FANC

FEDERAAL AGENTSCHAP VOOR NUCLEAIRE CONTROLE

REPORT

BENCHMARK NUCLEAR SAFETY REQUIREMENTS IN BELGIUM AND ABROAD

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Document history log

Revision	Revision date	Description of changes
0	2025-03-31	Initial version

Abbreviations & terms

ANVS	Autoriteit Nucleaire Veiligheid en Stralingsbescherming Dutch Authority for Nuclear Safety and Radiation Protection
ARBIS	Royal Decree of 20/07/2001 containing general regulations on the protection of the population, workers and the environment against the dangers of ionizing radiation
ASNR	Autorité de Sûreté Nucléaire et de Radioprotection French Authority for Nuclear Safety and Radiation Protection
AtG	Atomgesetz, German law
Bel V	Technical subsidiary of the FANC
BMUV	Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz, German federal authority for nuclear safety
ENSI	Eidgenössisches Nuklearsicherheitsinspektorat, Swiss authority for nuclear safety
FANC	Federal Agency for Nuclear Control
RD SRNI	Royal Decree of 30/11/2011 on the safety requirements for nuclear installations
KEV	Kernenergieverordnung, Swiss ordinance
KTA	Kerntechnische Ausschuss, German commission
LTO	Long Term Operation
Design basis	The range of conditions and events taken explicitly into account in the design and upgrading of a nuclear installation, according to established criteria, such that the installation can withstand them without exceeding authorised limits when the safety systems are operational. Analyses within the design basis must be conservative and there must be margins.
Design extension	The set of conditions and events that are more complex or more severe than those postulated as design basis accidents. These conditions can be caused by multiple initiating events, multiple failure events, highly unlikely events or postulated conditions. Analyses within the design extension may use more flexible and less conservative methods than for the design basis.
Exceedance frequency of $10^{-4}/10^{-5}$ per year	An event (e.g. earthquake) that occurs once on average in a 10,000 year (10^{-4} per year) / 100,000 year (10^{-5} per year) period. An event with an exceedance frequency of 10^{-5} per year is more serious than with an exceedance frequency of 10^{-4} per year.

PSR	Periodic Safety Review, to be carried out at least every 10 years
PWR	Pressurized Water Reactor
RSK	Reaktor-Sicherheitskommission, German advisory body
SiAnf	Sicherheitsanforderungen an Kernkraftwerke, German guidelines
SUR	Système d'Ultime Repli, emergency system at Tihange 1
SURe	SUR étendu, additional extended emergency system at Tihange 1
VOBK	Guide for the safe design and operation of nuclear reactors, Dutch guidelines
WENRA	Western European Nuclear Regulators Association
WENRA SRLs	WENRA Safety Reference Levels
Probabilistic analysis	A method of evaluating the safety or performance of a system by taking into account uncertainties and probabilities in the input parameters & models and obtaining quantified risk estimates.
Deterministic analysis	A method whereby a single numeric value is used for key parameters (without considering probability), resulting in a single outcome. This is a method where you start from a specific fixed scenario and calculate the result via predetermined assumptions and rules.

1. Introduction and scope

Belgium has 7 nuclear reactors on its territory which were built to generate electricity. There are 4 reactors at the site of the Doel nuclear power plant and 3 reactors at the site of the Tihange nuclear power plant. These reactors are all PWR (Pressurized Water Reactors). When these reactors were designed and built, Belgium did not have a national regulation with comprehensive safety requirements for nuclear installations. The choice was therefore made to observe foreign (mainly American) safety regulations and standards. Over time, new insights and evolutions in safety rules and standards and in design principles emerged, whereby the specific design of each reactor depends on when it was built.
The construction and operating licence was therefore issued for each reactor based on the chosen safety rules and standards set out in the reactor's 'safety report'. Subsequently, as is mandatory in all European countries, a Periodic Safety Review (PSR) was organised every ten years, with the aim of thoroughly evaluating the nuclear safety of the installations against the norms and standards of the time, and implementing improvement measures where necessary.

The Western European Nuclear Regulators' Association (WENRA) brings together the safety authorities of all European Union member states where nuclear power plants are operational, such as the FANC. Over the period 2006-2008, WENRA published a selection of "Safety Reference Levels for existing reactors" (WENRA SRLs). The benchmark at the time showed that the majority of WENRA SRLs were complied with in Belgium, but were not explicitly included in the regulations. Since the safety authorities that are members of WENRA committed to take the necessary initiatives to harmonise their regulatory framework based on the WENRA SRLs, the FANC launched a regulatory initiative that resulted in the Royal Decree of 30 November 2011 on the Safety Requirements for Nuclear Installations (RD SRNI).
Since the original publication of the WENRA SRLs, WENRA has further updated them. For example, in 2014, to take into account the lessons learned from the Fukushima-Daiichi nuclear accident (resulting from the underwater earthquake near Sendai and subsequent tsunami on 11/03/2011). The most recent update to the WENRA SRLs was in 2020. The RD SRNI has also been amended each time to reflect the revised WENRA SRLs.

The coalition agreement of the federal government, as published on belgium.be, states in the Energy chapter that the FANC has been requested to provide a report to compare the safety requirements for nuclear installations in Belgium with those in countries with similar technology. This request was formally submitted to the FANC by its responsible minister, Minister of Home Affairs Bernard Quintin, by letter dated 26/02/2025. To respond to this request, the FANC made a selection of countries to compare with. The following criteria were used:

- Presence of reactors with similar technology, PWRs, built in the same period as the first generation of Belgian reactors (Doel 1&2 en Tihange 1);
- Availability of sufficient publicly available information regarding the safety requirements for reactors, to facilitate a comparison;
- Being a member of WENRA.

Based on these criteria, **Germany**, **France**, the **Netherlands** and **Switzerland** were selected for comparison in this report.

Like Belgium, these countries have transposed (or are in the process of transposing) the WENRA SRLs into their national regulatory framework. Not every country has adopted the same approach in this regard. A brief summary of the regulatory framework of each country and how the WENRA SRLs were taken in consideration is given in *§2 - Regulation & Transposition of WENRA 'Safety Reference Levels for Existing Reactors'*.
When the WENRA SRLs (from 2014) were transposed into Belgian regulations in 2020, additional and specifically Belgian safety requirements and clarifications were included, such as resistance to aircraft crashes, shared systems and automatic/autonomous operation. These topics, along with earthquake resistance, are all important, well-known design concerns for the potential Long Term Operation of the first-generation Belgian reactors. The regulations on these four 'key topics' for all selected countries are therefore discussed in *§3 - Regulatory approach for the key topics*.
Because a comparison between different countries is not always possible on the basis of regulations alone, this report also refers to the current status of specific reactors. For Belgium, the selected reactors include both the first-generation reactors (**Doel 1&2** and **Tihange 1**) and the most recent reactors (**Doel 4** and **Tihange 3**). For the other countries, the FANC chose as the most relevant reactors[1], **Gravelines** (France), **Borssele** (Netherlands) and **Beznau 1** (Switzerland). For information, *Annex A - Characteristics of the considered reactors* summarises some basic data for these reactors. This status, to the extent known by the FANC and its subsidiary Bel V, is given for the same four 'key topics' and is summarised in *§4 - Overview of known status of reactors in Belgium and abroad*.

This report was possible thanks to the cooperation of colleagues from the FANC, from the technical subsidiary Bel V and from the foreign safety authorities BMUV (Germany), ASNR (France), ANVS (Netherlands) and ENSI (Switzerland). For each country, the FANC first described the regulations and the situation of the selected reactor based on, inter alia, the 'Convention on Nuclear Safety' reports, stress test reports (conducted in the aftermath of the Fukushima-Daiichi accident), exchanges within WENRA and other available documents. These descriptions were submitted for each country to the relevant safety authorities (i.e. BMUV, ASNR, ANVS, ENSI) for feedback, along with several questions. The comments and responses received[2] were taken into account when the report was finalised.

