee the availability of both internal and external telephone lines, the emergency response facility system ("ERF") is used. This system will block all unnecessary outgoing phone calls in order to keep the lines available.

The phone network also includes:

- a REGETEL phone (independent of the Belgacom network) for contact with the authorities;
- cell phones; the cell phone coverage in the emergency operations facility and the on-site technical support centres is guaranteed;
- an ASTRID device for direct contact with the municipal fire brigade of Beveren;
- 5 satellite phones that can be used in case the communication infrastructure is unavailable.

The on-call members who are not present on the site can be called in via three independent systems: public phones, semaphones (ASTRID pagers) and person-to-person pagers (beepers).
The call is automatically operated via the ECOS system. In case the regular communication devices are unavailable, the emergency planning organization will use the public radio broadcasting system to call them in.

There are also Belgacom fax lines with backed up power supply in the emergency operations facility and the on-site technical support centres.

b) The video network includes a video conference device located in the emergency operations facility, for the communication with the National crisis centre and Electrabel corporate services in Brussels. The video conference system can also be used for the communication with the municipal crisis centre in

Beveren, with the COS in Tihange NPP, and with the crisis centres of the provinces of East Flanders and Antwerp.

c) The emergency plan transmitting system is a radio transmitter-receiver network, intended, in the first place, for the communication with the radiation monitoring vehicles.

6.1.3. Evaluation of factors that may impede accident management and respective contingencies

6.1.3.1. Extensive destruction of infrastructure or flooding around the installation that hinders access to the site, including communication systems

The internal management of damage to the installations is covered by the emergency organisation in place.

A number of buildings on the sites are bunkerised and can be used in case other buildings are destroyed.

The clearing of the internal infrastructure in the eventuality of major obstacles (collapsed pylons, holes in the roads, etc.) depends on the availability, in the immediate vicinity of the site, of suitable equipment (removal equipment, heavy handling devices) which can be used by in-house personnel as well as external operatives. These means are available via contracts or corporate support.

The infrastructure outside the site is not the responsibility of the plant licensee. However, the internal emergency plan includes coordination with the relevant authorities (ministries, provincial government, and army) that will undertake the required measures needed to re-establish appropriate access to the power plant site.

Should the Tihange area be affected by floods, access will always be possible through the main public roads. In particular, the road network at Tihange is at a higher altitude than the maximum flood level. The power plant is located at an altitude of 71.50 m while the surroundings reach more than 200 m. The location of the power plant in the immediate vicinity of the town of Huy means that the road network is dense and will always allow access to the site.

6.1.3.2. Impairment of work performance due to high local dose rates, radioactive contamination and destruction of some facilities on site

Tihange NPP

Current situation

In order to perform the operations necessary to manage a severe accident, the intervention is concentrated in the following locations: main control room, emergency control room, unit operation centre ("COT"), site operation centre ("COS"), other zones (e.g. electrical rooms in the "BAE" building or sampling rooms in case of local actions).

a) Habitable zone of each unit (control rooms, COT and related rooms)

In the presence of contamination on the site, existing procedures define a single access route to the "habitable zone" of each unit. This access consists of an airlock, equipped with a changing room, contamination measurement equipment, basic decontamination means and a stock of protective equipment. The purpose of these items is to prevent the transfer of contamination to the "habitable

zone" and to allow personnel leaving the zone to equip themselves according to the instructions issued by the radiation protection officers.
Concerning the other zones, the actions that may be called for in the first hours of a deteriorated situation will first be subject to analysis / evaluation in terms of dose intake / justification, depending on the circumstances of the accident.
Any operation involving equipment repair and sampling will only be initiated after a full assessment of the intervention conditions. This aspect will be managed by the crisis team, if necessary making use of the means and resources of the off-site fall-back centre (CARA).

b) Site operation centre (COS)

The COS is located in the site administration building, outside the flood-prone area, and its "habitable zone" is fitted with external air filtering equipment. In the presence of contamination on the site, existing procedures define a single access route to the COS "habitable zone". This access is equipped with a changing room, contamination measurement equipment and basic decontamination means designed to prevent the transfer of contamination to the "habitable zone". A single exit route is also defined with a stock of protective equipment allowing personnel leaving the COS to wear according to the instructions issued by the radiation protection officers.

c) Off-site fall-back centre (CARA)

As soon as the site contamination is confirmed by the radiation protection section, instructions are issued to the security officers to deny access to the site. Only individuals authorised by the crisis management team will be granted access to the site according to the instructions issued by the radiation protection officers.
In accordance with the internal emergency plan, all people not required on site by the crisis centre are evacuated, according to existing procedures, to a "fall-back base" known as “CARA”.

<u>Analysis of the robustness of the existing situation in relation to the initiating events and the scenarios studied</u>

a) Habitable zone of each unit (control rooms, COT and related rooms)

The habitable zone of each unit is located in a building that is resistant to degraded external conditions (particularly earthquake and flooding), but the ventilation systems will no longer be operational in case of station black-out. The re-powering by means of an autonomous diesel generator is under study.

b) Site operation centre (COS)

The location and current structure of the building housing the COS are not sufficient to guarantee perfect operating conditions when facing extreme external events (mainly earthquake). The COT of each unit is equipped to serve as a backup COS if the main COS is lost. The new access control building, currently under construction, will incorporate a new COS. Safe from flooding, resistant to the design basis earthquake, fitted with decontamination infrastructure, powered by a stand-alone generator and equipped with external air filtration devices, this new COS will be perfectly suited to perform its expected functions.
In case of loss or inaccessibility of the COS, a fall-back room is provided at the off-site centre (CARA).

c) Off-site fall-back centre (CARA)

The current CARA fall-back base is housed in buildings that are not resistant to a major earthquake. Moreover, it is located in a zone that can potentially be flooded in case of a 10 000-yearly flood. Furthermore, it is aligned under the prevailing winds at 12 km from the nuclear site. As a result, alternative solutions for another fall-back base will be analysed.

d) Adequacy of radiological monitoring in case of a serious accident

The COTs and COS are equipped with indicators and recorders associated to the monitoring channels of the liquid and gaseous effluents exhausts of the 3 units. Basic equipment for measuring radioactivity

is also provided in these rooms. Two vans, parked close to the COS, are also fitted to measure radioactivity on the field.
In case of radioactive contamination or excessive dose rate, the radioactivity monitors at the exit of the nuclear zone of a unit may become inoperative. As a result, control may be transferred to the monitors of the access building at the site entrance. However, no radioactivity monitoring will be operational if the electricity is cut off.
A more detailed analysis of the additional means required for radioactivity monitoring in case of a severe accident affecting several units will be initiated.

e) Intervention capability in case of destruction of some on-site installations

Apart from the fact that some of the buildings are "bunkerised" and could act as an on-site meeting and dispatching point if some installations are destroyed, some devices that can be used to clear the roads are available. However, the use of heavy equipment is planned only via contracts with companies in the vicinity of the power plant.

Doel NPP

Current situation

In order to perform the operations necessary to manage a severe accident, the intervention is concentrated in the following locations: main control room, emergency control room, annex control room, on-site technical support centres ("OTSC"), and site emergency operations facility.

a) Habitable zone of each unit (control rooms, annex control rooms)

In the presence of contamination on the site, existing procedures define a single access route to the "habitable zone" of each unit. This access consists of an airlock, equipped with a changing room, contamination measurement equipment, basic decontamination means and a stock of protective equipment. The purpose of these items is to prevent the transfer of contamination to the "habitable zone" and to allow personnel leaving the zone to equip themselves according to the instructions issued by the radiation protection officers. These living areas are equipped for a long stay, with a kitchen with a food supply and sanitary equipment (showers and toilet units).

b) On-site technical support centres (OTSC) and site emergency operations facility

The OSTC and the site emergency operations facility are equipped with a changing room, contamination measurement equipment, basic decontamination means and a stock of protective equipment. The purpose of these items is to prevent the transfer of contamination to the "habitable zone" and to allow personnel leaving the zone to equip themselves according to the instructions issued by the radiation protection officers. These living areas are equipped for a long stay, with a kitchen with a food supply and sanitary equipment (showers and toilet units).

c) External care centre

There is a location in the municipality of Wachtebeke, situated at 45 km from the site equipped as an external care centre for site workers. The domain disposes of the necessary intervention material for the monitoring of a possible contamination and the decontamination of vehicles and persons.

Analysis of the robustness of the existing situation in relation to the initiating events and the scenarios studied

a) Habitable zone of each unit (control rooms, annex control rooms)

These locations are housed in buildings resisting to extreme circumstances, but the ventilation systems will no longer be operational in case of a station black-out.

b) OTSC and site emergency operations facility

The emergency operations facility offers a good shielding, a protection against internal contamination and has a guaranteed power supply. The building in which the emergency operations facility is housed, is not seismically designed. The Doel 3 and Doel 4 OTSC functions as a backup for the emergency operations facility. The Doel 3 and Doel 4 OTSC has the same measuring equipment and facilities as the emergency plan dispatching room, but its shielding is less performant.

c) Off-site fall-back centre

A location needs to be found to function as an off-site fall-back centre during "high mode" emergencies (see later on). The training center Scaldis in Kallo could be used for this purpose.

d) Adequacy of radiological monitoring in case of a serious accident

The control rooms, annex control rooms, OTSC and site emergency operations facility are equipped with indicators and recorders associated to the monitoring channels of the liquid and gaseous effluents exhausts. Basic equipment for measuring radioactivity and contamination levels in these locations is also provided in these rooms. One monitoring van is available on site to measure radioactivity on the field.
In case of radioactive contamination or excessive dose rate, the radioactivity monitors at the exit of the nuclear zone of a unit may become inoperative. As a result, control may be transferred to the monitors of the access building at the site entrance. The monitors are provided with an alternate power supply in case of loss of electrical power
A more detailed analysis of the additional means required for radioactivity monitoring in case of a severe accident affecting several units will be initiated.

6.1.3.3. Feasibility and effectiveness of accident management measures under the conditions of external hazards (earthquakes, floods)

External aggressions associated with exceptional natural phenomena may simultaneously affect all units on the same site. In case of an accident affecting several units on the same site, a suitable crisis organisation must be set up rapidly. Before this multi-unit organisation is in place, the on-call staff will be distributed according to the needs of the coordination centres, and the crisis team will be made up as the personnel is available.

In the organisation of the internal emergency plan, three operational levels are defined:

- "standard" mode, with a single unit involved; in this case, the current organisation of the internal emergency plan remains applicable;
- "alert" mode, when a predictable crisis situation is likely to affect several units (e.g. a large scale flood); in this case, on-call managers and some technical officers will always be on standby on the site;
- "high" mode: when a non predictable crisis situation suddenly affects several units simultaneously on the same site (e.g. earthquake).

The organisation of the internal emergency plan of the site in "High" mode will be analysed and defined precisely.

For the first 24 hours following the appearance of such a sudden event ("High mode"):

- the first stage in the management of the accident will be handled by the shift crew plus the on-call staff. The crisis team will be activated to manage the situation. It may call on other on-call officers (not yet called on in the framework of the internal emergency plan). They will come into action as quickly as possible;
- the technical management of the accident is performed from the COT (Tihange NPP) and from the annex control room (Doel NPP) of each affected unit. With this in mind, the plan is to strengthen the on-call teams to ensure that the same crisis functions are activated as if the accident was affecting that unit alone;

- crisis organisation within the COS (Tihange NPP) and site emergency operations facility (Doel NPP) focuses on communication, the management of transverse problems on the site and logistics coordination;
- the structure of the Corporate emergency plan will be extended with the addition of a new safety role, the "liaison officer" who will take on-site responsibility for the communication between the crisis team and the Corporate team;
- the organisation and the available resources should be suited to the management of this type of sudden event of considerable dimensions, including the implementation of non-conventional means which may be called for in the first 72 hours.

After the first 24 hours following such a sudden event ("High mode"), the emergency organisation at site level will be able to rely on extended support from the Corporate structure ("CMCPB" – Crisis Management Centre Production Belgium) within 24 hours at latest after being activated. Via the CMCPB, an organisation structure will be set up depending on the precise situation on site and as a function of the events taking place. In this situation, the safety "liaison officer" will be responsible for the communication between the site in question and the Corporate structure.

The organisation structure that will be set up to undertake the crisis management after the first 24 hours will comply with the following principles:

- a single crisis manager located on site at the COS (Tihange NPP) and site emergency operations facility (Doel NPP);
- the technical management of each unit will operate from the COT (Tihange NPP) and annex control room (Doel NPP) with the support of the on-call staff provided;
- support functions will be supplied by the Corporate structure;
- should reinforcements be required at the site, they will be supplied via the Corporate structure according to the needs (e.g. experts).

The support functions that the Corporate structure can provide will be, among others, logistics, radiological support, human factors, long term planning, communication matters…

An analysis of the exact organisation of the Corporate structure as well as the associated human and technical resources is planned.

In order to allow the Corporate structure to perform its duties as efficiently as possible under those circumstances, the following re-assessments will be initiated:

- the adequacy of the current infrastructure, particularly the off-site fall-back base;
- the performance of the communication media, particularly external communication;
- the software for calculating radiological consequences.

6.1.3.4. Unavailability of power supply

The design basis of the units takes account of the complete loss of external and internal electrical power supplies. The procedures for managing accidents and severe accidents are planned so as to incorporate this factor in the operation of the facilities.

6.1.3.5. Potential failure of instrumentation

The accident and severe accident procedures are based on a limited number of parameters which are monitored by safety rated instrumentation. During the implementation of accident and severe accident procedures, a permanent connection between the shift crew and the emergency management team is established. The physical parameters measured represent an important part of this interchange. An assessment of the validity of the parameters supplied is performed to ensure there is no malfunction.

In the highly unlikely hypothesis that all instrumentation is down, necessary actions will be assessed and carried out on the basis of calculation tools and graphs implemented by the crisis management team. A procedure designed to restore power from one protective system to another, in the case of a failure likely to affect the instrumentation, will be drawn up. It will take account of the various voltage levels of 6 and 6.6 kV, 380 V, 115 VDC, 220 VAC.

In the case of loss of all internal power sources (highly unlikely given the considerable amount of back-up sources), procedures exist in each unit where, by means of portable stand-along devices, the signals from each instrumentation channel can be detected and measured. This ensures that the measurements necessary for the management of the crisis remain available under all circumstances.

The non conventional means available at Tihange 2 and Tihange 3 units allow a restoration of instrumentation power by means of a stand-alone electricity generator.

6.1.3.6. Potential effects from the other neighbouring installations at site, including considerations of restricted availability of trained staff to deal with multi-unit, extended accidents

The possible external aggressions were considered in the design of the units. One topic of the periodic safety review examined the risks for a unit related to the presence of the other units on the site and the dangers related to toxic substances; all the assessed situations are covered in the design basis.

6.2. Loss of core cooling: accident management measures in place at the various stages of a scenario of loss of core cooling function

Above all, the management of a severe accident consists in restoring fuel cooling by all available means, while monitoring the risk associated to hydrogen. If the extent and/or the combination of the aggressions still lead to a partial or total meltdown of the fuel, the actions undertaken are intended to maintain (or to re-establish) the integrity of the safety functions. The aims are then to avoid or limit potential releases of radioacivity into the environment, and to stabilise the containment and the core.

6.2.1. Before occurrence of fuel damage in the reactor pressure vessel

Tihange NPP

<u>Strategy of the accident management procedures before switching to the severe accident management guidelines</u>

For Tihange 1, the response strategy to a loss of cooling of the primary circuit is based on the approach developed by Framatome (designer of the primary system of the unit), via a set of procedures developed during the 1980s and reviewed on a regular basis. The updating of the original procedures is currently handled by the "FROG" (FRamatome Owner Group).
Depending on the initial state of the unit at the time the problem occurs, a suitable response is made. These initial states are grouped into two categories. The first category includes the states from the full power operation down to intermediate shutdown (shutdown cooling system not connected). The second category covers the other states: temperature of the primary system lower than 177 °C, shutdown cooling system connected and primary circuit closed and vented.
For Tihange 2 and Tihange 3, the strategy is based on the approach developed by Westinghouse via the "ERG" (Emergency Response Guidelines) procedures developed during the 1980s and reviewed on a regular basis. The original procedures are now updated by the "WOG" (Westinghouse Owner Group).

<u>Strategy for preventing core damage</u>

In order to be able to cool the nuclear fuel at all times, the presence of a primary coolant and a heat sink are required:

- the primary coolant can be supplied via the safety injection injection paths (high and low pressure);
- the heat sink can be ensured as follows: making use of the steam generators to blow off steam into the atmosphere via steam release to the condenser or to the auxiliary feedwater turbopump.

<u>Strategy for depressurizing the primary circuit</u>

At Tihange 1, excess pressure in the primary circuit reduces the possibility of makeup to the primary circuit in the first stage of the accident and complicates the management of the accident in general. It is possible to reduce this pressure by the following means, depending on their availability: cooling of the primary circuit by the steam generators, normal spraying of the pressurizer if the primary circuit pumps are operational, auxiliary spraying using the charging pumps, opening one of the SEBIM assisted relief valves on the pressurizer.
At Tihange 2 and Tihange 3, it is possible to reduce the pressure by the following means, depending on their availability: cooling of the primary circuit by the steam generators, normal spraying of the pressurizer if the primary circuit pumps are operational, auxiliary spraying using the charging pumps, opening one of the pressurizer relief valves, second level spraying using the emergency injection circuit ("CIU") pumps.

Doel NPP

Strategy of the accident management procedures before switching to the severe accident management guidelines

For the Doel units, the strategy is based on the approach developed by Westinghouse via the "ERG" (Emergency Response Guidelines) procedures developed during the 1980s and reviewed on a regular basis. The original procedures are now updated by the "WOG" (Westinghouse Owner Group).

Strategy for preventing core damage

In order to be able to cool the nuclear fuel at all times, the presence of a primary coolant and a heat sink are required:

- the primary coolant can be supplied via the safety injection injection paths (high and low pressure);
- the heat sink can be ensured as follows: making use of the steam generators to blow off steam into the atmosphere via steam release to the condenser or to the auxiliary feedwater turbopump.

Strategy for depressurizing the primary circuit

Excess pressure in the primary circuit reduces the possibility of makeup to the primary circuit in the first stage of the accident and complicates the management of the accident in general. It is possible to reduce this pressure by the following means, depending on their availability: cooling of the primary circuit by the steam generators, normal spraying of the pressurizer if the primary circuit pumps are operational, auxiliary spraying using the charging pumps, opening one of the pressurizer relief valves, second level spraying using the emergency injection circuit pumps (RJ or EA systems).

6.2.2. After occurrence of fuel damage in the reactor vessel

Tihange NPP

If the accident procedures intended to prevent damage to the core described above are insufficient to face the event, and once the core exit temperature suggests core damage, the use of the severe accident management guidelines ("SAMG") is decided.

The SAMG are based on an approach focusing on the symptoms of the state of the power plant (symptom based) and are therefore valid for all scenarios that may lead to one of the entry criteria for the severe accident management guidelines (high core exit temperature or radioactivity within the containment building).

The different strategies developed in the SAMG all pursue the same goals (in order of priority):

- to stop the releases of fission products into the environment;
- to maintain the containment building in a stable and controlled state, or bring it back to that state;
- to bring the core back to a stable and controlled state.

If core cooling is lost and the core is damaged, the strategies developed in the Tihange guidelines to restore cooling before the rupture of the reactor vessel, and to reach a stable and controlled state in the core, are the following:

- injecting water into the steam generators to evacuate residual power;
- depressurizing the primary circuit to maximise the number of systems capable of injecting water into it;
- injecting water into the primary circuit;
- injecting water into the containment building to guarantee an adequate NPSH to start the recirculation phase.

Doel NPP

If the accident procedures intended to prevent damage to the core described above are insufficient to face the event, and once the core exit temperature suggests core damage, the use of the "BK-procedures" is decided (BK-procedures are the equivalent of SAMG at the Doel NPP).

The BK-procedures are symptom based; in other words, they are drawn up according to the state of the unit. They apply to all scenarios attaining the entrance criteria of the BK-0 procedure: high core exit temperature and a specific criterion in case the thermocouples at the core exit are unavailable during an outage.

The different strategies developed in the BK-procedures all pursue the same goals (in priority order):
- to stop the releases of fission products into the environment;
- to maintain the containment building in a stable and controlled state, or bring it back to that state;
- to bring the core back to a stable and controlled state.

If core cooling is lost and the core is damaged, the strategies developed in the BK-procedures to restore cooling before the rupture of the reactor vessel, and to reach a stable and controlled state in the core, are the following:
- injecting water into the steam generators to evacuate residual power;
- depressurizing the primary circuit to maximise the number of systems capable of injecting water into it;
- injecting water into the primary circuit;
- injecting water into the containment building to guarantee an adequate NPSH to start the recirculation phase and to flood the reactor pit beneath the reactor vessel.

6.2.3. After failure of the reactor vessel

Tihange NPP

In case of a loss of core cooling with damage to the core, the strategies developed in the Tihange guidelines to restore core cooling after the rupture of the reactor vessel, and reach a stable and controlled core state, are the following:
- injecting water into the containment building to guarantee a sufficient NPSH to start the recirculation phase;
- injecting water into the reactor pit, to cool down the core debris present in the reactor pit and those remaining in the reactor vessel.

Doel NPP

If the reactor vessel is perforated, it is possible that part of the nuclear fuel is still present in the reactor vessel, in the core and/or on its way to the bottom of the reactor vessel. Therefore, the BK procedures will always specify injection into the primary circuit so that the fragments which are not relocalised in the reactor pit can be cooled, but also that water is brought to the reactor pit via the perforation of the reactor vessel.

Water needs to be supplied to the reactor building, in the first place in order to immerse the reactor pit, increasing the possibility of cooling the core material and, secondly, to increase the water level which, in turn, will enable recirculation.

6.2.4. Cliff-edge effects and timing

To identify any possible cliff-edge effect following the loss of core cooling, two initial situations are considered: in the first case, the primary circuit is closed, and the residual heat is then evacuated by the steam generators. In the second case, the primary circuit is open to the containment building (shutdown states). The consequences of the loss of electrical sources and/or heat sinks are covered by the hypothesis of a complete station black-out (SBO) in the most unfavourable configuration of the unit.

Tihange NPP

Primary circuit closed

This first case is covered by the full power operation state of the unit (most unfavourable situation). Following the complete loss of electrical power, only the turbopump of the safety / auxiliary feedwater system (respectively "EAS" at Tihange 1, and "EAA" at Tihange 2 and Tihange 3) remains available in the short term to feed water into the steam generators. This configuration is characterised by high pressures and temperatures in the primary and secondary circuits, by the evacuation of the secondary steam via the atmosphere discharge valves ("VDA") or the safety valves of the steam generators, and by insufficient cooling of the seals of the primary circuit pumps that could lead, in the short term, to limited primary leakages.

The main limitation encountered is the depletion of the water in the "EAS" / "EAA" tanks. At Tihange 1, the volume of 120 m^3 only allows cooling of the primary system by the steam generators for 3 hours (until the steam generators are completely empty) if the station black-out occurs suddenly, and only for 7 hours if the accident is progressive and the total loss of electrical supply happens one hour after the reactor emergency shutdown. Non-conventional means are available to re-supply water in the "EAS" tank via the fire protection circuit. The diesel-powered pump of the fire protection circuit and the fitting of hoses allow this tank to be refilled in a short period of time (30 minutes). Feasibility studies will be initiated to examine the possibilities of increasing the capacity of the EAS tank at Tihange 1. A feasibility study for the addition of a safety water supply pump to the steam generators will also be undertaken.
At Tihange 2, the "EAA" tank is 680 m^3 and allows the feeding of the steam generators during 17 hours. At Tihange 3, the "EAA" tank is 800 m^3, which is sufficient to feed the steam generators during 23 hours.

To prevent damage to the seals of the primary circuit pumps, it is recommended to depressurise the primary circuit during the first hours following the accident. However, for Tihange 2 and Tihange 3 this is not clearly stated in the procedures. A modification to the procedures to clarify this is ongoing.

After the manual opening of the atmosphere discharge valves (VDA) and the depressurization of the primary circuit, the operator must manage the risk of injecting nitrogen from the safety injection system ("CIS") accumulators into the primary circuit by the manual actuation of these valves (the installation of manual controls on these valves should ease their setting – the feasibility study will be undertaken). In order to avoid deterioration of the heat transfer from the primary circuit to the secondary circuit, the pressure in the primary circuit must be kept above the threshold of nitrogen injection of the CIS accumulators. Secondary pressure must also be maintained compatible with the satisfactory operation of the feedwater turbopump.

When the batteries of the command and instrumentation panels are low (around 7 hours after the start of the accident for Tihange 1), the turbopump stops and water makeup at the steam generators is lost. Alternative means to recover control of the turbopump are required to prevent loss of core cooling. If this does not occur, the steam generators are expected to dry out within around 12 hours after the loss of power.
For Tihange 2, the batteries get low between 6 and 12 hours after the accident, while it takes from 7 to 14 hours for Tihange 3. When this happens, the turbopump velocity and the water flowrates to the steam generators must be set manually. At this time, the readings of the water level inside the

steam generators are lost, and hence the operator must have set a correct flowrate beforehand or this could eventually lead to the drying or overfilling of the steam generators.

However, this complete loss of electrical power is extremely unlikely, since it would imply that:
- all external electrical power sources have been lost;
- all (first and second level) internal electrical power sources have also been lost.

In the unlikely case of the loss of cooling by the steam generators, the primary circuit begins to boil and its pressure rises to the opening threshold of the pressurizer relief valves or the VDA discharge valves. The primary circuit steadily loses its water content which then leads to the uncovering and then to the meltdown of the fuel, the relocation of the corium towards the bottom of the reactor vessel and finally the piercing of the bottom of the reactor vessel. In the absence of any action from the operator, this process takes between 2 and 3 hours.

The operator is instructed by the accident procedures or the SAMG guides at the moment of the loss of cooling by the steam generators to depressurize the primary circuit and thereby to facilitate injection into the primary circuit and initiate primary circuit "feed and bleed". The opening of the SEBIM pressurizer relief valves ("PORV" and "MORV" valves at Tihange 2 and Tihange 3) results in the depressurization of the primary circuit, which allows the inventory of the accumulators to be passively injected. This action may slow down the progress of the accident by several hours. During this time, it is necessary to recover the active equipment or to deploy mobile equipment allowing for water injection into the primary circuit.
In order to increase the reliability of the SEBIM / PORV-MORV valves, an alternative electricity supply for their instrumentation and control will be studied.

The non conventional means ("CMU" circuit) are also available to feed the steam generators when they are at low pressure.

<u>Primary circuit open</u>

This case covers a wide number of configurations of the primary circuit which differ considerably according to the amount of residual heat and the water inventory of the primary circuit (including the volume of the reactor building pools). The least favourable situation is the first stage of a unit shutdown known as "mid-loop" or "reduced inventory". This configuration appears on average 5 days for Tihange 1 and 3 days for Tihange 2 and Tihange 3 after the beginning of the shutdown operations. It combines a reduced water inventory in the primary circuit with still relatively high levels of residual heat in the core. After the total loss of electrical power, the primary circuit water heats to boiling point in a period of less than half an hour followed by the release of the produced steam into the containment building. This steam release is likely to have the potential effect of causing a steady rise of pressure in the containment building, ultimately preventing the gravity-fed makeup to the primary circuit if nothing is done to depressurize the containment building.

At Tihange 1, the gravity-fed makeup from tank "B01Bi" is efficient and may delay the uncovering of the core for one day. If no action is taken, core meltdown may happen after one day.

At Tihange 2, the gravity-fed makeup of "CTP" tanks may delay the uncovering of the core for 8 hours.

At Tihange 3, the gravity-fed makeup to the depressurized primary system is not possible via the "CTP" tanks because they are located at a lower level than the primary loops. This peculiarity of Tihange 3 means that the deterioration of the core cooling is faster than in other units: unless the primary system is actively refilled, core meltdown would occur within 3 hours after the beginning of the accident (although the situation is still highly unlikely). A feasibility study is initiated to set up a primary system refilling system in this configuration.

Refilling B01Bi or CTP tanks from various water sources (partial drainage of the pools, "CAB" or "CEI" reservoirs) will extend the autonomous functioning of B01Bi or CTP tanks until recovery of a conventional cooling source.

By means of the CMU circuit fitted with hose connections, it is also possible to establish a water makeup system to the B01Bi and CTP tanks.

The steady pressurization of the containment building could be avoided by the creation of an outlet. For Tihange 1, the ventilation system ("VBP") also limits the pressurization by discharging the steam outside the containment buidling.

In the configuration where the reactor building pools are full, the time before uncovering of the fuel assemblies is estimated at five days for Tihange 1, and at least three days for Tihange 2 and Tihange 3 in the least favourable case (that is, in the absence of a connection between the reactor building pools and the one of the nuclear auxiliary building). This period of time is enough to deploy an alternative cooling / makeup strategy.

Doel NPP

Primary circuit closed

This first case is covered by the full power operation state of the unit (most unfavourable situation). Following the complete loss of electrical power, only the turbopump of the safety / auxiliary feedwater system (AFW for Doel 1/2, AF for Doel 3 and Doel 4) remains available in the short term to feed water into the steam generators. This configuration is characterised by high pressures and temperatures in the primary and secondary circuits, by the evacuation of the secondary steam via the atmosphere discharge valves or the safety valves of the steam generators, and by insufficient cooling of the seals of the primary circuit pumps that could lead, in the short term, to limited primary leakages.

In these circumstances, the accident procedure prescribes the cooling of the primary circuit as fast as possible in order to limit the pressure on the seals of the primary circuit pumps. The cooling of the primary circuit and the evacuation of the residual heat leads to a considerable water consumption by the AFW/AF circuit.

For Doel 1/2, after one and a half hour the first cliff edge effect appears: the emptying of the AFW reservoirs (2 x 90 m^3), after which the steam generators can still continue cooling the primary circuit for several hours.
After this, alternative water supply to the steam generators is available:

- a diesel fuel pump and temporary pipe lines are present to fill the AFW tank from the large MW tank;
- a study is ongoing to provide nozzles for the supply of water from the fire extinguishing circuit (FE) to the AFW turbopump's intake;
- a study is ongoing to seismically qualify the piping required for conveying the FE water to the AFW pump.

For Doel 3 and Doel 4, the large content of the AF reservoirs (minimum 700 m^3) allows a supply during 8 hours, after which the steam generators can still continue cooling the primary circuit for several hours.
Furthermore, alternative water supply to steam generators is available:

- the AFW turbopumps can perform the direct intake from the LU pond;
- a study is ongoing to provide nozzles are installed for the supply of FE water to the AFW turbopumps' intake;
- a study is ongoing to seismically qualify the pipes required for the purpose of conveying the FE water to the AFW pump.