It was also verified that this report does not contain any confidential or classified information. Aspects concerning nuclear security were also excluded from the scope of this report.

[1] There is no German reactor that was commissioned in the mid-1970s and which remained operational until recently. As such, no German reactor was used in the comparison.

[2] A more comprehensive description of the German regulatory framework (with a focus on resistance against earthquakes and aircraft crashes) and the analyses and safety measures carried out in the aftermath of the Fukushima-Daiichi accident, was made available to the FANC by the BMUV. Only an abbreviated and simplified version of this description could be included in this report. The BMUV stressed that this more comprehensive description should be consulted to obtain a full and complete picture of the German situation.

2. Regulation & transposition of WENRA 'Safety Reference Levels for Existing Reactors'

2.1. WENRA

Within the WENRA grouping of safety authorities, a working group was active in the early 2000s that pursued further harmonisation of the approaches to nuclear safety in European countries. The term 'harmonisation' refers to both regulation and implementation in the field, and was defined as, "*no substantial differences between countries from the safety point of view in generic formally issued national safety requirements, and in the resulting implementation on the Nuclear Power Plants*".

The activities of this working group resulted in the selection of a series of *reference levels* for the safety of existing nuclear reactors. The first version of these reference levels, or WENRA SRLs, was published in 2008. The origins of the WENRA SRLs can be found in the numerous safety guidelines and standards issued by the International Atomic Energy Agency (IAEA). These WENRA SRLs only relate to existing reactors for electricity production.

The managers of the safety authorities that are members of WENRA undertook to take the necessary initiatives to harmonise their regulatory framework based on the WENRA SRLs, and ensure their implementation in the field.

As regards the transposition of the WENRA SRLs, each country has been given a certain freedom on how to do it (in the form of laws, decrees, directives, etc.). Certain countries, where there was already an elaborate framework of safety regulations, chose to amend or expand these as needed. Other countries chose to develop a new general framework of safety regulations that incorporated all reference levels. These SRLs were therefore established as minimum requirements for existing reactors, with each country still free to adopt its own approach and additional requirements if it deems it necessary to protect its population.

A key principle for the transposition of the WENRA SRLs into a regulatory framework is that these requirements must always be formally laid down in a public and transparent manner, and must also be generic for all operators involved (i.e., including a requirement in the licence or safety report is not enough).

2.2. Belgium

In Belgium, the regulatory framework for nuclear safety is formed by the FANC Law (Law of 15 April 1994 on the protection of the public and the environment against the hazards of ionising radiation and on the Federal Agency for Nuclear Control) and its implementing decrees. For nuclear safety, these are the GRR-2001 (Royal Decree of 20 July 2001 laying down the General Regulation for the protection of the public, workers and the environment against the hazards of ionising radiation) and the RD SRNI (Royal Decree of 30 November 2011 on the safety requirements for nuclear installations).

In addition, the FANC may establish technical regulations on specific topics, insofar as this is provided for in a RD or a law. These technical regulations are binding. Finally, the FANC, like its subsidiary Bel V, issues non-binding notes and guidelines. Their purpose is to clarify the expectations of the safety authority and/or describe an approach that it deems acceptable.

All WENRA SRLs have been bindingly transposed into Belgian regulations through (primarily) the RD SRNI. This new royal decree was drafted taking into account the structure and topics of the WENRA SRLs. A distinction was made here between generic regulations (valid for all Class I nuclear installations) and specific regulations applicable only to 'power reactors'. This RD SRNI was subsequently further expanded to include specific regulations for radioactive waste and spent nuclear fuel storage installations, research reactors, etc.

These new regulations were always developed in consultation with the operator concerned, who could give feedback on the proposed requirements. The operator also had to propose a practical action plan to ensure compliance with the (new) requirements. Since some requirements are related to the design of the installations, the necessary transition periods have been included pragmatically. These transition periods generally run until the next Periodic Safety Review of the reactor (e.g. 2015 for Doel 1&2 and Tihange 1 for the implementation of the first requirements from the RD SRNI).

When the 2014 revision of the WENRA SRLs was transposed into the RD SRNI (in 2020), a conscious decision was made to include several additional requirements related to the specific situation in Belgium, and clarify or reformulate unclear and/or ambiguous requirements (see discussion in *§3 - Regulatory approach for the key topics*). This decision to include additional requirements was taken to ensure that the oldest reactors would get close to the safety level of the most recent Belgian reactors. The envisaged transition period ran again until the next Periodic Safety Review (i.e. 2025 for Doel 1&2 and Tihange 1).

2.3. Germany

The German Atomic Energy Act, the AtG (*Atomgesetz*) stipulates that a licence can only be granted if the necessary precautions, according to the current state of science and technology, have been taken against damage caused by the construction and operation of the installation.

The BMUV (German federal authority for nuclear safety) issues guidelines. These are not directly binding on the nuclear installations. However, by including them in the licence or by decision issued by the regional authority for nuclear safety, these guidelines can become binding.

The BMUV issued the SiAnf (*Sicherheitsanforderungen an Kernkraftwerke*, *Safety Requirements for Nuclear Power Plants*); which is one of these guidelines with safety requirements for nuclear power plants. The SiAnf contains the fundamental and overarching safety requirements that are intended to clarify these precautions according to the current state of science and technology (cf. the AtG). When the SiAnf was drafted, the WENRA SRLs were taken into account and most of these reference levels are therefore included here (although some of the WENRA SRLs are covered in other regulations).

The SiAnf does leave room for interpretation, which can lead to difficulties in design and technical implementation. The BMUV therefore issued clarifying interpretations with the SiAnf. These interpretations should fill the gaps and therefore lead to uniform implementation of the safety requirements.

In addition to the guidelines of the BMUV, the underlying regulations include the publications of the advisory bodies (the RSK, SSK and ESK) and the KTA safety standards. The recommendations and opinions of the advisory bodies are published by the BMUV, whereby the German authorities have to take these into account in their decisions. The KTA standards translate the general requirements of the SiAnf into concrete technical provisions. The KTA (*Kerntechnische Ausschuss*) is a committee of experts representing manufacturers and operators of nuclear installations, technical safety organisations and (both federal and regional) nuclear safety authorities. The KTA standards are developed based on consensus within the KTA and can only take effect with the approval of the nuclear safety authorities. The KTA standards are not binding in themselves, but in Germany they play an important role in the licensing and supervision of nuclear power plants. In this regard, they are regarded as an anticipatory expert judgment, whereby, normally, respecting the KTA standard also implies compliance with the current state of science and technology. Given the high level of detail in the KTA standards, some WENRA SRLs are also covered by KTA standards.

2.4. France

The regulatory framework for nuclear safety in France is provided primarily by the *Code de l'environnement* and the *Arrêté du 7 février 2012 fixant les règles générales relatives aux installations nucléaires de base* (INB decree). In addition, the ASNR (i.e., the French authority for nuclear safety) can also draft its own technical regulations, which become binding once they are approved by the French government. The ASNR regulations primarily clarify and detail the provisions of the INB decree. Some of the WENRA SRLs are included in these binding ASNR regulations.

In addition, the ASNR develops guidelines (*guides* in French) on various technical topics. These guidelines are not binding. They include recommendations intended to clarify safety objectives, indicate the expectations of the ASNR, and describe practices deemed appropriate in order to ensure compliance. They are therefore mainly used in the licensing process (for new reactors) and in safety assessments (such as the PSR for existing reactors).
Previously, these guidelines were included in so-called 'fundamental safety regulations' (*Règles fondamentales de sûreté*, *RFS*), which are similar to the *guides de l'ASNR*. The *RFS* still apply, but will gradually be replaced by the *guides de l'ASNR*.
The WENRA SRLs, to the extent they were not already covered by other regulations, were included in the *guides de l'ASNR*. Various *guides de l'ASNR* are also currently being revised to reflect the changes to the WENRA SRLs.