As soon as the AFW/AF tank's supply problems are solved, the pressure on the seals of the primary circuit pumps will be the next priority. The prescribed primary circuit's cooling and pressure decrease up to 12 bars reduces the pressure on the seals considerably. As soon as this pressure is reached (after several hours), manual intervention is needed to stop the cooling at the level of the atmospheric relief valves in order to prevent nitrogen injection into the primary circuit by the safety injection accumulators and loss of the feedwater turbopump. In the steam generators' cooling procedures, attention will be drawn to the possibility of manually opening the steam generators' relief valves.

The loss of direct current to the instrumentation and control devices (due to empty batteries) will not lead to the loss of the feedwater turbopump function, since the flow rate can be adjusted manually, but, it will lead to the loss of an overview of the accident's progress.
The first concern will then be the empty-boiling or overfilling of the steam generators due to the absence of information about the level. This scenario can occur 10 hours (Doel 1/2) or from 4 to 6 hours (Doel 3 and Doel 4) after a station black-out. A back-up 380 V network will be provided in order to feed the batteries' rectifiers alternatively.

In the unlikely case of a loss of cooling by the steam generators, the primary circuit begins to boil and its pressure rises to the opening threshold of the pressurizer relief valves or the VDA discharge valves. The primary circuit steadily loses its water content which then leads to the uncovering and then to the meltdown of the fuel, the relocation of the corium towards the bottom of the reactor vessel and finally the piercing of the bottom of the reactor vessel. In the absence of any action from the operator, this process takes between 2 and 3 hours.

The operator is instructed by the ERG and BK-procedures at the moment of the loss of cooling by the steam generators, to depressurize the primary circuit and thereby facilitate injection into the primary circuit and initiate primary circuit "feed and bleed". The opening of the pressurizer relief valves results in the depressurization of the primary circuit, which allows the inventory of the accumulators to be passively injected. This action may slow down the progress of the accident by several hours. During this time, it is necessary to recover the active equipment or to deploy mobile equipment allowing for water injection into the primary circuit.
In order to increase the reliability of the SEBIM / PORV-MORV pressurizer relief valves, an alternative electricity supply for their instrumentation and control will be studied.

For Doel 1/2, electrical cables are provided for the alternative supply of the containment spray pumps (SP) by using power generators. This way, in the case of an open primary circuit, the possibility will exist to convey water to the shutdown cooling system (SC) via the SI-SP connection by using the SP spray in the reactor building. In order to be able to perform this action with a closed primary circuit, a manual isolation valve will be installed on the spray line (study ongoing).
For Doel 3 and Doel 4, a study is being conducted to install external nozzles on the SP pumps enabling a mobile pump to achieve an alternative SP flow which can be aligned to the primary circuit.

Primary circuit open

This case covers a wide number of configurations of the primary circuit which differ considerably according to the amount of residual heat and the water inventory of the primary circuit (including the volume of the reactor building pools). The least favourable situation is the first stage of a unit shutdown known as "mid-loop" or "reduced inventory". It combines a reduced water inventory in the primary circuit with still relatively high levels of residual heat in the core. After the total loss of electrical power, the primary circuit water heats to boiling point in a period of less than half an hour followed by the release of the produced steam into the containment building. This steam release is likely to have the potential effect of causing a steady rise in pressure in the containment building, ultimately preventing the gravity-fed makeup to the primary circuit if nothing is done to depressurize the containment building.

At Doel 1/2, the gravity-fed makeup from tank "R11" may delay the uncovering of the core for several hours. At the start of an outage, when the reactor is stopped for only 1 to 3 days, this delay is between 12 and 18 hours.
For Doel 1/2, electrical cables are provided for the alternative supply of the SP pumps by using power generators. This way, in the case of an open primary circuit, the possibility will exist to convey water to the SC circuit via the SI-SP connection by using the SP spray in the reactor building.

At Doel 3 and Doel 4, the gravity-fed makeup from the RWST is efficient and may delay the uncovering of the core for several hours. At the start of an outage, when the reactor is stopped for only 1 to 3 days, this delay is between 10 and 18 hours.
For Doel 3 and Doel 4, a study is being conducted to install external nozzles on the SP pumps enabling a mobile pump to achieve an alternative SP flow which can be aligned to the primary circuit.

6.2.5. Adequacy of current accident management and possible additional measures

6.2.5.1. Severe accident management procedures

Tihange NPP

The mitigation measures currently in place to cope with a loss of core cooling and to protect the integrity of the containment are described in the accident procedures as well as the SAMG guides. These texts cover the various stages of the accident and take account of the various possible initial states of the units.

The Tihange emergency operations procedures ("EOP") are based on the standard procedures from Framatome-EDF or from the WOG. These documents were subjected to an independent assessment by the designer before they were put into application.
Likewise, the specific procedures of second level systems for Tihange 2 and Tihange 3 were assessed by Westinghouse, before being put into application during the commissioning of Tihange 3, or during the change (FROG approach to WOG approach) for Tihange 2 at the end of the 1980s.

Each procedure is linked to an operating rule (Tihange 1 unit) or an operating basis (Tihange 2 and Tihange 3). This operating basis / rule connects the generic documentation to the procedures that are specific to the unit, and details the basic principles which led to the procedure (evolution of the parameters and justification of the philosophy).

The Tihange SAMG guides consist of an adaptation for each unit of the generic Westinghouse Owners Group (WOG) guides issued in 1994, which were validated when published.

In the framework of the periodic safety review, the first Tihange SAMG guides and the strategies developed therein were validated through various severe accident scenarios. The guides revealed to be free-standing with no need of any additional tool to help decision making. Some minor corrections and improvements were also suggested.
In addition, a number of topics were subjected to an analysis that led to slight improvements which did not question severe accidents management as planned in the current SAMG guides.

The multiplicity of means available to implement the various strategies represents a strong point of the Tihange SAMG guides. In order to further improve the management of a possible severe accident and to better control the risk of a loss of integrity of the containment building by slow overpressure, a decision was taken to initiate a feasibility study for filtered vents on the reactor building of every Tihange unit.

As a complement to the work already carried out in the framework of the periodic safety review, the decision was taken to continue monitoring international research and development about basemat alteration due to corium-concrete interaction. This R&D is currently, and will continue to be, actively monitored. In parallel, a feasibility study about the use of an additional method of injecting water (in addition to all the methods already existing) will be initiated. The international feedback from the Fukushima accident, and all new revisions of the WOG SAMGs, will be considered and applied if necessary, according to the international recommendations of those from the WOG.

The introduction of new non-conventional means implies indeed that these resources will have to be integrated into the accident procedures and the severe accident management guides.

Doel NPP

The mitigation measures currently in place to cope with a loss of core cooling and to protect the integrity of the containment are described in the ERG procedures and BK procedures. These texts cover the various stages of the accident and take account of the various possible initial states of the units.

Each ERG procedure for a Doel unit is accompanied by a background document. This document links the generic ERG procedures of the WOG with the specific ERG procedures per unit. This way, insight is gained into the similarities and differences with regard to the generic ERG procedures and, where necessary, explanatory remarks can be given.

The Doel BK procedures are inspired by the philosophy of the Westinghouse Owners Group (WOG) Severe Accident Management Guidelines (SAMG), further completed with specific procedures. The Doel 3 and Doel 4 BK-0 and BK-1-procedures have been verified by the regulatory body. These procedures are similar for Doel 3 and Doel 4 and Doel 1/2, which implies that the regulatory body's remarks and answers apply to all four units.

The BK procedures (and the strategies developed in them) were validated during the periodic safety reviews of Doel 1/2 and Doel 3 and Doel 4.

The introduction of new non-conventional means implies indeed that these resources will have to be integrated into the accident-procedures and the BK procedures. The necessary instructions for the use of these non-conventional means will be integrated into the procedures.

6.2.5.2. Availability and adequacy of the instrumentation

According to the emergency procedures (EOP for Tihange, ERG for Doel), the post-accidental monitoring systems ("PAMS") are used to manage the accident. These monitoring systems were validated to resist design basis accidents conditions. They supply information that may be confirmed by all other valid systems.

The SAMG guides (Tihange) and BK procedures (Doel) include diagnostic guides which call for the use of a limited number of key parameters representing the different strategies and whereby severe accidents can be managed. They are as follows:

- core exit temperature;
- pressure in the primary circuit;
- water level in the steam generators;
- pressure in the containment building;
- water level in the containment building sumps;
- dose rates on the site;
- hydrogen concentration in the containment building (Doel NPP).

There is no provision for monitoring hydrogen concentration in the containment in the Tihange SAMG guides, as passive autocatalytic recombiners limit the average concentration in the containment building at less than 5 %.

The implementation strategy in the SAMG guides and BK procedures is intended, among other things, to minimise the risk of damage to the equipment and instrumentation under severe accident conditions.

At the international level, the WOG generic SAMGs approach is seen as adequate with respect to the needs and capacities of the instrumentation. Indeed:

- the analyses carried out have shown that instrumentation that has been conservatively qualified for design accidents can remain operational under severe accident conditions, as accuracy requirements are reduced;
- the redundancy and the existence of alternative measurements for obtaining the necessary information on the key parameters reinforces the capacities of the existing instrumentation;
- it has been shown that it is not necessary to have an exact picture of the accident and the way it is progressing, and that a limited number of key parameters is sufficient to correctly manage a severe accident.

This adequacy was established by a work carried out during the 1990s by the CSNI (Committee on the Safety of Nuclear Installations) concerning the use of the instrumentation to manage severe accidents. This work quotes as an example the approach adopted in the Tihange SAMG guides.
This approach was also validated at the Belgian level during the periodic safety review.

The international feedback following Fukushima accident with respect to instrumentation, and any review of the WOG SAMGs approach on this matter, will be examined and implemented if necessary, in line with WOG and international recommendations.
Monitoring hydrogen concentration in the reactor buildings will be implemented in the Tihange SAMG guides, to ensure that no risk due to the presence of hydrogen in the next buildings exists.

6.2.5.3. Availability and habitability of the control room

Tihange NPP

For all three units, the ventilation and air-conditioning of the main control room and the COT are controlled by the CSC system (two backed up redundant trains). Specifically, this ventilation / air-conditioning circuit covers the control rooms, as well as some rooms in the electrical auxiliary building (BAE).

The purpose of this system is to:

- keep ambient conditions within the limits defined and ensure the comfort of the occupants and the proper functioning of the equipment;
- ensure the habitability of the control room and the COT zones by isolating them in the case of accidents such as a radioactive contamination of the site, or the release of fumes or toxic / explosives gases on the site.

The system mainly consists of two redundant air-conditioning units, with mutual back-up: one can be used as an emergency unit if the other one fails. Absolute filters and activated charcoal filters are fitted inside the ventilation ducts on the external air intake. Identical batteries are also fitted for the internal filtering of the control room and the COT.

In case of radioactive contamination on the site, the transition to the "isolated control room and COT" configuration is triggered either by the safety injection signal (for Tihange 2 and Tihange 3) or by the "high radioactivity at external air intake plenum" signal (for all three units). In this case, the atmosphere of these zones switches to "recirculation" mode, with no intake of unfiltered external air.
A temporary makeup of filtered air ensures the pressurization and air renewal of the control room and the COT.

The design of the various filter banks allows uninterrupted operation for 720 hours under the conditions of the design basis accident (loss of coolant accident with sealed containment building). In case of a complete SBO, the ventilation is shut down and the equipement switches to the safe position (isolation of the control room and COT). The operators can manage the subsequent operations by using filter masks if necessary. Masks with appropriate filter cartridges (dust, iodine), as well as stand-alone compressed air respirators, are available in the units. The available quantities are adequate to meet needs in case of an accident with radiological consequences.

In addition to the main control room, Tihange 2 and Tihange 3 units are equipped with an emergency control room (BUS) where the ventilation / air conditioning circuits are composed of three stand-alone systems.
In case of an off-site accident causing a leakage of radioactive products on the site or the contamination of the site by gases, explosives, fumes or vapours, this system should ensure the habitability of the control room and isolate one or more air intakes.
In case of an explosion outside the building, it will protect the equipment from the blast wave. In case of fire, it will restrict the spread of the fire and smoke.

To protect the operators from radioactive iodine, stable iodine tablets are provided at various locations throughout the site (assembly points, unit operations centres, first aid team rooms, medical section).

In case of a severe accident with core damage combined with a station black-out, the ventilation of the control room will be lost. Habitability conditions will be monitored by the emergency team to ensure the strict compliance with dosimetry limits and the suitability of the systems implemented to limit the dose intakes. The rotation of the operators will help limit the individual doses. Reinstating the ventilation of the control room is a priority task in order to limit the doses to the operators.

Doel NPP

The ventilation system (VP) in the Doel 1/2 main control room consists of one or two ventilators, each with a 100 % capacity. The air is cooled with CF and refreshed by an injection ventilator. The control room also disposes of four separate and autonomous air cooler sets (4 x 50 %).

In the case of an internal accident, the ventilation will isolate automatically. The safety ventilators (2 x 100 %) with their filter banks (prefilter, absolute filter, activated charcoal filter) will become operational at that moment. They are supplied by the safety diesel generators. The filter batteries have a 720 hour standby capacity.

In case there are problems at a neighboring installation, the ventilation will isolate automatically when detecting ionizing radiation. The access doors are kept closed so as to prevent contamination. The operators can also manually seal the ventilation from the outside air.

The personnel of the Doel 1/2 control room has the possibility to move to an emergency control room in case the habitability of the main control room makes it necessary. The internal ventilation of this emergency control room is supplied by the GNS system. When toxic gases are detected, the air intake is cut off. There are no filters present to capture radioactive particles or radioactive iodine.

The ventilation system of the Doel 3 and Doel 4 main control room consists of one or two ventilators (each 100 %). In case of an internal accident, the ventilation will isolate automatically. At that moment, the air intake will be cut off, as well as the normal internal recirculation. Safety ventilators (2 x 100 %) with their filter banks (prefilter, absolute filter, activated charcoal filter) will at that moment become operational, together with the heat removal system CD/CF. The circuit is set up redundantly and is supplied by safety diesel generators.

The personnel of the Doel 3 and Doel 4 control room has the possibility to move to an emergency control room in case the habitability of the main control room makes it necessary. The internal ventilation is supplied by the BKR system. When toxic gases are detected, the air intake is cut off. There are no filters present to capture radioactive particles or radioactive iodine.

There are sufficient filter masks with their appropriate cartridges (for classical pollutants, dust and iodine) and sufficient oxygen masks available at various places on the site. A specific procedure describes the oxygen cylinders' refilling method. According to whether the ambient air is radioactively contaminated or not, a shuttle service will take the oxygen cylinders to Kieldrecht or Kallo to be refilled.

In the main control rooms, in the emergency control rooms, at the entrance of the controlled zones, in the emergency operations facility and the intervention vehicles are sufficient potassium iodine tablets present to effectively protect the personnel.

The dose to which the personnel is exposed, is subject to a follow-up. The legal dose limits are not exceeded. Staff rotation is foreseen.

Personal protective equipment is also available for the protection against other forms of contamination. Flashlights and helmet lights can be used in case the emergency lighting batteries are empty.

6.3. Accident management measures to maintain the containment integrity after core damage

6.3.1. Management of hydrogen risks inside the containment

As a result of the zirconium cladding oxidation in the reactor core or the corium-concrete interaction after failure of the reactor vessel, significant amounts of hydrogen can be produced and find their way into the containment.

The reactor buildings of all Doel and Tihange units are fitted with passive autocatalytic recombiners (PAR) in various compartments of the containment building. These devices are designed to keep the average hydrogen volume concentration below 5 %, so as to prevent a detonation which could threaten the integrity of the containment. In addition, the active area of the autocatalytic surface is greater than necessary and provides a safety margin of 20 %. Furthermore, the use of the thermal recombiner available on the site allows limiting further the quantity of hydrogen present in the containment.

Hydrogen may transfer from the containment to an adjacent building via a variety of leakage paths:

- a bypass of the containment resulting from an accident sequence (rupture of steam generator tubes, interfacing systems loss of coolant accident (ISLOCA));
- the normal leakage rate (design leak) of the containment ;
- a failure of the containment building isolation;
- a breach or a structural leak from the containment due to a severe accident phenomenon.

The impact of a potential accumulation of hydrogen in the adjacent buildings on the adequacy of the existing severe accident management measures is limited thanks to:

- some measures adopted at the design phase, the use of accident procedures and severe accident management guides, which guarantee a minimum impact of these hydrogen leaks on the further development of a severe accident;
- the availability of PARs that limit the concentration of hydrogen in the containment building, and hence the amount of hydrogen able to spread into the adjacent buildings.

The actions recommended in the accident procedures consist in identifying a potential ISLOCA and in isolating it in order to prevent transfers into the nuclear auxiliary building or the annulus space. The SAMGs insist on the importance of the actions aimed at isolating the containment building and consider those actions as a priority.

The existing procedures and specific design measures, including the installation of the PARs which limit the quantity of hydrogen inside the containment, represent a sound basis for minimising the accumulation of hydrogen in a building connected to the containment. In the framework of the periodic safety review, measures have been taken to complete the SAMGs, especially with respect to the detection of radioactive products (and hence hydrogen) via potential leakage paths. The implementation of these measures is in progress.

In case the quenching of the corium does not lead to a coolable geometry of the corium, a core-concrete interaction can occur. In such a scenario, the accumulation of hydrogen in the annulus space (Doel 1/2), or in the nuclear services building GNH (Doel 3 and Doel 4) – after performing the unfiltered containment venting – and, even though very unlikely, cannot be excluded. The installation of a filtered containment venting offers a possible solution in this case.

6.3.2. Prevention of overpressure of the containment

To prevent excess pressure in the containment, the primary circuit must be depressurized in order firstly to facilitate safety injection at low pressure, and secondly, to mitigate or even prevent the phenomena of the direct containment heating following the dispersal of the corium, and sudden pressurization following the release of significant quantities of the high pressure water and steam present in the primary circuit. These two phenomena may lead to excess pressure in the containment building.

The strategy consists in depressurizing the primary circuit by using the following methods:

- cooling and depressurizing the secondary circuit by a bypass to the condenser or bypass to the atmosphere;
- direct depressurizing of the primary circuit by the auxiliary / emergency spraying of the pressurizer or by the opening of the pressurizer relief valves.

When the pressure in the containment no longer corresponds to a stable and controlled state over the long term, the main strategy consists in lowering the containment pressure by cooling with the following means:

- the containment spray pumps;
- the low-pressure safety injection pumps, after connection of the low pressure injection lines with the containment spray system lines.

For the Tihange units and Doel 3 and Doel 4, in order to increase diversification of the containment building spraying function, a feasibility study will be initiated to add an external flanged connection on the containment spray pumps in order to achieve an alternative spraying flow rate with a mobile spraying pump.
For Doel 1/2, electrical cables are installed for the alternative power supply of the SP pumps with power generators.

Following a reactor vessel rupture and the potential subsequent corium-concrete interactions, non condensable gases could be produced and would then add to the pressurization of the containment building. The methods listed above do not work with non-condensable gases. However, carbon monoxide is recombined by the hydrogen recombiners.

A feasibility study will be carried out to fit a filtered vent, intended to deal more efficiently with the overpressure issue inside the containment building. This filtered vent will be the ultimate containment building depressurization measure, which shall only be used to prevent damage to the containment building, should all the other preventive measures fail to reduce the pressure.

6.3.3. Prevention of re-criticality

Tihange NPP

The site has significant provisions of boric acid, so that recourse to under-borated or even non-borated water can be avoided. When the borated water inventory available in the "B01Bi" or "CTP" tanks is getting low, these tanks are then refilled with water having satisfactory characteristics.

However, the return to criticality following the use of under-borated or non-borated water in the primary circuit has been studied in a generic and conservative way. On this basis, the generic SAMG guides issued by the WOG ultimately authorise the injection of under-borated or non-borated water into the primary circuit. Such use of non-borated water is subjected to a prior assessment by the emergency management team and to severe usage restrictions. In the framework of a variety of studies initiated by the WOG in the wake of the Fukushima accident, analysis of makeups using borated water / non borated water will be tackled. The conclusions will be incorporated into the future developments of the SAMG guides.

The borated water resources are injected with a minimum flow rate, sufficient to achieve the correct cooling of the core and to ensure a minimum consumption of boric acid.

Doel NPP

Before the reactor vessel is perforated, only borated water may be injected into the reactor vessel.

After the perforation of the reactor vessel, preventing the nuclear reactor to return to criticality is important. To prevent this from happening – in case of borated water shortage – clean water (without boric acid) will only be injected to a limited extent into the reactor building.

6.3.4. Prevention of basemat melt through

As a preventive approach, the global strategy consists in avoiding the rupture of the reactor vessel. This implies injecting water inside the primary circuit by using the following methods:

- the high pressure safety injection pumps,
- the low pressure safety injection pumps,
- the emergency injection pumps,
- the spray pumps of the containment building, after connection of the low pressure injection lines with the containment spray system lines,
- the alternative injection systems: the boric acid pumps and deaerated water from the chemical and volume control system, the primary pumps.

Tihange NPP

For the Tihange units, to prevent the breach in the basemat after the rupture of the reactor vessel, the main strategy consists, initially, in keeping the reactor pit dry to allow the corium to sprawl on the basemat and preventing the risk of a steam explosion, and then, in injecting water in the reactor pit using the methods described previously. Actually, the water injected in the primary circuit will finally reach the reactor pit due to the rupture of the reactor vessel.

A feasibility study about the use of an additional method for injecting water in the reactor pit (in addition to those already existing) will be initiated.

Doel NPP

For the Doel units, to prevent the breach in the basemat after the rupture of the reactor vessel, the reactor pit is flooded as a preventive measure (before the rupture of the reactor vessel) by means of a gravity filling from the RWST and the opening of the recirculation valves.

After the reactor vessel is perforated, there are two ways of injecting into the reactor pit:

- injecting into the primary circuit by means of the above-mentioned injection equipment via the perforation of the reactor vessel;
- spraying into the reactor building; the injected water will reach the reactor pit via the connections between the reactor sumps and the reactor pits.

The insights regarding the corium-concrete interaction will be followed up closely.

6.3.5. Need for and supply of electrical AC and DC power and compressed air to equipment used for protecting containment integrity

Tihange NPP

<u>Tihange 1</u>

Amongst the means identified for the implementation of the aforementioned strategies, the pumps related to the following circuits will be powered by safety diesel generators: safety feedwater system, safety injection system, containment spraying system, chemical and volume control system, groundwater system and compressed air system.

The instrumentation and control is backed up by batteries and by the emergency diesel generators via rectifiers.

The operation of the valves of the pressurizer auxiliary spray line and those of the bypass to the condenser and to the atmosphere, as well as the bleedoff of the chemical and volume control system, do not require alternating current and their control is backed up by batteries and the safety diesel generators via rectifiers. The SEBIM valve tandems of the pressurizer use direct current backed up by batteries and the safety diesel generators via rectifiers.

Tihange 2 and Tihange 3

Amongst the means identified for the implementation of the aforementioned strategies, the pumps related to the following circuits will be powered by the first level safety diesel generators: safety feedwater system, safety injection system, containment spray system, chemical and volume control system, boric acid system and compressed air system.

The ultimate emergency pumps are powered by the second level emergency diesel generators.

The instrumentation and control is backed up by batteries and by the safety diesel generators via rectifiers. The bleedoff of the chemical and volume control system is backed up by two levels of protection.

The operation of the discharge valves, the auxiliary and emergency spray line of the pressurizer, as well as the bypass to the condenser and to the atmosphere, do not require alternating power, and their control is backed up by batteries and the safety diesel generators via rectifiers. The emergency spray valves of the pressurizer are backed up by the second level. The PORVs require resupplying with compressed air.

The electricity supplies of the two levels of protection of the units may be connected to perform mutual back-up in case of a failure. A procedure will be drawn up to integrate this manipulation. It will include the storage of cables to realise connections between the different electrical panels.

In order to obtain the most reliable power supply for the instrumentation, a repowering alternative using autonomous diesel generators will be studied for all three units.

Doel NPP

The BK procedure BK-3 describes the electrical power supply of the equipment necessary to protect the integrity of the containment. In this same procedure, alternative electrical power supply systems are proposed.
In the following systems the pumps are powered by the safety or emergency diesels:

- the auxiliary feedwater system;
- the emergency feed water system;
- the safety injection system;
- the primary circuit’s emergency makeup water system (Doel 3 and Doel 4);
- the primary pumps’ seals’ emergency cooling system;
- the charging system;
- the containment spray system.

Batteries and emergency diesel generators will perform the control operation of the pumps. The steam generators’ relief valves – to the condenser and to the atmosphere – do not need alternating power. The ultimate spray of the pressurizer, the cooling of the ventilation batteries and the ventilators are supplied by the safety or emergency diesel generators.

The pressurizer’s SEBIMs (Doel 1/2) need direct current, supplied by batteries, with diesel generators as emergency power supply. The PORVs (Doel 3 and Doel 4) need direct current, as well as compressed air. The MORVs (Doel 3 and Doel 4) need direct current, as well as 380 V.

An alternative power supply of the IAK compressors will be provided by the back-up 380 V network. The power supply for PORVs/MORVs and SEBIMs will also be provided by the back-up 380 V network.

6.3.6. Cliff-edge effects and timing

The reactor buildings at Doel and Tihange belong to the "large dry containment" type. The large volume available for the expansion of gases allows, in the first instance, to limit pressurization following a discharge of water, steam and non condensable gas in the reactor buiding.

The primary containment building of the Tihange units is composed of a prestressed concrete cylinder with an inner air-tight metallic liner. The Doel 1/2 steel spherical primary containment is characterized by a considerable mechanical strength. The Doel 3 and Doel 4 primary containment consists of a prestressed concrete cylinder with an inner air-tight metallic liner.

The following table shows the characteristics of the reactor buildings taken into account for the integrity studies of the containment building in the event of a beyond design accident. The "ultimate pressures" are those for which significant leaks become probable at the equipment hatch. Nevertheless, exceeding the ultimate pressure does not result in the total loss of the containment building.

Table 15: Characteristics of the Tihange reactor buildings

	Tihange 1	Tihange 2	Tihange 3
Design pressure [bar abs]	4.1	4.5	4.5
Ultimate pressure [bar abs]	> 6	> 6	> 6
Free Volume [m^3]	68 446	67 856	71 812
Basemat thickness [m]	2.15	2.64	2.64
Number of PARs [-]	37	38	40
Surface area of PARs [m^2]	376	329	396

Table 16: Characteristics of the Doel reactor buildings

	Doel 1/2	Doel 3	Doel 4
Design pressure [bar abs]	3.86	4.5	4.7
Ultimate pressure [bar abs]	8	> 6	> 6
Free Volume [m^3]	42 828	60 758	60 302
Basemat thickness [m]	2.45 + 1.4	3.25	3.45
Number of PARs [-]	24	40	37
Surface area of PARs [m^2]	227	306	336

The cooling / depressurization system of the reactor building includes multiple containment spray pumps – allowing to work in direct spray mode or in recirculation mode – to which the low pressure safety injection pumps are added to fulfil this cooling function in case of multiple failures.

The possible failure modes of the reactor building up to the breach in the reactor vessel are listed below.

a) Bypass of the reactor building at the level of a penetration

This would be the result of a beyond design initiating event. All penetrations in the reactor building are equipped with two redundant isolating devices, of which the valves automatically close in case of loss of control. In most cases, the operator may, after having identified the leak, operate additional valves to isolate the line in question. Such leaks, although unlikely, are difficult to exclude but can be easily isolated.

b) Induced rupture of a steam generator tube

Such a rupture may constitute a bypassing path of the containment building during the initial hours of a core meltdown accident, before the breach in the reactor vessel. This type of failure may generally be avoided as the breach in the primary circuit due to creeping is more likely at the hot leg.
A breach may arise at the steam generator tubes if a high pressure in the primary circuit is combined with depressurized and dry steam generators on the secondary circuit side. The SAMGs identify numerous methods to remedy this phenomenon: reduce the pressure in the primary circuit, isolate and/or refill the steam generators.

c) Hydrogen explosion

The oxidation of the fuel cladding, in a scenario of a core meltdown, produces hydrogen. The accumulation of this gas in the containment building could result in a risk of explosion.
To prevent this risk, the reactor buildings are equipped with passive autocatalytic recombiners (PARs) in the different compartments of the containment building. Once the concentration of hydrogen reaches 2 % in volume in the containment building (i.e. well before the explosive threshold), these recombiners become operational and reduce the concentration of hydrogen and carbon monoxide. The PARs also cover the risk of a hydrogen explosion in the long-term, i.e. after breach of the reactor vessel.
The thermal recombiner also helps to limit the amount of hydrogen present in the reactor buildings in the long term.

d) Other failure modes

In the highly hypothetical case where all means of water injection inside the primary and secondary circuits fail, the core meltdown would occur in the first hours and the breach in the reactor vessel after several hours.

The following phenomena could question the integrity of the containment building in this phase:

- the dispersion of corium in the reactor building ("high pressure melt ejection"), causing sudden heating of the air inside the reactor building ("direct containment heating");
- the pressurization due to the release in the reactor building of significant amounts of water and steam present in the primary circuit;
- the pressurization due to an explosion of steam due to the contact of the corium and the water present in the reactor pit.

The first two phenomena may be lessened, or even avoided, through the depressurization of the primary circuit before the breach in the reactor vessel occurs, principally through the pressurizer relief valves.

In the hypothetical event of a complete flooding of the reactor pit (e.g. as a result of the leakage / breach in the primary circuit ending in the reactor pit), a steam explosion might occur following the rapid fragmentation of corium in water, causing damage to the containment building. Yet, a steam explosion is unlikely according to experiments carried out as part of diverse research programs that were unable to create this phenomenon.

In the long term, two failure modes of the containment building may exist at Doel and Tihange. On the one hand the basemat melt-through, and on the other hand the pressurization of the reactor building by the production of steam resulting from the removal of residual heat, and/or the production of non-condensable gases produced by corium/concrete interactions.

For the Tihange units, when the breach in the reactor vessel occurs, the reactor pit is dry in most cases (as recommended in the SAMGs). Without additional water via the primary circuit, corium/concrete interactions are unavoidable. Based on conservative estimates, the breach in the basemat in dry conditions would occur several days after the breach in the reactor vessel.