2.5. Netherlands

The Nuclear Energy Act (KEW in Dutch) is the basis for the regulatory framework for nuclear safety in the Netherlands. This is supplemented by decrees, ministerial regulations and ANVS regulations, including the 'Ministerial regulation on nuclear safety of nuclear installations'. This regulatory framework is designed to achieve objectives-based regulation and only uses prescriptive safety requirements in exceptional cases.

The ANVS (i.e., the Dutch authority for nuclear safety) also develops guidelines that are non-binding. These guidelines reflect the expectations of the ANVS, clarify the binding rules and describe practices that are deemed sufficient in order to ensure compliance. These may be derogated from if (at least) an equivalent level of nuclear safety is achieved.

One of these guidelines is the "Handreiking VOBK" (Guidance on the safe design and operation of nuclear reactors), which is intended for new installations. The WENRA SRLs were taken into account (as were other references) when the VOBK was drawn up. New licence applications are evaluated on the basis of the rules inluded in the VOBK. In addition, for existing installations, this VOBK is also used as a reference during the Periodic Safety Review (PSR) of an installation.

In addition, some of the WENRA SRLs are also covered by binding regulations (Ministerial regulation on the nuclear safety of nuclear installations). Taking into account the existing practice of referring to specific guidelines in the licence to make them binding, the licence of the existing reactor in Borssele was modified to include the other WENRA SRLs (from the 2014 revision of the WENRA SRLs) as a condition for obtaining the licence.

Modifications to transpose the most recent revision of the WENRA SRLs are ongoing. The ANVS will also look at a more systematic implementation of the WENRA SRLs in the coming period. For now, the ANVS assesses whether the individual SRLs have already been implemented within the Dutch system, for example in regulations, a licence requirement, or in a guidance document (such as the VOBK). If not, the relevance and added value of the SRL are assessed, where it may be decided to incorporate that particular SRL.

2.6. Switzerland

The regulatory framework for nuclear safety in Switzerland primarily includes the Nuclear

Energy Act (KEG, *Kernenergiegesetz* SR 732.1) and the Nuclear Energy Ordinance (KEV, *Kernenergieverordnung* SR 732.11). Among other things, these lay down the basic principles and require preventive and protective measures to be taken during the design and operation, in accordance with internationally accepted principles. There is also an obligation to modify the installation, not only to the extent necessary, but also to the extent that further improvement is desirable. In addition, there are several ordinances, which impose more detailed obligations and are also binding, such as the ordinance SR 732.112.2 on external threats.

Finally, the ENSI (i.e., the Swiss authority for nuclear safety) issues directives either on the basis of an express delegation in an ordinance or in its capacity as nuclear safety authority. These guidelines concretise the legal requirements and are intended to facilitate uniform implementation. They also clarify the current state of science and technology. These guidelines are binding under the limitation of proportionality. The ENSI may grant derogations in individual cases if (at least) an equivalent level of nuclear safety is achieved.
An assessment of the application of regulatory requirements is carried out as part of the PSR. Any identified deviations from the regulatory framework may then result in mandatory changes for continued operation.

Through new guidelines or by modifying existing guidelines, the ENSI implements the WENRA SRLs to the extent they are not already covered in existing regulations. A screening of international guidelines (WENRA, IAEA) is mandatory when the ENSI guidelines are drafted and revised. Modifications for the most recent revision of the WENRA SRLs are ongoing, but have already been mostly completed.

3. Regulatory approach for the key topics

3.1. Aircraft crashes

The WENRA SRLs stipulate that external threats (natural phenomena and human activities that may unintentionally constitute a threat to the site) must be identified, and this must include aircraft crashes. Based on a site-specific risk assessment, occurrences must then be defined for the design basis. An exceedance frequency must be used and cannot be higher than 10^{-4} per year. Regardless of the probability, an accidental aircraft crash must be taken into account in the design basis.

According to the WENRA SRLs, that does however mean that the type of aircraft taken into account in the design basis must meet a probability criterion. This criterion is linked to the probability of an aircraft crash and not the probability of an unacceptable radioactive release (which is a criterion in some countries). The WENRA SRLs do not otherwise specify the type or category of aircraft. If the probability criterion does not impose a specific type of aircraft, a small recreational aircraft can also be taken as a reference.

3.1.1. Belgium - aircraft crash

The amendment to the RD SRNI in 2020 stipulated that the design basis must include crashes of both commercial aircraft and military aircraft in any case, regardless of the exceedance frequency. Existing reactors must comply with this through the implementation of their PSR action plan (i.e. in the event of an LTO). There is certain flexibility (such as less conservative assumptions and methods) provided in the RD to demonstrate the level of protection if an aircraft crash had not yet been taken into account in the design basis. This specifically refers to accidental aircraft crashes. Intentional aircraft crashes are not within the scope of the RD SRNI. Nonetheless, protection against accidental aircraft crashes simultaneously constitutes protection against intentional aircraft crashes.

This requirement (which therefore goes further than the WENRA SRLs) aims to evolve the level of protection against aircraft crashes from the oldest reactors to a level of safety in line with that of the most recent Belgian reactors. In this regard, the following arguments were made in 2020 when the 2014 WENRA SRLs were transposed:

- For Doel 3, Doel 4, Tihange 2 and Tihange 3, a commercial aircraft crash was already taken into account in the design, this was not the case for Doel 1&2 and Tihange 1, for which no aircraft was taken into account.
- Due to the proximity of the Bierset military airport to Tihange at the time, the design of Tihange 2 and Tihange 3 took into account a military aircraft crash, this was not the case for the other reactors.
- The military airport at Bierset has become the commercial Liège Airport, with both passenger and cargo flights (but no longer military flights).
- There has been a general rise in the number of flights since the reactors were built.

This objective is consistent with the position of the FANC that nuclear regulations must evolve according to the principle of continuous improvement. Specifically, this requirement ensures that the level of protection for aircraft crashes for all reactors at a single site must tend toward the same level.

There is a FANC guideline (ref. 2014-03-18-RK-5-4-4-EN) for new installations, such as the new irradiated fuel storage buildings at the sites of the Doel and Tihange nuclear power plants. This guideline states that commercial and military aircraft crashes must be included in the design basis as soon as the probability of a crash onto the installation exceeds 10^{-6} per year. Smaller aircraft (e.g. recreational) must always be included in the design basis.

3.1.2. Germany - aircraft crash

The SiAnf stipulates that aircraft crashes must be included in the design basis and imposes the drawing of a deterministic load curve. This load corresponds to a specific military aircraft (Phantom F4E) and is site-independent. This type of aircraft was chosen due to the high number of accidents involving military aircraft. No other aircraft, such as commercial aircraft, has to be taken into account. It should be noted here that the requirements in the SiAnf regarding physical separation and spatial distribution of shared systems may provide intrinsic protection against aircraft crashes. These requirements can ensure that shared systems are sufficiently far apart that they cannot be affected simultaneously by such accidents.

Finally, the guideline for the PSR provides a list of events for which deterministic and probabilistic approaches must be followed. This list also includes location-specific external civil impacts, whereby reference is made to more detailed recommendations for probabilistic assessment for aircraft crashes, among others. The probabilistic assessment is not required for reactors designed to withstand aircraft crashes in accordance with the SiAnf and not located near military training areas.

Stoßzeit [ms]	Stoßlast [MN]
0	0
10	55
30	55
40	110
50	110
70	0

Moreover, the RSK (*Reaktor-Sicherheitskommission*) also ruled on commercial aircraft crashes in 2021. In such a case, the conclusion was that for all German reactors that were then operational, reactor cooling could be maintained and no radioactive releases were expected.