Nevertheless, prototype experiments of corium in interaction with limestone-type concrete (as present at Tihange) show that it is possible to cool the corium with water after the attack on the concrete has begun. The steam released will then cause a slow pressurization of the containment building. Even in extremely deteriorated configurations, the available time before the breach in the basemat happens, is more than sufficient to set up the appropriate connections to bring water into the reactor pit by injection into the primary circuit. A feasibility study for the implementation of additional water injection to the reactor pit of the Tihange units will be initiated.

Because for the Doel units the reactor pit will probably be flooded at the moment the reactor vessel fails, the corium will likely be quenched and broken into pieces, and, as a result the surrounding water will be able to cool it more quickly. If this is only partially the case or, in case the amount of cooling water that can be added is too little, it is not excluded that the concrete floor of the reactor pit would be affected by the corium-concrete interactions. This process will however be slower than the pressurization of the reactor building caused by the development of steam due to the removal of the residual heat. Without adding cooling water to the reactor pit, the basemat is estimated to fail after more than 5 days (value for Doel 3).

The residual heat released in the reactor building in the form of steam can be dealt with by spraying cold water in the medium term and/or through a cooling circuit with a heat exchanger in the long term (containment spray system and/or safety injection circuit in recirculation mode). If such cooling is not achieved, the design pressure of the reactor buildings could, in this case, be reached within 40 to 48 hours following the loss of all heat sinks. The same estimates refer to an ultimate collapse pressure reached after a period of 3 to 4 days.

A feasibility study will be carried out on the installation of a filtered vent, in order to better cope with the overpressure issue in the containment building and to prevent the loss of containment due to a failure of the containment building if all other preventive measures have failed to reduce the pressure.

For the Tihange units and Doel 3 and Doel 4, in order to increase diversification of the containment building spraying function, a feasibility study will be initiated to add an external flanged connection on the containment spray pumps in order to achieve an alternative spraying flow rate with a mobile spraying pump.
For Doel 1/2, electrical cables are installed for the alternative power supply of the SP pumps with power generators.

6.3.7. Current accident management measures for a return to a stable and controlled state

The extent and combination of the external agressions considered in this context lead, in a number of cases, to beyond design accidents during which essential safety functions can be lost. The first aim of the accident management strategies described previously is to avoid the loss of safety functions and, when this is not possible, to minimise the consequences of such losses. If safety functions are lost, the strategy targets the restoration of a stable and controlled state, by ensuring that:

- the releases into the environment are negligible;
- the pressure and temperature in the reactor building are normalized and stable;
- the core is cooled and any residual energy is evacuated.

The core cooling configuration can vary depending on the initial state of the plant unit, the development of the accident and the availability of the equipment used for the removal of residual heat. Heat removal by boiling in the primary system, or in the reactor pit if the reactor vessel has ruptured, is possible in the short and medium terms, provided that there is a guaranteed supply of water that is sufficient to compensate for evaporation and condensation, and for the steam released in the reactor building.

In the long term, it is necessary to move towards a closed loop cooling configuration in order to stop water makeup to the sump. Otherwise the containment spray in the reactor and/or the injection into the primary circuit will cause the water level in the sump to rise, resulting in the loss of safety equipment and eventually the loss of integrity of the reactor building.

6.3.8. Overview of the accident management strategies and means

Table 17: Strategy for the management of severe accidents and means involved at Tihange NPP

Strategy	Objectives	Means	Power supplies
Injection of water into the steam generators	Remove the residual heat and prevent the rupture of the reactor vessel	Normal feedwater pumps	AC power supply is not backed up
		Water extraction pumps	
		Raw water pumps	AC power supply is backed up by the “GDS” first level diesel generators
		Safety feedwater pumps (Tihange 1) Auxiliary feedwater pumps (Tihange 2 and 3)	
		Emergency feedwater pumps (Tihange 2 and Tihange 3)	AC power supply is backed up by the “GDU” second level diesel generators
Depressurization of the primary circuit	Maximise the number of water sources able to supply the primary circuit	Steam generators relief valves (bypass) to the condenser	AC power supply is not required
		Steam generators relief valves (bypass) to the atmosphere	
		Auxiliary spray of the pressurizer	
		SEBIM valves (Tihange 1) Relief valves of the pressurizer (Tihange 2 and Tihange 3)	DC power supply is required at Tihange 1 and is backed up by batteries and GDS diesel generators AC power supply is not required for the relief valves at Tihange 2 and Tihange 3
		Bleedoff of the chemical and volume control circuit (“CCV”)	Power supply is not required at Tihange 1 Power supply is backed up by the first and second levels at Tihange 2 and Tihange 3
		Emergency spray of the pressurizer at Tihange 2 and Tihange 3 through the emergency injection circuit	AC power supply is backed up by the “GDU” diesel generators
Injection of water into the primary circuit	Remove the energy accumulated in the core	Low pressure safety injection pumps	AC power supply is backed up by the “GDS” diesel generators
	Provide a means of cooling down the core	High pressure safety injection pumps	
	Prevent or delay the breach in the reactor vessel	Containment spray pumps connected to the safety injection system	
		Charging pumps of the “CCV” circuit	

		Boric acid pumps	
		Deaerated demineralized water pumps	
		Emergency injection pumps (Tihange 2 and Tihange 3 units)	AC power supply is backed up by the "GDU" diesel generators
		Primary pumps	AC power supply is not backed up
Injection of water into the containment building	Guarantee sufficient NPSH to enable recirculation	Containment spray pumps	AC power supply is backed up by the "GDS" diesel generators
		Low pressure safety injection pumps connected to the containment sray system	
Injection of water in the reactor pit	Cool down the debris of the core present in the reactor pit	Low pressure safety injection pumps	AC power supply is backed up by the "GDS" diesel generators
	Cool down the debris of the core remained in the reactor vessel	High pressure safety injection pumps	
		Containment spray pumps connected to the safety injection system	
		Boric acid pumps	
		Deaerated demineralized water pumps	
Reduction of the pressure inside the containment building	Keep the containment building integrity	Containment spray pumps	AC power supply is backed up by the "GDS" diesel generators
	Facilitate low pressure injection	Low pressure safety injection pumps connected to the containment spray system	
	Prevent hydrogen explosion	Autocatalytic recombiners	Passive

Table 18: Strategy for the management of severe accidents and means involved at Doel NPP

Strategy	Objectives	Means	Power supplies
Depressurization of the primary circuit	Prevent a high pressure rupture of the reactor vessel Allow low pressure injection	Steam generators relief valves to the condenser	AC power supply is not required
		Steam generators relief valves to the atmosphere	
		Auxiliary spray of the pressurizer	AC power supply is backed up by safety diesel generators
		Emergency spray of the pressurizer	AC power supply is backed up by safety or emergency diesel generators
		SEBIM valves (Doel 1/2)	DC power supply is required and is backed up by batteries and emergency diesel generators
		PORV valves (Doel 3 and Doel 4)	Besides the direct current, compressed air is also required
		MORV valves (Doel 3 and Doel 4)	380 AC power is needed

Injection of water into the primary circuit	Prevent or delay the breach in the reactor vessel Mitigate the consequences of the corium- concrete interactions in the reactor pit	High-pressure safety injection pumps	AC power supply is backed up by safety or emergency diesel generators
		Low-pressure safety injection pumps	AC power supply is backed up by safety or emergency diesel generators
		Emergency make-up water pumps of the primary circuit (Doel 3 and Doel 4)	AC power supply is backed up by safety or emergency diesel generators
		Containment spray pumps (Doel 3 and Doel 4)	AC power supply is backed up by safety or emergency diesel generators
		Charging pumps	AC power supply is backed up by safety or emergency diesel generators
Injection of water in the reactor pit	Mitigating the consequences of the corium- concrete interactions in the reactor pit	Gravity filling from the RWST	Passive
Reduction of the pressure inside the containment building	Keep the containment building integrity	Containment spray pumps	AC power supply is backed up by the safety or emergency diesel generators
		Low pressure safety injection pumps	AC power supply is backed up by the safety or emergency diesel generators
		Ventilation cooling batteries of the reactor building	AC power supply is backed up by the safety or emergency diesel generators
		Venting of the reactor building (if no other possible solutions left)	
	Prevent hydrogen explosion	Autocatalytic recombiners	Passive

6.4. Accident management measures to restrict the radioactive releases

Before applying the guides recommending the following strategies, the shift crew must check all potential release paths of fission products. The use of these strategies also involves long-term monitoring of the risks that can result from their implementation.

6.4.1. Mitigation of fission products releases

This strategy comes into effect when the amount of radioactive materials inside the containment building reaches a level at which atmospheric releases can reasonably be expected and require protective measures for the population outside the site. The mitigative measures identified depend on the origin of the release:

- for the releases from the containment building, the measures identified are:
    - the spraying inside the reactor building
    - the ventilation/filtration of the annulus space,
    - and the addition of soda to the water in the sumps of the containment building (to trap iodine);
- for the releases from the steam generators, the measures identified are:
    - the filling of the steam generator with water,
    - the isolation and the release of the steam from the affected steam generator to the condenser rather than to the atmosphere,
    - and other alternative measures (such as spraying the released steam with fire hoses);
- for the releases from the nuclear auxiliary building, the measures identified are:
    - the operation of ventilation/filtration systems,
    - in the event of containment penetration failure, the isolation of the containment penetration causing the release,
    - and in the event of a leak in one of the recirculation loops, the reduction of the flowrate in the loop in question, the isolation of the loop, and the use of other recirculation loops.

6.4.2. Injection of water into the steam generators to trap the fission products leaking from damaged steam generator tubes

This strategy comes into effect when there is an inadequate level of water in the steam generators. The measures identified are, when the pressure in the steam generators is high: the auxiliary feedwater pumps, the emergency feedwater pumps and the normal feedwater pumps.
When the steam generators are at low pressure, the pumps of the water extraction system and those of the raw water system are used.

6.4.3. Injection of water into the primary system to trap fission products released from the core debris

This strategy comes into effect when the core exit temperature indicates an uncovered core. The measures identified are

- the pumps of the high pressure and low pressure safety injection systems,
- the pumps of the containment spray system,
- the pumps of the emergency injection system
- the pumps of the chemical and volume control system,
- the water and boron makeup pumps,
- the primary pumps and the special means in shutdown state.

6.4.4. Injection of water into the containment building

The aim of this strategy is to guarantee a sufficient NPSH to allow recirculation phase and to ensure, as a preventive measure, that there is a sufficient quantity of water in the containment building to trap the fission products resulting from the debris located outside the reactor pit. It comes into effect when the water level in the containment sumps is too low.
The measures identified are the containment spray pumps, the low pressure safety injection pumps and the addition of soda to the water in the containment building sumps.

6.4.5. Monitoring containment building conditions

The aim of this strategy is to reduce the concentration of fission products and to trap the fission products released from the containment building. It comes into effect when the containment building pressure no longer corresponds to a stable and controlled state in the long term.
The measures identified are the containment spray pumps, the low pressure safety injection pumps and the addition of soda to the water in the containment building sumps.

6.4.6. Injection of water in the reactor pit

The aim of this strategy is to trap the fission products released by the debris located in the reactor pit and in the reactor vessel. This strategy comes into effect when the core exit temperature indicates that the core is still deteriorating.
The measures identified are the high pressure and low pressure safety injection pumps, the emergency injection pumps, the containment spray pumps, the water and boron feed pumps and the pumps of the chemical and volume control system.

6.5. Accident management measures for loss of cooling of spent fuel pools

The main aim here is to avoid uncovering the fuel stored in the storage pools, either by re-establishing active cooling of the pools or by ensuring a water supply by any available means (conventional or not). Even without a supply of water, the time before the fuel is uncovered can be calculated in days for spent fuel pools at the Doel and Tihange units and in weeks for the DE temporary storage facility at Tihange. That leaves sufficient time to install or bring an alternative water supply, if all traditional methods are unavailable.

6.5.1. Current accident management measures

Tihange NPP

The cooling of the spent fuel pools of the reactor units is ensured by a pool loop system (CTP) with two pumps and two heat exchangers.

The spent fuel pools of DE building are cooled by a pool loop system (STP) with two pumps and two heat exchangers.

Four major types of failures can affect the spent fuel pools cooling system: the loss of an individual piece of equipment (a pump or a heat exchanger), the loss of power supply to the pumps, the loss of the ultimate heat sink and the loss of water inventory.

In the event of an individual piece of equipment being lost (pump or exchanger), the cooling function is recovered by switching manually to the back-up equipment.

In the event of a complete loss of off-site power (LOOP) at Tihange 1, a gravity-fed makeup would be available from a water reservoir.
In the event of a complete LOOP at Tihange 2 and/or Tihange 3, the cooling pumps CTP and STP are resupplied from the 380 V backed up electrical boards of the "BUS", subject to an adequate connection (switching in the electrical panels). Procedures for operation in accidental conditions automatically require this resupply. In both cases, the power supply for the CTP (and STP) pumps is switched to the second level 380 V backed up switchboards.

In the event of a complete loss of the primary ultimate heat sink at Tihange 1, the heat exchangers cooling the pools are supplied from ground water in accordance with the operation procedures in accidental conditions.
In the event of a complete loss of the primary ultimate heat sink at Tihange 2 and/or Tihange 3, a fixed connection resupplies the CTP exchangers with cooling water from the "CRU" system (emergency cooling system). Any of the three CRU trains can then supply the CTP exchangers. The switch to the alternate ultimate heat sink (CRU/CEU) is required systematically when the above-mentioned procedures are applied.
In the event of a complete loss of the primary ultimate heat sink of the pools in building DE, Tihange 3 is supplied by CEU system (second level emergency water supply) via hosepipes. If the CEU supply from Tihange 3 fails, the wells on Tihange 2 can be connected by hosepipe to supply the STP exchangers.

All of these factors facilitate the cooling of the storage pools and prevent them from boiling, hence avoiding the associated loss of water inventory.

In the event of a complete loss of all heat sinks, and before any significant loss of water, a continuous makeup can be provided by mobile supply resources via the fire extinction water system ("CEI"). This supply can also be provided in case of station black-out or flooding. In addition, at Tihange 1, an additional pump is available for supplying the spent fuel pools and providing an adequate supply of cooling water (CTP). This pump, powered by the normal electrical network, can be backed up by the emergency diesel generator ("DUR"). In case of loss of water inventory in the pool, the potential sources of resupply are the other unaffected compartments of the pool, the B01Bi tank or the CTP reservoirs, the boric acid and deaerated water pumps and reservoirs, the CEI circuit via the hose-reels in building D or the non-conventional supply means ("CMU").

Doel NPP

Doel 1/2

The PL circuit (Pool Loop) of the spent fuel pool of Doel 1/2 consists of two parts:
- a purification part with two pumps, with a first level power supply;
- a cooling part with three pumps and three heat exchangers.

The normal water supply sources possibilities for the PL-pools are the MW and PL systems of the WAB. In emergency situations, the water supply/reservoir from the RWSTs can be used. Also supply with FE-water is a possibility.

In case of an earthquake, the FE circuit in the GNS is the guaranteed water supply system. The supply is operated from the Doel 3 LU pond. If necessary, a fire-hose can be connected from the FE circuit in the GNS to the PL-pools. For a flow rate of 13 tons per hour, one fire hose is sufficient.

Doel 3 and Doel 4

The PL circuit (Pool Loop) of the spent fuel pools of Doel 3 and Doel 4 consists of two loops. Each loop consists of a pump and a heat exchanger.