3.1.3. France - aircraft crashes

RFS I.2.a requires that a risk assessment should be made for three categories of aircraft (general aviation, commercial aviation and military aviation). A probabilistic approach is used to determine which aircraft must be considered. The acceptance criterion in this regard is that the probability for an unacceptable release is no more than an order of magnitude of 10^{-7} per year in each category and 10^{-6} per year for the three categories combined.

3.1.4. Netherlands - aircraft crashes

The VOBK guidelines for new reactors stipulates that it must be ensured that the safety of the installation is not unacceptably compromised by an aircraft crash. Both commercial and military aircraft must be taken into account.

3.1.5. Switzerland - aircraft crashes

Aircraft crashes must be included in the design of Swiss reactors. In this regard, both the impact of a military aircraft, which represents the maximum point load, and the impact of an incident involving a commercial aircraft, which causes additional damage from a kerosene fire, must be considered. Ordinance SR 732.112.2 also stipulates that the aircraft (commercial or military) that is in use at the time of the licence application, and is likely to cause the heaviest load, must be taken into account.

In addition, guideline HSK-R-102 states that aircraft crashes must be included in the design basis and imposes the drawing of a deterministic load curve which is equal to the load curve specified in the German regulations (SiAnf) (i.e. a specific military aircraft).

Ordinance

3.2. Earthquake

The WENRA SRLs stipulate that external threats must be identified, including earthquakes (*seismotectonic hazards*). Based on a site-specific risk assessment, occurrences must then be defined for the design basis. An exceedance frequency must be used and cannot be higher than 10^{-4} per year.

However, for locations with little seismic activity, such a probabilistic determination (coupled with the exceedance frequency) of the earthquake to be taken into account in the design basis would result in a very low earthquake level. Consequently, the WENRA SRLs defined a minimum level, i.e. a maximum horizontal peak ground acceleration of at least 0.1g (corresponding to 0.98 m/s^2).

3.2.1. Belgium - earthquake

The RD SRNI stipulates that seismic loading must be included in the design basis. As with all external threats, an exceedance frequency less than or equal to 10^{-4} per year must be considered. However, a minimum value of 0.98 m/s^2 (i.e. 0.1g) must apply as the maximum horizontal peak ground acceleration.
Existing reactors must comply with this through the implementation of their PSR action plan. However, the RD SRNI allows for alternative methods (which are less conservative) to demonstrate resistance, if a more severe earthquake has to be considered as a design basis event.

This requirement corresponds to the WENRA SRLs and also aims to faithfully transpose the relevant WENRA SRLs without any modifications.

3.2.2. Germany - earthquake

The SiAnf states that a design basis earthquake (i.e., an SSE) must be determined based on both deterministic and probabilistic approaches. The earthquake must have a minimum intensity (i.e., "intensity VI"). In general, the SiAnf stipulates that all safety equipment must be designed to perform its safety function at all times even during an external event, including during an SSE.

More detailed requirements can be found in KTA 2201, of which section KTA 2201.1 states that with the probabilistic approach, the characteristics of the design basis earthquake are based on an exceedance frequency of 10^{-5}/year.

A maximum horizontal peak ground acceleration of 0.1g may be more severe than the minimum intensity imposed in the SiAnf and KTA 2201.1. The RSK (*Reaktor-Sicherheitskommission*) therefore made a recommendation to assess the safety impact of this, which was made with a probabilistic seismic safety analysis for the reactors that were still in operation. The RSK indicated that there was adequate protection for a PGA of 0.1g.

3.2.3. France - earthquake

Guide ASNR 22 stipulates that to determine the characteristics of natural phenomena (such as earthquakes) in the design basis, an exceedance frequency of 10^{-4} per year applies. However, the maximum horizontal peak ground acceleration for an earthquake must be at least 0.1g.

This guideline supplements the 'fundamental safety regulation' RFS-2001-01, in which the deterministic approach is defined.

3.2.4. Netherlands - earthquake

The VOBK guidelines stipulate that a design basis earthquake be determined based on a site-specific risk assessment that is both deterministic and probabilistic. In this regard, an exceedance frequency of 10^{-4} per year applies. However, the maximum horizontal peak ground acceleration for an earthquake must be at least 0.1g.

3.2.5. Switzerland - earthquake

Ordinance SR 732.112.2 states that natural phenomena, such as earthquakes, with an exceedance frequency of 10^{-4} per year or greater must be included in the design basis.

The maximum peak ground acceleration for earthquakes of this frequency, as determined from modified probabilistic analyses from 2013, must be taken into account.

When the severity of a given event is revised - e.g., an earthquake with greater maximum peak ground acceleration – the robustness of each reactor to the new limits must be demonstrated. In addition, more stringent requirements apply when systems are modified or modernised (or when spare parts are purchased). Design considerations must also take into account the new limits and fully comply with the applicable guidelines.

No minimum value is defined, but the seismic activity in Switzerland is such that the design basis earthquake easily meets the WENRA SRL of at least 0.1g for maximum horizontal peak ground acceleration.

Ordinance

3.3. Shared systems

The WENRA SRLs require appropriate independence between different units, but allow for the possibility of one reactor providing support to another.

The specific topic of 'twin reactors' (such as Doel 1&2), where two reactors are highly integrated with each other and designed with several such shared systems, is not dealt with in the WENRA SRLs. As such, no distinction is made for support between reactors and shared systems between stand-alone reactors of a nuclear power plant (e.g. Tihange 1, Tihange 2 and Tihange 3) and, on the other hand, this specific (and less common) case of twin reactors.

3.3.1. Belgium - shared systems

The RD SRNI stipulates that in the design basis the safety functions of the different reactors must be guaranteed independently of each other, for all reactors. In addition, shared support systems must be designed to have sufficient capacity to do so. For two reactors with shared safety systems, this means that these shared systems must have the capacity to handle, for example, accident conditions at both reactors simultaneously. Existing reactors must comply with this through the implementation of their PSR action plan.

This requirement is intended to transpose the relevant WENRA SRLs with an additional clarification for the specific Belgian situation of the twin reactors Doel 1&2. With this clarification, the capacity of shared systems on twin reactors must be sufficient to handle an accident on both reactors independently (and therefore simultaneously).

3.3.2. Germany - shared systems

Most German nuclear power plants are designed with only one reactor on site, even if there are multiple reactors. This limits the number of shared systems, and the SiAnf stipulates that internal threats on one reactor must not result in an unacceptable impact on a neighbouring reactor. In addition, the interpretations of the SiAnf provide clarification for nuclear power plants with multiple reactors. In case of an accident, the available equipment from one reactor may be used at another reactor, provided that this does not compromise the safety of the first reactor.

Additional and more detailed requirements can be found in various KTA standards, which include seismic instrumentation, lightning protection and electrical connections between reactors.

3.3.3. France - shared systems

Guide ASNR 22 stipulates that using shared equipment which is essential for safety must be limited and always justified. Among other things, reference is made to natural water reservoirs. There is also the requirement that these shared systems be dimensioned in such a way to allow each reactor to stop, cool and evacuate residual heat. These shared systems must not result in insufficient autonomy in terms of cooling water or electrical power supply.

3.3.4. Netherlands - shared systems

The VOBK guidelines stipulate that, for nuclear power plants with multiple reactors, each reactor must have its own equipment and systems to deal with incidents and design basis accidents.

3.3.5. Switzerland - shared systems

The ENSI-G02 guideline states that, for nuclear power plants with multiple reactors, the equipment can be shared. Any sharing of mechanical or electrical equipment with a safety function within the design basis must be justified and evaluated from a safety perspective. Typical examples of such systems are diesel generators or supplemental water supply. Specific equipment from these systems can then be connected to one of the reactors, if necessary, as required.

3.4. Automatic/autonomous operation

The WENRA SRLs stipulate that any design basis event should be followed by an automatic phase where no action is required from the staff. This phase lasts for half an hour. Exceptions are possible, but must be justified.

3.4.1. Belgium - automatic/autonomous operation

The RD SRNI stipulates that in the design basis, safety functions must be activated automatically (or by using passive means) so that no operator intervention is required for the first 30 minutes. However, some accidents may require faster manual intervention. In such cases, the time required to take these actions must be specified and justified.

When the main control room is stricken, for example, by a major fire, and the operators have to use the emergency control room, it is not enough to merely observe the 30-minute period. In this situation, the safety functions, which have been automatically triggered, must be maintained without the operator's intervention, and not just for 30 minutes, but for the necessary duration. The time required here must be specified and justified. In addition, modifications may be necessary to achieve this necessary duration. Existing reactors must comply with this requirement after having implemented their PSR action plan.

This topic therefore includes several aspects that are interrelated: on the one hand, the automatic activation (or by using passive means) of safety equipment and how long they must be maintained without manual intervention, on the other hand, the manual activation of safety equipment and the period of time within which this must occur.

Compared to the WENRA SRLs, this requirement contains an additional clarification for the control room. Indeed, in Belgium, the oldest reactors, unlike the most recent, do not have a more extensive automatic phase if the main control room is lost. Consequently, the purpose of this addition is to achieve a similar situation in the oldest reactors and in the most recent Belgian reactors.

3.4.2. Germany - automatic/autonomous operation

The SiAnf imposes automation to ensure that no manual intervention is required for the first 30 minutes after a design basis accident.

In addition, the independent operation ('*Autarkie*') of the safety functions must be guaranteed in the case of three specific external threats caused by human activities: aircraft crashes, external explosions and exposure to hazardous materials. This applies to the power supply and all cooling and operating equipment necessary to bring the system to a controlled state and maintain it as such for at least 10 hours.

3.4.3. France - automatic/autonomous operation

Guide ASNR 22 stipulates that the first manual intervention must occur after 30 minutes if it must be performed in the main control room. In other cases, a period of 1 hour without manual intervention must be observed. This applies to new reactors. Existing reactors were designed with shorter periods (20 minutes and 25 to 35 minutes, respectively).

3.4.4. Netherlands - automatic/autonomous operation

The VOBK guidelines impose automation to ensure that no manual intervention is needed during the first 30 minutes after an internal design accident. If a specific event requires a faster manual intervention, this is permitted insofar the accident diagnosis in that specific situation can be made unambiguously, clearly and quickly.

In addition, for external threats, the autonomous operation of the safety functions must be guaranteed. This applies to the power supply and all cooling and operating equipment necessary to bring the system to a controlled state and maintain it as such for at least 10 hours.

Finally, the reactor protection system must automate the necessary safety actions so that intervention by the operators is not necessary within a certain period of time, which must be justified.

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3.4.5. Switzerland - automatic/autonomous operation

The ENSI-G02 guideline imposes automation if there is insufficient time to diagnose and manually perform the intervention. In addition, no manual actions must be necessary for safety functions for the first 30 minutes after certain internal design basis accidents. Finally, in the event of external threats (e.g., earthquakes, aircraft crashes), the safety systems must have autonomous operation for at least 10 hours to ensure continued cooling during that time.

4. Overview of known status of reactors in Belgium and abroad

4.1. Aircraft crash

4.1.1. General aspects concerning aircraft crashes for Belgium

Protection against aircraft crashes is considered both deterministically (e.g., the reactor withstands the impact of an aircraft with specific characteristics such as speed, weight, etc.) and probabilistically (e.g., the probability of radioactive release).
The following discussions focus on the deterministic analyses. This involves taking a reference aeroplane and then analysing whether the reactor can withstand its impact. This assessment can take place either during the design or subsequently (e.g., during a PSR).

There are also probabilistic analyses. For all Belgian reactors, as part of the evaluation of an aircraft crash, a risk assessment is conducted and updated during the PSR. These assessments calculate the probability of an unacceptable release from an aircraft crash, taking account of various conservative assumptions. The safety report specifies an order of magnitude of 10^{-7} per year as the acceptance criterion.

The risk of an aircraft crash can be split into the risk from overflying air traffic on the one hand and the risk from airport operations (i.e. takeoff and landing phases) on the other. The latter depends on the distance from the airport, the number of flight movements at that airport and the types of aircraft that take off from or land at the airport. 3 categories are considered in Belgium for this assessment:

- general aviation (small recreational aircraft weighing up to 5.7 tons, with a further distinction between single-engine and twin-engine aircraft);
- military aircraft;
- commercial aircraft (possibly further split into classes).

4.1.2. Status of protection against aircraft crashes at Doel 1&2

No requirement regarding resistance to aircraft crashes was considered in the original design of the Doel 1&2 NPPs.

It was demonstrated in the first PSR (1985) that the Doel 1&2 reactor buildings and spent fuel pools could withstand the impact of a typical general aviation-type aircraft. In addition, the bunkered GNS (Emergency Systems Building) was installed at the time, which itself was protected against the same type of aircraft, for the purpose of withstanding an aircraft crash/accident, among other things.

Additional analyses on aircraft crashes were conducted, both after 11/09/2001 and during the stress test. The commercial aircraft considered in these analyses was heavier than in the design basis for Doel 4. These analyses were not made according to the requirements of the design basis, but using a more flexible and less conservative method (as for the design extension).
The conclusion was that significant damage to the external concrete structure of the reactor building could not be ruled out from the impact of an aircraft. However, the damage would not necessarily result in damage to the primary circuit, cooling systems and safety systems, as an inner containment and concrete structures in the reactor building provide additional protection.

No analyses have been conducted regarding the impact of a military aircraft.

As part of the verification of compliance with the 2014 WENRA SRLs (i.e., the so-called '*WENRA gap analysis*') there was discussions this between Electrabel and FANC &

Bel V). However, these discussions were halted after Electrabel itself no longer envisioned operating Doel 1&2 after 2025. Moreover, this requirement (which goes beyond the WENRA SRLs) has since been included in the RD SRNI.

The calculations for the probability of an unacceptable release from an aircraft crash at Doel 1&2 have so far consistently concluded that the probability is kept sufficiently low.

The Doel 1&2 NPPs do not meet the requested resistance to aircraft crashes should they remain in operation after 2025. A purely probabilistic method is not sufficient, since a deterministic approach is required. According to the requirements for the design basis, a deterministic approach was only used for a general aviation-type aircraft, but not for a military or a commercial aircraft.

4.1.3. Status of protection against aircraft crashes at Tihange 1

No requirement regarding resistance to aircraft crashes was considered in the original design of the Tihange 1 NPP.

It was demonstrated in the first PSR (1985) that the Tihange 1 reactor building and spent fuel pools could withstand the impact of a typical general aviation-type aircraft. In addition, the bunkered SUR (*Système d'Ultime Repli*) was installed at the time, which also provides protection against the same type of aircraft. When the SURe (*SUR étendu*) was built in the context of the LTO of Tihange 1 (2020), resistance against impacts of the same type of aircraft was incorporated.

Additional analyses were conducted, both after 11/09/2001 and during the stress test The commercial aircraft considered in these analyses was heavier than in the design basis for Tihange 3. These analyses were not made according to the requirements of the design basis, but using a more flexible and less conservative method (as for the design extension).
The conclusion was that significant damage to the external concrete structure of the reactor building could not be ruled out from the impact of an aircraft. However, this damage would not necessarily result in damage to the primary circuit, cooling systems and safety systems, as an inner containment and concrete structures in the reactor building provide additional protection.

No analyses have been conducted regarding the impact of a military aircraft.

In the context of verifying compliance with the 2014 WENRA SRLs (i.e., the so-called "*WENRA gap analysis*") and Electrabel's intention to keep Tihange 1 operational after 2025, Electrabel initiated the first studies and discussions with the Safety Authority on this matter between 2017 and 2020. The aim was to demonstrate an adequate level of protection for Tihange 1 against aircraft crashes by applying an alternative method. The discussions regarding this approach and preliminary studies were halted by Electrabel when it no longer envisioned operating Tihange 1 after 2025.