There is an incident procedure in which one single pump can guarantee the PL cooling in case the other pump ceases to function for whatever reason (electrical or mechanical). There is a reserve pump present together with the necessary coupling equipment. The incident procedure also presents alternative cooling possibilities in case the normal cooling via the heat exchanger is not available. In case the FE network is intact, the procedure prescribes the use of FE-hoses. In case the FE network is isolated as a consequence of the safety signals, an alternative connection point is proposed.

A specific incident procedure prescribes the actions to be taken in case of an uncontrolled level decrease in the spent fuel pools. In first instance, the pumps that are intended for the purification of the circuit will be shut down. This way, possible leaks can be localized. Supply possibilities are SI (from the RWST), MW and FE. A water supply of 13 m^3 per hour is sufficient to compensate for the evaporation.
A study is conducted in order to be able to provide a fixed piping for the alternative supply of the spent fuel pools of Doel 1/2, Doel 3 and Doel 4.

6.5.2. Cliff-edge effects and timing

Spent fuel pools of Doel and Tihange units

The loss of active cooling of a spent fuel pool is a slow and progressive incident. The large quantities of water, mainly there for shielding, and the low residual heat (by comparison with the core) result in considerable inertia.
The stages successively reached in the event of the loss of cooling of a spent fuel pool are the following:
- the water heats up to the boiling point. After this stage, the steam around the pool and in some adjacent rooms impedes access for any on-site intervention (for example, providing a water makeup to the pool or recovering cooling through forced convection);
- shielding is lost after the evaporation of several metres of water above the fuel assemblies. This makes the area even less accessible for dosimetric reasons. In addition, the configuration of the water intakes for forced convection no longer allows active cooling below this level;

- the assemblies are uncovered. From this point on, the temperature of the clads begins to rise, which eventually leads to the loss of their integrity and potentially to the meltdown of the assemblies.

The actions required to avoid this sequence of events consist in providing a water supply to the pools and restoring forced convection. These actions must be carried out while bearing in mind the restrictions imposed by the different stages, for which the timing is set out in the following table. Three initial configurations are considered for the concerned unit: during normal power operation, at the end of complete unloading of the core when the reactor building pool and the nuclear auxiliary building pool are not connected (the most disadvantageous situation for the spent fuel pools), and at the end of a complete unloading when the reactor building pool and the nuclear auxiliary building pool are connected.

Table 19: Timing of the different stages during loss of pools cooling in Tihange units

Unit	Stage	Power	Unloading without connection to the reactor building	Unloading with connection to the reactor building
Tihange 1	Boiling [hours]	40.7	10.2	10.2
	Loss of shielding [days]	13.0	3.7	5.8
	Uncovering [days]	16.5	4.7	9.3
Tihange 2	Boiling [hours]	24.6	7.8	7.8
	Loss of shielding [days]	4.2	1.5	3.6
	Uncovering [days]	6.6	2.4	6.8
Tihange 3	Boiling [hours]	30.8	9.2	9.2
	Loss of shielding [days]	6.7	2.3	4.3
	Uncovering [days]	9.9	3.4	6.6

At Tihange 2, a high "residual heat / water volume" ratio results in the uncovering of the fuel assemblies after 2.4 days without water makeup, in the worst case scenario. For most situations, there is more time (about a week or even more) for all three units.

Table 20: Timing of the different stages during loss of pools cooling in Doel units

Unit	Stage	Power	Unloading without connection to the reactor building	Unloading with connection to the reactor building
Doel 1/2	Boiling [hours]	43	15	15
	Loss of shielding [days]	7	3	5
	Uncovering [days]	11	4	9
Doel 3	Boiling [hours]	26	8	8
	Loss of shielding [days]	5	2	3
	Uncovering [days]	8	3	5
Doel 4	Boiling [hours]	34	10	10
	Loss of shielding [days]	7	3	3
	Uncovering [days]	11	3	6

The strongest correlation between the residual heat and the water volume in the pools is found in Doel 3. This means that after a 3 day period – in the most penalizing configuration – water has to be added in order to prevent the uncovering of the spent fuel assemblies.

Building DE (Tihange)

The loss of active cooling of the spent fuel pools in building DE is a slow and progressive process. The large quantities of water, mainly there for shielding, and the low residual heat (by comparison with the core) result in considerable inertia.

The timing shown in the following table represents the conservative case of all fuel assemblies having the maximum allowed residual heat.

Table 21: Timing of the different stages during loss of pools cooling in building DE

Unit	Stage	Time
Building DE	Boiling [hours]	102
	Shielding [days]	16.6
	Uncovering [days]	24.1

The significant inertia (at least 3 weeks) allows the implementation of the measures required to avoid the loss of cooling of the assemblies stored in building DE.

Spent fuel container building (Doel)

The spent fuel in the spent fuel container building (SCG) is stored in transport containers that are resistant against extreme conditions. Together with the storage building, the containers provide the necessary biological shielding and, in normal circumstances, an improved heat removal.

The cliff edge effects that may lead to nuclear fuel damage and beyond design radiological consequences, are a result of the overheating of the nuclear fuel due to insufficient cooling and/or the failure of the leak tightness of the container at the level of the primary lid's double seal. The loss of the neutron absorbing resin of the containers and/or the shielding of the building will not lead to nuclear fuel damage. The radiological consequences are never unacceptable.

The spent fuel containers can resist a 60 minute fire, e.g. as a result of a plane crash. In the design basis accident, the fire will burn out spontaneously because it is excluded that the metal containers would burn. In case a beyond design fire would break out, considerable margins are built in at the level of the weakest link, being the primary seals.

6.5.3. Instrumentation needed to monitor the spent fuel and to manage the accident

Tihange NPP

All the spent fuel pools are fitted with level sensors, sounding an alarm in the control room if there is a change from the nominal level. In addition, any change in the level is detected by pressure measurements at the intake of the pool skimming pumps.
The temperature of the pools is also measured continuously, and any increase sets off an alarm in the control room. The temperatures in DE building at Tihange 3 are measured and an alarm is also triggered in the control room.

With regard to the power supply, these measures are normally powered by non safety-rated boards but are backed up by the first level diesel generators and fitted with batteries capable of compensating for power failures of up to three hours.

In the framework of the periodic safety reviews, additional level measuring instrumentation, resisting accidental ambient conditions, has been proposed for the pools.

Doel NPP

Doel 1/2

In the GNH there are two pools with nuclear fuel elements and both are equipped with two temperature and two level measurements. One of both measurements is supplied by the first level and the other one by the second level power supply system.

There are ambient radioactivity measurement equipment present in the vicinity of the pools but they have no safety function. The radioactivity instrumentation on the chimney of the GNH does have a safety function. The radioactivity measurements on the chimney of the GNH trigger the filtering of radioactive releases.

There is a local ventilation on top of the pools but it has no safety function. The ventilation of the GNH, the building housing the pools, is the safety-related pool ventilation.

Doel 3 and Doel 4

In the SPG there are two spent fuel pools. Both are equipped with two temperature and two level measurements. Each measurement is performed via the second level power supply from the bunker.

The ventilation of the nuclear fuel pools building is a safety-related circuit consisting of two redundant trains. In case the presence of radioactive noble gases is detected by redundant qualified measurement equipment, the filters are put into operation. In the vicinity of the pools in the SPG, two ambient radioactivity measurement devices can be consulted from the control rooms.

6.5.4. Hydrogen accumulation

To assess the risk of hydrogen accumulation in the spent fuel pool buildings, it is necessary to estimate the production rate of this gas. Two sources of hydrogen production have been identified:

- the oxidation of the zirconium fuel cladding by the water vapour, after the assemblies have been uncovered;
- the radiolysis of the water in the pools due to the radiation emitted by the fuel assemblies. This hydrogen production also occurs in normal conditions. In accidental circumstances, such production can result in the long term in significant accumulation if the building's ventilation system is unavailable.

Three main conclusions can be drawn:

- first of all, the uncovering of the fuel assemblies, resulting in the oxidation of the zirconium clad, can be avoided by ensuring a water makeup to the pools. This is made possible by the time before the assemblies become uncovered (a few days) and the considerable diversification of makeup means. A water makeup of 14 m^3/h is always sufficient to compensate for the evaporation from the pools of all three Tihange units. For building DE, a makeup of 5.1 m^3/h is sufficient. A water makeup of 13 m^3/h is always sufficient to compensate for the evaporation from the pools of all the Doel units.
- the ventilation system must ensure the permanent renewal of the air in the spent fuel pool buildings. If this system is unavailable, the hydrogen produced by radiolysis can accumulate, so that the risk of an explosion cannot be ruled out. In the worst case scenario, where the entire core has just been unloaded into the spent fuel pool, the flammability threshold can be reached after a few days;

- given the very low residual heat present in building DE, the eventuality of hydrogen accumulation can be ruled out. Indeed, hydrogen production by radiolysis is negligible and the fuel assemblies only become uncovered about twenty days after the total loss of cooling.

The impact of potential hydrogen production in the spent fuel pool buildings after an accident causing a total loss of pool cooling is limited. The recovery of the ventilation systems and the available means of supplying the pools with water allow to avoid the risk of hydrogen accumulation.
However, an additional study will be initiated in order to assess the residual risk of hydrogen accumulation.

6.5.5. Adequacy of current management measures and possible additional arrangements

Tihange NPP

Without active pool cooling, the heat is evacuated by the ventilation system of the pools area via the filtration system fitted on the extraction of the pools halls.
A water makeup of 14 m^3/h is always enough to compensate for the evaporation of water from the spent fuel pools of the three units.
The ambient conditions are monitored by radioactivity measuring equipment located in the pools halls and on the ventilation system at the exhaust stack.
The instructions in the event of a loss of water in the pools are included in the fuel handling procedure. There are also instructions in case of problems during the handling of fuel assemblies.

Doel NPP

Doel 1/2

The measures in a severe accident situation are not different from the measures before the accident. They are always aimed at preventing nuclear fuel damage by ensuring the supply and cooling of the pools. Nuclear fuel pool cooling in the GNH can be performed in different ways.
Ventilation is present above the spent fuel pools, but it has no safety function. The building ventilation of the GNH, leading to the GNH's chimney is the safety-related ventilation for the pools. There are filters but they can only capture the radioactivity if the humidity of the supplied air can be limited.
There is also a specific procedure with guidelines regarding an uncontrolled level decrease in a spent fuel pool. The procedure describes how the personnel members can bring themselves to safety and how the preparation for a possible intervention in the pools will proceed.
In the walls of the pools are functional holes for the detection of cracks in the liner. These holes can be preventively sealed.

Doel 3 and Doel 4

The spent fuel pools area is ventilated by the safety part of the VF, consisting of two redundant trains which are equipped with filters to be used after radioactivity has been detected by measurements.
In order to make the filters function effectively, the humidity degree has to be managed. The air exhaustion is conducted to a chimney where measurement equipment register the discharge.

6.5.6. Returning to a stable and controlled state

Returning to a stable and controlled state after the prolonged loss of pool cooling consists firstly in restoring the normal level in the pools. Without active cooling, the cooling configuration is characterised by a water supply that compensates for the evaporation of the boiling pools and by passive evacuation of the steam to the environment.
A closed loop cooling system must be introduced in order to stop the release of steam into the environment in the long term.

6.6. Synthesis of the main results presented by the licensee

Based on the information in the licensee's stress test reports and the additional information provided by the licensee during technical meetings and on-site inspections, the main results for the topic "severe accident management" are as follows.

A large number of severe accident management strategies and measures (means and procedures) have been addressed by the licensee, with a description of their current status and a proposal for potential additional measures.

The results of the assessments reaffirmed the need for power supplies and water sources available at all time and in all circumstances to guarantee the cooling of the nuclear fuel. To this end, the licensee relies on the introduction of new safety means ("non conventional means") and the reinforcement of its emergency organization.

The new emergency means planned by the licensee include, among others, mobile diesel generators, mobile pumps, electrical cables, and hoses for connection to diverse water sources and systems. The licensee emphasizes that a number of these non conventional means were supplied soon after the Fukushima accident and are already available on the field.
Furthermore, some selected loops on the fire extinction networks will be reinforced to improve their resistance to an earthquake, so as to use them to resupply water to some safety systems if necessary.

With respect to the emergency organization, the licensee defined three operational levels to better manage multi-units events:

- the "standard" mode, with a single unit involved; in this case, the current organisation of the internal emergency plan remains applicable;
- the "alert" mode, when a predictable crisis situation is likely to affect several units (e.g. a large scale flood); in this case, on-call managers and some technical officers will always be on standby on the site; the detailed organization of the "alert" mode is ongoing;
- the "high" mode: when a non predictable crisis situation suddenly affects several units simultaneously on the same site (e.g. earthquake); the detailed organization of the "high" mode is ongoing.

The full implementation of the new emergency organization will be effective in 2013.

Meanwhile, the current on-site operation centre ("COS") at Tihange will move to a seismically qualified building, equipped with a backed up power supply and with a ventilation system fitted with charcoal filters to protect the personnel against iodine.

In parallel, the licensee plans to launch complementary studies on the following topics:

- the installation of filtered vents on the containment building of each unit on both sites: these devices would allow to filter efficiently the atmospheric releases in case a decompression of the reactor building is necessary after a severe accident;
- the assessment of the residual risk of hydrogen accumulation in the spent fuel pools buildings: the aim is to evaluate, in the different accidental scenarios considered, the possibility that the hydrogen produced in the spent fuel pools could reach a dangerous concentration.

Finally, the licensee will continue to follow the international research and development on the limitation of the corium-concrete interactions in the reactor pit.

6.7. Assessment and conclusions of the regulatory body

The approach adopted by the licensee to re-evaluate the management of severe accidents complies with the methodology provided by the licensee and approved by the regulatory body.

The improvements proposed by the licensee, particularly in terms of supplementary safety means and emergency organization, will enhance the response capacity of the plants and will further increase the ability to mitigate the potential consequences of a severe accident.

Based on the assessment of the licensee's reports and the subsequent technical meetings and on-site inspections, the regulatory body identified additional demands and recommendations in order to further improve the management of emergency situations.

1. The adequacy of the procedural guidelines (BK procedures for Doel and severe accident management guidelines for Tihange) to cope with a severe accident has been assessed by the licensee, relying mainly on the fact that those procedures are inspired from the Westinghouse owners group severe accident management guidelines ("WOG SAMG"), are regularly updated, and are validated in the framework of the ten-yearly periodic safety reviews.
   Yet, those procedures still need to be improved with respect to the following aspects:
   - the Doel BK procedures should be supplemented with long term monitoring and exit guidelines, such as those already existing for Tihange (SAEG-1 and SAEG-2);
   - in some Doel BK procedures, reference is made to (the distinct) FRG procedures for the explanation of recommended methods. This constant switching between different procedures should be avoided, and therefore the BK procedures should be more self-supporting and contain all information needed for their application;
   - an in-containment pH calculation tool should be added to the BK/SAMG procedures to determine the sump water acidity from the volumes and water quantities used during the management of the accident, taking into account all other physical and chemical pH influencing processes; this tool would also be used as a check and back-up for a dedicated sampling system;
   - a decision support tool (table/flow chart) should be added to the BK/SAMG procedures to quickly pinpoint the (most probable) location of a containment leak path based on the readings of certain detectors and to determine the most appropriate actions to limit the spread of fission products. This approach might involve the deployment of mobile detectors at specified locations;
   - the BK procedures should provide quantitative criteria for selected key parameters to quickly arbitrate between the evacuation of the residual heat and the isolation of a leak in recirculation lines;
   - a decision support tool should be added to the BK procedures to arbitrate between injecting into the primary circuit and spraying inside the containment building.