The calculations for the probability of an unacceptable release from an aircraft crash at Tihange 1 have so far consistently concluded that this probability is kept sufficiently low.

For Tihange 1, the requested resistance to aircraft crashes has not been demonstrated if the NPP remains operational after 2025. A purely probabilistic method is not sufficient, since a deterministic approach is required. According to the requirements for the design basis, a deterministic approach was only used for a general aviation-type aircraft, but not for a military or a commercial aircraft.

4.1.4. Status of protection against aircraft crashes at Doel 4

The design and construction of the Doel 4 NPP included resistance to the impact of a typical commercial aircraft in the design basis. The external concrete structure of the reactor building withstands the impact of these aircraft and this design basis accident does not affect the primary circuit. The second-level emergency equipment ensures that the essential safety functions are maintained in the event of an external accident, including an aircraft crash. This emergency equipment is located in bunkered buildings that can withstand a design basis aircraft crash.

Additional analyses were conducted, both after 11/09/2001 and during the stress test. The commercial aircraft considered in these analyses was heavier than in the design basis. These analyses were not made according to the requirements of the design basis, but using a more flexible and less conservative method (as for the design extension). The conclusion was that Doel 4 would be able to withstand such a crash.

The impact of a military aircraft is not part of the design basis of Doel 4. As part of the LTO process for the Doel 4 NPP, Electrabel initiated studies to demonstrate that this unit would withstand the impact of a typical military aircraft according to the requirements of the design basis.

The calculations for the probability of an unacceptable release from an aircraft crash at Doel 4 have so far consistently concluded that this probability is kept sufficiently low.

Doel 4 is partially able to withstand aircraft crashes, which is mandatory if it remains in operation after 2025. Indeed, resistance to crashes involving commercial aircraft was included from the design stage. Electrabel is being demonstrating the remaining element, i.e. resistance to the impact of a military aircraft, as part of the LTO process for the Doel 4 NPP.

4.1.5. Status of protection against aircraft crashes at Tihange 3

The design and construction of the Tihange 3 NPP included resistance to the impact of a representative commercial aircraft and a representative military aircraft in the design basis. The external concrete structure of the reactor building withstands the impact of these aircraft and this design basis accident does not affect the primary circuit. The second-level emergency equipment ensures that the essential safety functions are maintained in the event of an external accident, including an aircraft crash. This emergency equipment is located in bunkered buildings that can withstand a design basis aircraft crash.

Additional analyses were conducted, both after 11/09/2001 and during the stress test. The commercial aircraft considered in these analyses was heavier than in the design basis. These analyses were not made according to the requirements of the design basis, but using a more flexible and less conservative method (as for the design extension). The conclusion was that Tihange 3 would be able to withstand such a crash.

The calculations for the probability of an unacceptable release from an aircraft crash at Tihange 3 have so far consistently concluded that this probability is kept sufficiently low.

Tihange 3 already fully complies with the RD SRNI requirements relating to aircraft crashes, as resistance against aircraft crashes was already included from the design stage, both for commercial aircraft and military aircraft.

4.1.6. Status of protection against aircraft crashes in Gravelines (France)

According to available data on the '*palier 900 MW_e*' (to which the Gravelines reactors belong), for accidental aircraft crashes, only general aviation-type aircraft are included in the design basis. Depending on the reactors in question, the aircraft selected is either both a Cessna 210 and a Learjet 23, or just a Cessna 210.
A study of local air traffic characteristics was conducted for each nuclear power plant in France (including Gravelines). This study is re-evaluated every 10 years during the PSR. It was confirmed that the dimensioning (i.e., choice of aircraft in the design basis) was adequate.

The ASNR indicated that the situation in Gravelines complies with the RFS I.2.a rule.

4.1.7. Status of protection against aircraft crashes in Borssele (Netherlands)

No requirement regarding resistance to aircraft crashes was considered in the original design of the Borssele NPP.

As part of a Periodic Safety Review in the 1990s, resistance to a crash involving a small recreational aircraft (Cessna 210) was demonstrated. This aircraft was chosen given that Borssele is not located on an approach route used by large commercial aircraft. There is an airport nearby, primarily intended for recreational flights.

As part of the stress test (2011), analyses showed that the containment would not collapse if it was struck by a specific type of commercial aircraft. However, for larger aircraft such as the Boeing 767, the resistance of the containment cannot be demonstrated. The reactor vessel is however situated deep in the containment and is protected there by its own bunker.

Based on the annual frequency of crashed aircraft in the Netherlands and the local intensity of air traffic over the site of the nuclear power plant, the frequency for direct and indirect impact was calculated (and not the probability of an unacceptable release). This calculation included the three types of aircraft.

4.1.8. Status of protection against aircraft crashes at Beznau 1 (Switzerland)

When the oldest Swiss nuclear power plants, such as Beznau, were built, aircraft crashes were not included in the design. Later, in the 1980s, bunkered emergency systems designed to withstand crashes involving military aircraft were added.

A specific safety analysis for Beznau 1 subsequently showed that the design requirements regarding aircraft crashes are met for more recent Swiss nuclear power plants. This is equivalent to a crash involving a Boeing 707. It was demonstrated that there are additional safety margins for a plane crash of this intensity.

Probabilistic safety assessments were conducted to assess the risk of radioactive releases resulting from an aircraft crash. It was confirmed that the risk is sufficiently low due to the bunkered emergency systems.

4.2. Earthquake

Earthquake resistance is often expressed in terms of theoretical earthquakes that the reactor can withstand:

- An SSE (*Safe Shutdown Earthquake*) is an earthquake in which the reactor can be safely shut down. An SSE constitutes the design basis earthquake and is the most important earthquake which the reactor must be able to withstand. The SSE is similar to the DBE (*Design Basis Earthquake*) which is also sometimes used.
- An OBE (*Operating Basis Earthquake*) is a lighter earthquake that the reactor can withstand without having to proceed to shutdown (to perform verifications).
- An RLE (*Reference Level Earthquake*) is the most severe earthquake. It is not part of the design basis, but part of the design extension. Resistance to the RLE may therefore be demonstrated by more flexible and less conservative methods. Among other things, the RLE was used for the stress tests.

The level of these earthquakes is often expressed in terms of peak ground acceleration, in quantities of m/s^2 or g (i.e., gravitational acceleration).

4.2.1. Status of protection against earthquakes at Doel 1&2

The Doel 1&2 NPPs were originally built without taking into account any design basis seismic resistance. Seismic risk was assessed during the first PSR (1985). Based on this, the SSE for both units was set at 0.058g. The seismic resistance was assessed for a number of circuits, and improved by installing new emergency systems in the seismically designed GNS (Nuclear Emergency Systems Building).
For Doel 1&2, no OBE was initially defined. An OBE of 0.02g was subsequently determined during the second PSR (1995). This PGA level was used to check the relevant resistance of the safety-related mechanical and electrical equipment.

The suitability of the SSE was assessed at various times, most recently in 2015. An SSE of 0.058g corresponds to an exceedance frequency between 10^{-3} and 10^{-4} per year. On the other hand, an earthquake of 0.1g corresponds to an exceedance frequency between 10^{-4} and 10^{-5} per year.

For the LTO of Doel 1&2, a Seismic Margin Assessment was conducted and improvement actions were implemented. All this resulted in the demonstration that the systems used to shut down the reactor after an earthquake had a minimum earthquake resistance of 0.1g (by using a more flexible method than is normally used for the design basis). In addition, resistance to 0.1g in long-term management of other accidents was also demonstrated. However, this was not analysed for all safety-related systems (including essential systems for the short-term management of certain accidents). If Doel 1&2 remain in operation after 2025, seismic resistance to earthquake of 0.1g must be verified and achieved for all safety-related systems.

As part of the stress test, seismic resistance and margins were further investigated for an RLE of 0.17g. This was achieved for most buildings with level "high." The only exception was the GNH (nuclear auxiliary services building) that includes the spent fuel pools.

The Doel 1&2 NPPs still do not fully meet the required design basis seismic resistance, should it remain in operation after 2025. Indeed, the Seismic Margin Assessment and the subsequent actions could not lead to the demonstration that all safety-related systems are resistant to 0.1g.

4.2.2. Status of protection against earthquakes at Tihange 1

The construction of the Tihange 1 NPP originally included design basis seismic resistance. This corresponds to an SSE of 0.1g or an OBE of 0.05g. Seismic risk was once again assessed for Tihange during the first PSR (1985). This showed that the SSE needed to be raised to 0.17g.

Since then, the suitability of this SSE has been confirmed several times, most recently in 2015. The SSE corresponds to an exceedance frequency between 10^{-4} and 10^{-5} per year.

As part of the stress test, seismic resistance and margins were further investigated for an RLE of 0.3g. This resistance was achieved for most buildings with level "high." The only exception was the building housing the spent fuel pools and the BAE (*Bâtiment des Auxiliaires Electriques*).

The Tihange 1 NPP therefore meets the required design basis seismic resistance.

4.2.3. Status of protection against earthquakes at Doel 4

The construction of the Doel 4 NPP originally included design basis seismic resistance. This corresponds to an SSE of 0.1g and an OBE of 0.05g.
Since then, the suitability of this SSE has been confirmed several times, most recently in 2015. The SSE corresponds to an exceedance frequency between 10^{-4} and 10^{-5} per year.

As part of the stress test, seismic resistance and margins were further investigated for an RLE of 0.17g.

The Doel 4 NPP therefore meets the required design basis seismic resistance.

4.2.4. Status of protection against earthquakes at Tihange 3

The construction of the Tihange 3 NPP originally included design basis seismic resistance. This corresponds to an SSE of 0.17g and an OBE of 0.05g.
T Since then, the he suitability of this SSE has been confirmed several times, most recently in 2015. The SSE corresponds to an exceedance frequency between 10^{-4} and 10^{-5} per year.

As part of the stress test, seismic resistance and margins were further investigated for an RLE of 0.3g. The resistance was estimated to be even higher for several buildings.

The Tihange 3 NPP therefore meets the required design basis seismic resistance.

4.2.5. Status of protection against earthquakes in Gravelines (France)

The French reactors have a specific situation, as historically it was opted to build reactors by type ("*palier technique*"). In this approach, reactors of the same '*palier*' are almost completely identical and have the same design basis for the similar components, regardless of their location. For seismic resistance, this is reflected in the use of standardised response spectra. The Design Basis Earthquake (DBE) spectrum applicable to the design of structures at the Gravelines site is the site-independent EDF spectrum, standardised at 0.2g. Gravelines is located in an area that is more seismically active than the sites of the Belgian reactors.

Based on historical data, a site-specific Safe Shutdown Earthquake (SSE) was calculated. For Gravelines, this roughly corresponds to an SSE of 0.27g. An exceedance frequency of 10^{-4} per year is complied with.

As part of a *Seismic Margin Assessment* following the Fukushima-Daiichi accident, a study concludes that for the reactors at the Tricastin nuclear power plant (i.e., the same '*palier*' as Gravelines), the seismic resistance is higher than 0.3g and shows significant margins of robustness. This is due to the very cautious methods used, both for calculating the seismic risk and for designing the installation.

After Fukushima and at the request of the ASNR, the operator took additional measures, i.e. the '*noyau dur*', to cope with potential extreme situations. These means are dimensioned for 0.41g in Gravelines.

4.2.6. Status of protection against earthquakes in Borssele (Netherlands)

The Netherlands is a region with relatively low seismic activity, including the area around the Borssele nuclear power plant. Consequently, no design basis earthquake was considered when the NPP was designed.

The design basis earthquake was subsequently set during several Periodic Safety Reviews. The design of the nuclear power plant conservatively assumes an earthquake resulting in a peak ground acceleration of around 0.06g at ground level (and 0.075g at the level of the supporting soil layer of the foundation). This design basis earthquake could occur in Borssele once every 30,000 years according to probability calculations and therefore has an exceedance frequency of about 3.10^{-5} per year.

In 2011, in the context of the stress test, the operator EPZ demonstrated, through seismic analyses and a Seismic Margin Assessment, that the plant complies with this design basis and that there are sufficient safety margins on top of that. All safety-related SSCs, including the reactor building, can withstand seismic loads up to at least 0.15g. Multiple parts of the NPP (safeguard systems and bunkered buildings) can withstand heavier loads.

4.2.7. Status of protection against earthquakes at Beznau 1 (Switzerland)

The Beznau 1 NPP is located in an area that is more seismically active than the sites of the Belgian reactors. As such, the reactor was designed and subsequently modified to withstand more severe earthquakes.

The construction of the Beznau 1 NPP originally included design basis seismic resistance, which equates to a SSE of 0.12g.
The seismic hazard maps from 1977 and their conversion into a probabilistic hazard curve provided the basis for subsequent modernisation and renovation projects at Beznau 1. As a result, the design basis earthquake was raised to an SSE of 0.15g at the bottom of the reactor building and 0.21g at the ground surface.

Since 2015, new risk estimates based on an occurrence frequency of 10^{-4} per year have been taken into account. The result was an additional change to the seismic design basis. The current seismic design basis resistance corresponds to an SSE of 0.3g at the bottom of the reactor building and 0.38g at the ground surface.

4.3. Shared systems

4.3.1. Status of shared systems at Doel 1&2.

The Doel 1&2 unit is a twin power plant, meaning that various systems and equipment are shared and highly integrated from the design. Since the start of operations, the operator has implemented improvement projects so that both individual reactors are more independent from each other, but because of the initial design, complete independence is difficult to achieve.

For example, safety-related equipment is powered from a shared electrical grid and then divided into four trains. Overall, two of the four electric trains power the safety-related equipment of Doel 1, while the other two electric trains are assigned to Doel 2. Nevertheless, there are several pieces of equipment from Doel 1 that are powered by an electric train from Doel 2, and vice versa.

In addition, this shutdown cooling system, like some other equipment, is cooled by the ‘intermediate cooling circuit', which in turn is cooled (including in the case of internal accidents) by auxiliary cooling towers with forced draft. However, the dimensioning of these systems is not enough to be able to simultaneously shut down both Doel 1 and Doel 2 in all circumstances while ensuring the necessary cooling. As a result, the evacuation of the subsequent heat in one reactor - through the steam generators - will last longer than in the other.

Doel 1&2 also have a shared control room. The systems used only for Doel 1 or Doel 2 are operable from separate control panels. Shared control panels are used for the shared systems mentioned above.

Finally, as a result of the stress test, additional mobile resources, the BUM (additional ultimate resources) were installed that are shared by all reactors at the Doel site. These shared systems provide an additional layer of protection and do not compromise the required independence between reactors.

In the context of the verification of compliance with the 2014 WENRA SRLs (i.e. the so-called WENRA gap analysis) in 2016-2017, this topic was the subject of further exchanges between Electrabel and the FANC & Bel V. However, these discussions were stopped after Electrabel no longer envisaged keeping Doel 1&2 operational after 2025. This requirement has since been included in the RD SRNI.

Although complete independence between Doel 1 and Doel 2 is not required, the dimensioning of the systems is currently insufficient to ensure that the safety-related functions of Doel 1 and Doel 2 are independent from each other.

4.3.2. Status of shared systems at Tihange 1

There are no such 'shared systems' at Tihange 1 as with Doel 1 & 2. Nevertheless, some systems from Tihange 2 and Tihange 3 can provide support to Tihange 1. This is the case, for example, with the CEU (*Circuit d'eau d'ultime secours*, emergency water circuit) and the CEI (*Circuit d'eau d'incendie*, fire-fighting water circuit).