2. As much as possible, the licensee should consider to increase the consistency between the Tihange NPP and the Doel NPP with respect to the emergency training and refresher training programs (different in duration and frequency).

3. For the Doel NPP, the licensee states that the probability of a steam explosion when corium falls out of the reactor vessel into a flooded reactor pit is very low and can thus be neglected, based on various experiments carried out as part of international research programs that were unable to create this phenomenon.
   For the Tihange NPP (where the reactor pit is not flooded prior to the reactor vessel breach), the licensee states that a feasibility study of a system allowing water injection into the reactor pit will be launched.
   However, the licensee should follow-up the ongoing steam explosion experiments closely. If needed, the current strategies for flooding of the reactor pit before the rupture of the reactor vessel should be adapted.

4. The licensee should also assess the need of fitting new devices that would be useful for severe accident management (pH measurement in the sumps, temperature measurement at the

bottom of the reactor vessel to monitor a potential core melt).
The associated hardware modifications to improve those aspects should be sought where appropriate.

5. The licensee should identify the effective means to control the pH inside the containment building after a severe accident. This requirement applies in the early stages of the accident, and also during the long term phase.
   For the management of the long term phase of a severe accident, the licensee should take into consideration the impact of other severe accident management actions on the possibility of refilling the NaOH tank and the possibility for non-NaOH injection related measures to influence the sump water pH in the alkaline direction.

6. As a further diversification of the strategies available to manage a severe accident, an optimal battery load shedding strategy (in order to extent as long as possible the lifetime of the batteries and thus the period of availability of vital equipment for the management of the severe accident), should be developed and added to the ERG procedures (severe accident prevention) and to the BK/SAMG procedures (severe accident mitigation).
   A calculation and decision support tool should be studied in parallel to determine the loads that can be shed, the extra battery autonomy gained by shedding a specific load, the severe accident management functions that will be lost by shedding a specific load, and the alternatives that could be considered to (partly) compensate for the loss of each particular severe accident management function.

7. The licensee should review the plants technical specifications in order to further improve the availability of the second level emergency equipment. In particular, the maximum allowed downtimes and the time limits for return to service should be re-evaluated and justified, given the risks involved.

8. The licensee should regard the additional means (including non conventional means) as safety related equipment as long as they play a key role in the prevention, the detection and/or the mitigation of a severe accident (defence in depth). In this context, the licensee shall determine the specific provisions applicable to this equipment where appropriate (introduction in the technical specifications, inspections and testing, preventive maintenance…).

7. General conclusions

7.1. Mains results and safety improvements proposed by the licensee

The assessment results are detailed in the previous chapters of this report. They are now highlighted in the upcoming paragraphs. There are different types of actions consisting in:

- adjusting or accelerating ongoing modifications or studies;
- new technical modifications or adaptations;
- additional studies or R&D programs;
- organisational modifications (resources, emergency management, external support);
- adjusting or creating new procedures.

Globally, the stress test assessments revealed that the facilities of the Tihange and Doel nuclear power plants are capable of maintaining their essential safety functions, either relying upon the redundant and diversified equipment and systems that were considered in the design phase or using mobile devices deployed on the sites. In some cases, extra improvements have been proposed in order to further enhance the robustness of the facilities against situations that are unlikely to occur when considering the diversity of the water and electric power sources already available at both sites.

The assessments show that the facilities are robust enough to face extreme conditions, considering the numerous lines of defence and the additional mobile devices that were deployed and implemented soon after the accident in Fukushima.

These assessments also show that providing external resources is not necessary in the early days after the occurrence of the considered situations, since the technical equipment needed are all available on the sites.

7.1.1. Earthquakes

Concerning the adequacy of the design basis earthquake (DBE), a first seismic risk assessment was performed by the Royal Observatory of Belgium.
For the Doel NPP, the results obtained are still in conformity with the values used in the design basis of the four units.
For the Tihange NPP, the assessment resulted in a slight increase of the peak ground acceleration ("PGA") in comparison with the value considered when designing the facilities. The assessment must still be completed and consolidated and therefore allows no definitive conclusion on the adequacy of the DBE. Nevertheless, the safety margin assessment performed during the stress tests has demonstrated that the equipment have much more robustness than required by the DBE.

The safety margin assessment for the Doel and Tihange units was performed on the basis of a review level earthquake ("RLE") being as high as 1.7 time the peak ground acceleration (PGA) of the current design basis earthquake. It showed that all systems, structures and components ("SSC") required for achieving and maintaining safe shutdown state are robust enough, except for a few mechanical and electrical elements whose justification or improvement through easy-to-implement modifications is currently in progress. The assessment whether the Tihange 1 electrical building should be strengthened is ongoing.

Finally, a potential break in a water tank or a water line located on the sites, resulting from an earthquake, would not have any consequence on safety.

7.1.2. Flooding

Tihange NPP

The initial design basis flood ("DBF") (the flood of 1926 + 20 %, corresponding to a river flow rate of 2 200 m^3/s) was re-evaluated during the last periodic safety review.
With an altitude of 71.5 m above sea level, the site of Tihange is protected against the new design basis flood (2 645 m^3/s), which corresponds to a return period of about 200 years, since the maximum height of the river is 71.30 m.

The changes in nuclear regulation resulted in a new methodology to determine the water level of the Meuse river: the river level is now calculated taking into account a flood with a return period of 10 000 years. The new assessment revealed that even though the Meuse river would progressively overflow its banks, the existing systems shall maintain fuel cooling up to a flood level corresponding to a return period of about 400 years for Tihange 1 unit, 1 600 years for Tihange 2 unit, and 900 years for Tihange 3 unit. However, additional means and resources, combined with a preventive flooding management process (a large-scale flood is a slow and predictable phenomenon with a sufficiently long warning period), are already available on the site to ensure safety functions in all circumstances.
The implementation of the action plan that has been drawn up as a result of the last periodic safety review in order to guarantee a "dry site" for this 10 000-yearly flood has been speeded up. It consists of peripheral (volumetric) protection of the site, local perimeter protection of some buildings and strengthened non-conventional devices.

Moreover, a potential rupture of the upstream dam on the Meuse river and the failure of the downstream dam were considered in the design phase and could not result in a water inflow onto the site.

Doel NPP

In the design basis of the Doel NPP, the design basis flood was set at 9.13 m TAW ("tweede algemene waterpassing" or "second general waterlevel measurement"). TAW is the reference height used for measuring topological height measurements in Belgium. A TAW-height of 0 metre is equal to the average sea level at low tide in Ostende.
This design basis flood has a return period of once every 10 000 years. Recently, as part of the periodic safety reviews, this design basis value was re-evaluated and slightly adjusted to 9.35 m TAW.
It should be mentioned that the highest level of the Scheldt river ever registered in Belgium is situated at 8.10 m TAW.

In the design basis two important protection measures are taken against flooding of the Doel NPP site.
The first one relates to the Scheldt embankment at the site, which initially was raised to 12.08 m TAW and is always required to be higher than 11.08 m TAW. The second measure refers to the raising of the site platform level with regard to the surrounding polders: in the design basis, the site's platform was situated at 8.86 m TAW, which is a few metres higher than the surrounding polders.
These measures ensure that the units and their safety systems are protected against a 10 000-yearly flood.

As part of the periodic safety reviews, various theoretical storm scenarios were combined with various flood levels which might lead to a wave overtopping over the Scheldt embankment for return periods between 1000 and 10 000 years.

Additionally, a beyond design situation was examined in which the Scheldt river level was once more raised by 85 cm above the design basis flood, and this, in combination with a hypothetical embankment breaching at the most penalizing location. The on-site water flooding resulting from this theoretical exercise, as well as from the wave overtopping phenomenon, can be remedied by installing a perimetric protection of a few tens of centimetres in height at the entrances of the respective safety buildings.
Moreover, the early warning system for flooding always enables the Doel NPP to take preventive measures given the slowness of these types of natural phenomena.

7.1.3. Extreme weather conditions

The various extreme weather conditions (heavy rainfalls, strong winds, tornadoes, lightning, snowfalls hail and extreme temperatures) that were considered when designing the facilities and verified during periodic safety reviews, have no impact on the safe operation of the units.

7.1.4. Loss of electrical power supply or heat sink

Tihange NPP

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

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

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

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

Doel NPP

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

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

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

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

In every unit are 2 internal electrical power supply levels. These 2 levels function independently from one another and are mainly physically separated. For the power supply of the safety equipment, there are 19 diesel generators with – in total – a few weeks fuel supply.
Moreover, most diesel generators are air-cooled, thus making them independent from an external heat sink.
Finally, every unit disposes of a pump, powered by a steam turbine, in order to be able to continue supplying cooling water to the steam generators. This cooling water is available in various tanks and in the cooling ponds.

On both sites

Nonetheless, some measures are considered to still enhance the robustness of the facilities on both sites, in particular by strengthening power and water supplies through the following actions:

- feasibility studies for enhancing the autonomy of the EAS reservoir, for adding an emergency feedwater pump and for securing power supply of the CTP and RRA pumps for the Tihange 1 unit;
- study for implementing extra instruments to monitor the water level in storage pools at Tihange site;
- strengthening non-conventional devices used to recharge batteries and repower some equipment (pumps, compressors, valves);
- new or adjusted procedures (power supply for equipment through non-conventional means, spent fuel pool management, minimization of the fuel consumption by the diesel generators in case of an extended loss of the external power supply…).
- installation of the necessary nozzles on the intake and discharge of the spraying pumps in order to achieve an alternative spraying flow with a mobile spraying pump at Doel 3 and Doel 4 units.

7.1.5. Emergency organisation and severe accident management

So far, the licensee's organisation in emergency situations has been designed to overcome events affecting a single unit of the NPP and to manage design basis external events. This organisation is periodically tested and improved through exercises. The organisation also relies upon external resources and skills provided by Electrabel corporate services, Tractebel Engineering, and public authorities.

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

In this respect, many actions have been decided or are being considered:

- the Tihange site operation centre ("COS") will be moved to an underground room in the new DBE-resistant entrance building, that is equipped with all the required infrastructure;
- a study on modifying and strengthening the emergency management organisation will be launched in order to be able to work according to three warning levels:
    - a "standard level" (currently in force),
    - an "alert level" (preventive measures in case of predictable events such as flooding affecting the whole site),
    - and a "high level" (unpredictable event affecting more than one unit). With this warning level, on-call teams would be reinforced so that the incident could be technically managed at the level of each affected unit.

  The current emergency management organisation at the corporate level will also be reviewed and strengthened so as to ensure – within 24 hours at most – the implementation of logistic and technical tasks and to provide human resources to assist the site teams.
- a study aimed at optimising mobile means and their storing infrastructure will be conducted taking into account the analysis of the extensive damage mitigating guidelines ("EDMG");
- for the Doel NPP, an off-site operating base will be defined from where on-site interventions will be organised if site access is difficult.

In the same way, the scenarios involving severe accidents have been reassessed from a "defense in-depth" perspective – though prevention still prevails – in order to identify the actions that could further reduce the risk of potential releases into the environment resulting from an extreme situation.
In this respect, the following actions will be initiated or continued:

- feasibility study for installing a filtered vent system on the containments of each unit;
- assessment of the residual risk of hydrogen production and accumulation in spent fuel pool buildings;
- follow-up of R&D activities related to the "corium-concrete" interaction issue.

7.1.6. Action plan

The planning for implementing the identified studies and proposed adjustments must be finalised after detailed evaluation of its content and potential implications, as it interacts with other projects, internal and external resources or time constraints related to supply and implementation on the sites.

The table below lists all the major actions defined by the licensee with deadlines for their implementation. Some actions will be completed in 2012 (short-term actions).

Table 22: Action plan summary

	Objective	Applicability	Actions	Indicative deadline
1	**Enhanced protection against external hazards (earthquake, flooding, weather conditions)**	Tihange + Doel	SSC upgrade from "low" to "medium" via calculation or modification	2012-2013
		Tihange	Assessment of the opportunity of strengthening the electrical building ("BAE") of Tihange 1 unit	2012
		Doel	Seismic qualification of the refuelling water storage tanks ("RWSTs") of Doel 1/2 units	2014
		Doel	Increase of the reliability of the water supply to the steam generators of Doel 1/2 units in case of an earthquake (automatic start of the emergency feedwater pumps)	LTO project
		Tihange	Review of the design basis flood for Tihange site as a result of the periodic safety review	2012
		Tihange	Acceleration of actions resulting from the periodic safety review: 1. peripheral protection of the site 2. local perimeter protection 3. strengthening non conventional devices/resources	 2014 2012-2013 2011-2012
		Doel	Perimetric protection of the relevant safety buildings against flooding	2012-2013
		Doel	Additional embankment reinforcement	2012
2	**Enhanced power supply**	Tihange + Doel	Alternative power supply (380 V) for non conventional means or safety equipment (compressors, pumps, valves…) using suitable connectors and cables or via the existing electrical boards	2012
		Tihange	Feasibility study for re-powering the pumps of the CTP and RRA cooling systems from the SUR system on Tihange 1 unit	LTO project
		Tihange + Doel	Alternative power supply (380 V) for rectifiers using suitable connectors and cables or via the existing electrical boards	2011-2012
		Tihange + Doel	Introduction of a procedure for minimising the diesel generators fuel consumption by stopping non-essential equipment	2012
		Doel	Purchase of a fuel tanker truck for the on-site transportation of diesel fuel and identification of the required nozzles	2012
3	**Enhanced water supply**	Tihange	Feasibility study for enhancing the autonomy of the EAS auxiliary feedwater reservoir on Tihange 1 unit	LTO project
		Tihange	Feasibility study for adding an auxiliary feedwater pump on Tihange 1 unit	LTO project
		Doel	Study of alternative supplies of the safety-related water reservoirs (RW and RN cooling towers, AFW) including supplementary nozzles, if required	2012-2013

	Objective	Applicability	Actions	Indicative deadline
		Doel	Installation of valves on the SP spray lines of Doel 1/2 units to allow injecting into the SC circuit with the SP pumps in case the RC pressure increases	2014
		Doel	Installation of nozzles on the intake and discharge of the SP pumps and purchase of a mobile pump in order to achieve an alternative SP flow rate for Doel 3 and Doel 4 units	2014
		Doel	Study of alternative water supply for the spent fuel pools (PL) with supplementary nozzles, if required	2012-2013
		Doel	Seismic qualification of further parts of the FE circuit on Doel 1/2 units and installation of FE nozzles on the intake (directly or via AFW tank) of the auxiliary feedwater turbo pump	LTO project
4	**Enhanced operation management (procedures)**	Tihange	Modification of "earthquake procedure" intended to speed up the detection of induced flooding on the site	2012
		Tihange	Accelerated implementation of the procedures related to the actions resulting from the periodic safety review about flooding	2012-2013
		Tihange + Doel	Introduction of a procedure describing the actions to take in case of: 1. a total loss of internal or external power supplies 2. a total loss of heat sinks	2012-2013
		Tihange + Doel	Introduction of a procedure for the connection and the commissioning of alternative power supplies	2012-2013
		Doel	Completion of the procedures for the connection and use of the alternative water supplies	2012-2013
5	**Enhanced emergency management (PIU)**	Tihange + Doel	Enhance the organisation and logistics of the internal emergency plan to include "multi-unit" events: 1. description of the new organization 2. implementation of the new organisation	Mid-2012 2013
		Tihange	Transfer of the site operation centre ("COS") in the new entrance building	2013
6	**Enhanced protection against severe accidents (SAM)**	Tihange + Doel	Preliminary study for installing a filtered vent system on each unit (already included in the LTO project for Tihange 1 and Doel 1/2 units)	2012
		Tihange + Doel	Evaluation of the need to extend the non conventional means based on the analysis of the extensive damage mitigation guidelines ("EDMG")	2013
		Tihange + Doel	Assessment of the residual risk of hydrogen production and accumulation in spent fuel pool buildings	2012
		Tihange	Feasibility study for the implementation of additional water injection into the reactor pit	2013
		Tihange + Doel	Follow-up of R&D activities related to the corium-concrete interaction issue	Continuously
		Tihange	Study for improving water level monitoring in the pool of every unit	2012
7	**Non conventional means ("NCM")**	Tihange	Feasibility study to provide a technical solution for water make-up to the primary system of Tihange 3 unit in "CRP open" configuration (motor-driven pump powered by a non conventional diesel generator)	2012

7.2. Synthesis of the assessment and additional improvements required by the regulatory body

The approach adopted by the licensee to re-evaluate the safety of its facilities complies with the methodology provided by the licensee and approved by the regulatory body.

The licensee reassessed the events and combinations of events included in the field of the European stress tests program, namely earthquake, flooding, extreme weather conditions, loss of electrical power and loss of ultimate heat sink, and severe accident management.
The assessments consider scenarios involving a single unit but also several units simultaneously on the same site. The timeline of events is described and the potential cliff-edge effects are analyzed.

Overall, the robustness of the facilities is satisfactory.

The basic safety principles, such as defence in depth, redundancy of important safety equipment, their physical or geographic separation, as well as their diversification, were applied from the design phase, and upgrades were performed on the earliest units to enhance their robustness when faced with scenarios not considered originally. Some structural reinforcements were also carried out where appropriate.

The reassessments performed in the wake of the Fukushima accident thus show that in all considered scenarios, the essential safety functions are preserved.

Yet, the licensee has proposed a series of technical, organizational and human improvements in order to further increase the safety of its facilities and better cope with specific accidental conditions, particularly for the earliest units.

Based on the assessment of the licensee's reports and the subsequent technical meetings and on-site inspections, the regulatory body has complemented the licensee's proposals with additional demands and recommendations that will extend the improvement opportunities within the scope of the European stress tests.

The actions proposed by the licensee and the additional improvements required by the regulatory body shall be implemented in the shortest possible time, considering the complexity of the works to be undertaken and their importance for the safety of the facilities. To this end, the licensee will update a consolidated action plan, and propose ambitious deadlines that will be approved by the regulatory body.

On this basis, the regulatory body will set up a dedicated follow-up of the action plan implementation, including:

- regular update by the licensee of the action plan progress, which will be communicated periodically to the regulatory body,
- periodic information meetings between the regulatory body and the licensee, to discuss the action plan status and potential difficulties / delays,
- on-site inspections by the regulatory body, on a periodic basis and also after the main achievements, to check on the field the physical progress of the work and their compliance with the expectations.

This follow-up will allow the regulatory body to control the proper implementation of the licensee's action plan, and to ensure that the licensee's commitments are fulfilled in due time.

The dedicated site inspectors from the FANC and Bel V will be involved in this process.

The following paragraphs recall the additional improvements identified by the regulatory body.

7.2.1. Earthquake

1. For all weaknesses identified during the walkdowns (SSC assessed as having a "low" probability of preserving their integrity and performing their function in an earthquake exceeding the RLE), the licensee reported that either complementary studies are underway or simple modifications can be undertaken. The licensee shall provide a detailed action plan containing actions taken and actions planned. This also applies to the feasibility study on reinforcement of the electrical building ("BAE") at Tihange 1.

2. Due to the stringent timeframe of the European stress tests, the PSHA study of the ROB had to be conducted in quite a short time. As suggested by the ROB, the licensee should carry out a more elaborated study with due consideration of (1) other elements such as the use of a more recent ground-motion prediction equation or such as a cumulative absolute velocity ("CAV") filtering, (2) external reviews by international experts and (3) results arising from other studies such as the EC-project SHARE (seismic hazard harmonization in Europe).

3. The licensee must continue its efforts towards fostering awareness of potential seismic interaction inside the facilities. In particular, thorough attention must be paid to the strict application of the relevant procedures to avoid the interactions of scaffoldings with SSC that are seismically qualified.

7.2.2. Flooding

Tihange NPP

1. The licensee shall include a safety margin for the first level of defense to adequately cover uncertainties associated with a 10,000-year flood (the wall of the peripheral protection should thus be designed higher than the flood level associated with a 10,000-year flood).

2. For the flooding risk, further improvement of the emergency preparedness strategy and organization, including corresponding procedures, should be implemented by mid 2012.

3. The robustness of the currently installed non-conventional means (NCM), i.e. the so-called Ultimate Means Circuit (CMU) should be further improved:
   - Since the CMU is currently needed for floods exceeding the "reference flood" of 2615 m^3/s (i.e., floods with return periods exceeding 100 to 400 years), the licensee should determine specific provisions as applicable to equipment important for safety (tests, maintenance, inspections, …).
   - The currently implemented alternate power sources for I&C systems and emergency lighting should be further improved, where needed, and the sufficiency of available or recovered I&C equipment to safely control the three units should be checked.
   - The technical characteristics of these non-conventional means (NCM) should account for the adverse (weather) conditions they may be subject to during the whole period of operation. If this is not covered by design, an appropriate protection or compensatory strategy should be developed.

4. The robustness of the currently implemented emergency preparedness strategy and organization should be further improved for the following aspects:
   - The flooding alert system, which is based on a direct communication between the regional service competent for forecasting river flow rates in the Meuse basin (SETHY, making use of a dedicated forecasting system) and the NPP (with Tihange 2 being the single point of contact and responsible for warning Tihange 1 and Tihange 3), is a crucial factor. Therefore, its robustness and efficiency should be further improved. In particular,
     - the protocol between the NPP Tihange and SETHY should be formalized as soon as possible.

  - The licensee should pursue regular tests of the secured communication channels and transmitted data (i.e., on-line measurements and predictions of river flow rates).
  - The licensee should organize emergency preparedness exercises involving both the NPP and SETHY personnel.
  - Criteria used to launch the internal emergency plan and to start the "alert phase" and associated actions should be unambiguously defined in the applicable emergency procedures.
- Means for *on-site transport* of personnel and equipment towards the units, inside the units, or from one unit to another, while the site is flooded, should be further implemented and considered in the emergency preparedness strategy.

5. Internal hazards potentially induced by the flooding (fire, explosion) should be examined and additional measures should be taken where needed (e.g., because the automatic fire extinction system is lost during a flood exceeding the "reference flood"). The potential deficiency of the Ultimate Means Circuit (CMU) in case of induced fire, in particular because of dependencies when the CMU is connected to the fire extinction system (CEI), should be examined and potential weaknesses should be resolved.

Doel NPP

1. The technical characteristics of the non-conventional means (NCM) that can be used in case of flooding of safety-related buildings (for all potential causes) should account for the adverse (weather) conditions they may be subject to during the whole period of operation. If this is not covered by design, an appropriate protection or compensatory strategy should be developed.

2. Improvement of the procedures after earthquake (I-QM-01): after an earthquake, it shall be rapidly and visually verified if flooding due to cooling tower basin overflow (e.g. due to obstruction of its outlet channel) is ongoing or imminent. In that case, the CW pumps must be rapidly stopped.

3. As recent inspections evidenced locations with embankment heights approaching the minimal required height (Technical Specifications criterion), embankment height inspections should be done more regularly (e.g., two-yearly, and at least 5-yearly, instead of ten-yearly) in order to avoid a risk of excessive embankment overtopping by wind waves for floods within the design basis (embankment overtopping may occur for return periods larger than 300 years).

7.2.3. Extreme weather conditions

1. The reassessment of the capacity of the sewer system (five separate networks at Doel, separate networks per unit at Tihange), using a detailed hydrodynamic model must cover both short-duration heavy rains and long-lasting rains (95th percentile) for return periods up to 100 years. Moreover, to define such 100-yearly rains, observations of rain intensities over a sufficiently long period of time must be used, including the latest observations (e.g. the exceptional rain of 23rd August 2011). Depending on the results, potential improvements of the sewer system shall be envisaged and the licensee's action plan shall be updated accordingly where appropriate.

2. Given the fact that tornadoes of high intensities were observed in the past years in the neighbouring countries (class EF4 on the enhanced Fujita scale), the robustness of the second-level systems of Doel 1/2 and Tihange 1 should be confirmed in case of a beyond-design tornado with wind speed exceeding 70 m/s (250 km/h).

7.2.4. Loss of electrical power and loss of ultimate heat sink

1. The operability of the non conventional means should be justified on the basis of technical data (design, operation, alignment and connections, periodic testing, preventive maintenance, etc.).

2. The technical characteristics of the non-conventional means (NCM) should account for the adverse (weather) conditions they may be subject to during the whole period of operation.

3. The licensee should, in collaboration with ELIA, manager of the high voltage network, make a feasibility study to ensure a better geographical separation of the high voltage lines (380 and 150 kV) to further improve the reliability of the external power supply to the NPPs. In addition, the licensee should, in agreement with ELIA, ensure that in case of LOOP the NPPs have the highest priority for reconstruction of the external power supply to the NPPs. The regulatory body shall take the necessary steps, in collaboration with other competent authorities, to ensure the fulfilment of this recommandation.

4. In relation to the "total SBO" scenario, the potential overfilling or draining of the steam generators due to the loss of ultimate compressed air should be examined.

5. In relation to the "total SBO" scenario, the operability of the AFW turbine-driven pump due to the loss of ventilation in the turbine-driven pump room should be examined.

6. In case of (total) station black-out, the licensee should assess whether all containment penetrations can be closed in due time and whether the relevant containment isolation systems remain functional, in particular during outage situations. The feasibility of closing the personnel and material hatches should be assessed. These topics should be addressed in the "total station black-out" procedure.

7. The licensee shall justify that the water capacity (quantity and flow of cooling water for the consumers) of the second level of protection is sufficient when all the units of the site are affected by the loss of primary UHS. If needed a strategy to optimize the water consumption should be developed.

8. For Tihange, the licensee should reinforce the emergency lighting in the different rooms and places where the operators should intervene during the different scenarios.

9. In relation to the "loss of primary UHS" scenario, the licensee shall carry out alignment and operating tests of the emergency deep water intakes from the Meuse river bed in 2012 (for Tihange 2 and 3).

10. In relation to the "loss of primary UHS" scenario, the licensee should justify the availability (accessibility, operability and alignment) of the emergency water intakes of Tihange 2 and 3 in accordance with the requirements of US NRC RG 1.27.

11. Two configurations should be evaluated by the licensee for the spent fuel pools:
    - Configuration with a fuel assembly handled in the reactor pool during a "Total SBO". The fuel assembly should manually be handled in a safe position. The licensee should investigate the provisions (hardware installations, procedures, lighting, etc.) to be implemented for this configuration.
    - Configuration with the loss of water inventory in the spent fuel pools. The international experience feedback has already pointed out potential problems with the design of the siphon breakers in the spent fuel pools. In case of piping rupture, an insufficient capacity of the siphon breakers may lead to a fast uncovering of spent fuel assemblies. The licensee should examine this safety concern.

7.2.5. Severe accident management

1. The adequacy of the procedural guidelines (BK procedures for Doel and severe accident management guidelines for Tihange) to cope with a severe accident has been assessed by the licensee, relying mainly on the fact that those procedures are inspired from the Westinghouse owners group severe accident management guidelines ("WOG SAMG"), are regularly updated, and are validated in the framework of the ten-yearly periodic safety reviews.
   Yet, those procedures still need to be improved with respect to the following aspects:
   - the Doel BK procedures should be supplemented with long term monitoring and exit guidelines, such as those already existing for Tihange (SAEG-1 and SAEG-2);
   - in some Doel BK procedures, reference is made to (the distinct) FRG procedures for the explanation of recommended methods. This constant switching between different procedures should be avoided, and therefore the BK procedures should be more self-supporting and contain all information needed for their application;
   - an in-containment pH calculation tool should be added to the BK/SAMG procedures to determine the sump water acidity from the volumes and water quantities used during the management of the accident, taking into account all other physical and chemical pH influencing processes; this tool would also be used as a check and back-up for a dedicated sampling system;
   - a decision support tool (table/flow chart) should be added to the BK/SAMG procedures to quickly pinpoint the (most probable) location of a containment leak path based on the readings of certain detectors and to determine the most appropriate actions to limit the spread of fission products. This approach might involve the deployment of mobile detectors at specified locations;
   - the BK procedures should provide quantitative criteria for selected key parameters to quickly arbitrate between the evacuation of the residual heat and the isolation of a leak in recirculation lines;
   - a decision support tool should be added to the BK procedures to arbitrate between injecting into the primary circuit and spraying inside the containment building.

2. As much as possible, the licensee should consider to increase the consistency between the Tihange NPP and the Doel NPP with respect to the emergency training and refresher training programs (different in duration and frequency).

3. For the Doel NPP, the licensee states that the probability of a steam explosion when corium falls out of the reactor vessel into a flooded reactor pit is very low and can thus be neglected, based on various experiments carried out as part of international research programs that were unable to create this phenomenon.
   For the Tihange NPP (where the reactor pit is not flooded prior to the reactor vessel breach), the licensee states that a feasibility study of a system allowing water injection into the reactor pit will be launched.
   However, the licensee should follow-up the ongoing steam explosion experiments closely. If needed, the current strategies for flooding of the reactor pit before the rupture of the reactor vessel should be adapted.

4. The licensee should also assess the need of fitting new devices that would be useful for severe accident management (pH measurement in the sumps, temperature measurement at the bottom of the reactor vessel to monitor a potential core melt).
   The associated hardware modifications to improve those aspects should be sought where appropriate.

5. The licensee should identify the effective means to control the pH inside the containment building after a severe accident. This requirement applies in the early stages of the accident, and also during the long term phase.
   For the management of the long term phase of a severe accident, the licensee should take into consideration the impact of other severe accident management actions on the possibility of refilling the NaOH tank and the possibility for non-NaOH injection related measures to influence the sump water pH in the alkaline direction.

6. As a further diversification of the strategies available to manage a severe accident, an optimal battery load shedding strategy (in order to extent as long as possible the lifetime of the batteries and thus the period of availability of vital equipment for the management of the severe accident), should be developed and added to the ERG procedures (severe accident prevention) and to the BK/SAMG procedures (severe accident mitigation).
   A calculation and decision support tool should be studied in parallel to determine the loads that can be shed, the extra battery autonomy gained by shedding a specific load, the severe accident management functions that will be lost by shedding a specific load, and the alternatives that could be considered to (partly) compensate for the loss of each particular severe accident management function.

7. The licensee should review the plants technical specifications in order to further improve the availability of the second level emergency equipment. In particular, the maximum allowed downtimes and the time limits for return to service should be re-evaluated and justified, given the risks involved.

8. The licensee should regard the additional means (including non conventional means) as safety related equipment as long as they play a key role in the prevention, the detection and/or the mitigation of a severe accident (defence in depth). In this context, the licensee shall determine the specific provisions applicable to this equipment where appropriate (introduction in the technical specifications, inspections and testing, preventive maintenance…).