In addition, after the stress test, some additional resources, called “MSU” (*Moyens Supplémentaires Ultimes*), were installed that are shared by all reactors at the Tihange site. These shared systems provide an additional layer of protection and do not compromise the required independence between reactors.

In the context of the verification of compliance with the 2014 WENRA SRLs (i.e. the so-called WENRA gap analysis) in 2016-2017, both Electrabel and the FANC & Bel V concluded that Tihange 1 complied with the WENRA SRL E9.5 (which the national regulatory requirement on this topic is inspired from).

Both for the interconnections between systems of different reactors, and for the shared systems, there are no situations that pose a problem for the independence of Tihange 1 from the other reactors.

4.3.3. Status of shared systems at Doel 4

The situation with shared systems at the Doel 4 NPP is similar to the situation at Tihange 1, as described in *§4.3.2*, with additional mobile resources installed at the Doel nuclear power plant as a result of the stress test.

Both for the interconnections between systems of different reactors, and for the shared systems, there are no situations that pose a problem for the independence of Doel 4 from the other reactors.

4.3.4. Status of shared systems at Tihange 3

The situation with shared systems at the Tihange 3 NPP is similar to the situation at Tihange 1, as described in *§4.3.2*.

Both for the interconnections between systems of different reactors, and for the shared systems, there are no situations that pose a problem for the independence of Tihange 3 from the other reactors.

4.3.5. Status of shared systems in Gravelines (France)

Gravelines is a nuclear power plant consisting of 6 similar reactors. The first French reactors (i.e. '*palier 900 MW_e*,' as in Gravelines) were built in pairs. There are shared systems between these two reactors ('*systèmes intertranches*'), but these are limited in number.

The safety demonstration for these reactors makes it possible to manage events that could affect the entire site.

4.3.6. Status of shared systems in Borssele (Netherlands)

There is only one reactor on the site of the Borssele NPP. As a result, there are no problems of independence with regard to other reactor units.

4.3.7. Status of shared systems at Beznau 1 (Switzerland)

Beznau is a nuclear power plant with two more or less identical reactors (i.e. Beznau 1 and Beznau 2). Some safety-related systems can be used by both reactors: diesel generators, the original emergency well water system (which can supply auxiliary feedwater and cooling water to the 'intermediate cooling system among other things) and the new special emergency well water system designed for specific external accidents.
There is also the possibility of making electrical connections between the two reactors.

4.4. Automatic/autonomous operation

4.4.1. Status of automatic/autonomous operation at Doel 1&2

Reactor shutdown and the activation of safety-related equipment are automatised in the event of "first-level" accidents.

During the first PSR (1985), the bunkered GNS (Emergency Systems Building) was installed to withstand "2nd level" accidents (these are mainly external accidents). This also included a back-up control room that replaced the previous auxiliary control room and can be used to command the installed emergency systems. It was assumed that the back-up control room in the GNS building could be staffed within 10 minutes. Automation in the GNS building is therefore designed to cover at least a 10-minute period without human intervention, including, among other things:

- automatic injection of water into the seals of the primary pumps;
- automatic start of emergency refilling of steam generators;
- automatic operation of the steam dump system.

The Doel 1&2 NPPS do not yet meet the autonomy requirement if it remains in operation after 2025. Studies are needed to ascertain the necessary autonomy, and can then also lead to improvements that must be implemented to achieve this autonomy.

4.4.2. Status of automatic/autonomous operation at Tihange 1

Reactor shutdown and the activation of safety-related equipment are automatised in the event of internal reactor accidents.

During the first PSR (1985), the bunkered SUR building (*Système d'ultime repli*) was installed to withstand external accidents. To also withstand several possible 'common cause' failures in the control system or electrical power supply, resulting in loss of control from the main control room, the SURe (*SUR étendu*) was built as a result of the LTO of Tihange 1. This emergency back-up system is capable of progressively taking over control in the event of the loss of the main control room or the BAE (*Bâtiment des Auxiliaires Electriques*).

It is assumed that the operators are only able to take control from the SURe building 30 minutes after they leave the main control room. In the meantime, no human action is required. However, the SURe must be activated by human action.

This scenario of losing control from the main control room is covered in a procedure. It is assumed that the loss of control is gradual and the operators can still take actions in the main control room before heading for the SURe. The purpose of these actions is to stabilise the unit and bring the equipment to a safe state, or to such a state that the reactor is in an acceptable state when the operators resume control from the SURe buildings.

In the context of a LTO of Tihange 1 after 2025, as envisaged by Electrabel, this issue was discussed between Electrabel and the FANC & Bel V over the period 2019-2020. Back then, Electrabel planned to study a scenario of a sudden loss of both the main control room and the BAE, without any possible short-term human intervention, by postulating a major accident of external origin that would lead to the destruction of the BAE building, with the assumption that the physically isolated SURe buildings would remain 100% operational. Tihange 1 would be operating at full power at the start of this scenario. The aim of these studies was to demonstrate autonomy without operator intervention for a period long enough to summon a new team that would take control from the SURe buildings. This period would be compared to the 3-hour autonomy at Tihange 2 and 3.

These studies may also result in improvements that will have to be implemented to achieve this autonomy. Since Electrabel itself no longer envisions keeping Tihange 1 operational after 2025, these studies were not conducted.

4.4.3. Status of automatic/autonomous operation at Doel 4

Reactor shutdown and the activation of safety-related equipment are automatised in the event of "first-level" accidents. With some justified exceptions, there is a 30-minute period before manual actions are required.

In addition, for "second-level" accidents, the bunker can automatically start up and operate for at least 3 hours following any design basis initiating event.

The Doel 4 NPP therefore meets the expectations regarding automation and autonomous operation.

4.4.4. Status of automatic/autonomous operation at Tihange 3

Reactor shutdown and the activation of safety-related equipment are automatised in the event of "first-level" accidents. With some justified exceptions, there is a 30-minute period before manual actions are required.

In addition, for "second-level" accidents, the bunker can automatically start up and operate for at least 3 hours following any design basis initiating event.

The Tihange 3 NPP therefore meets expectations regarding automation and autonomous operation.

4.4.5. Status of automatic/autonomous operation in Gravelines (France)

The situation in Gravelines for automatic/autonomous operation of the safety-related systems complies with the generic information for the ‘*palier 900 MW$_e$*’ NPPs.

The first manual action should normally take place only after 20 minutes if performed in the main control room. For actions that are not performed in the main control room, a period of 25 to 35 minutes is taken into account before manual action is required.

The ASNR asked in 2016 to evaluate how the '*palier 900 MW$_e$*' NPPs perform in comparison with the reference framework of new reactors, in case of a LTO beyond a 40-year lifespan. In the PSR, specific studies were conducted on threats (fire, explosion, internal flooding) and accidents that may occur. In this regard, the operator demonstrated that safety requirements are met or that there is no ‘cliff-edge’ effect (i.e. a small change in circumstances that leads to an excessive escalation of consequences).

The new ultimate emergency resources (the so-called '*noyau dur*') are also automatised.

4.4.6. Status of automatic/autonomous operation in Borssele (Netherlands)

In the event of external threats, the reactor is automatically shut down and placed in a 'hot subcritical' state for a period of 10 hours. The staff only have to intervene once this period is over, allowing ample time to take appropriate action. However, it is also possible to intervene earlier.

The electrical power supply to the control room and back-up control room is provided over two power supplies, so that control of the systems is not compromised even if one power supply fails.

The design provides that any error signals caused by failures due to external influences cannot adversely affect the proper operation of the safety-related systems in the back-up control room building.

In the event of an accident of internal origin, no action is expected from operators for the first half hour (30 min).

4.4.7. Status of automatic/autonomous operation at Beznau 1 (Switzerland)

Automatic actions following a design basis accident are provided for in the Beznau 1 NPP.

In addition, Beznau 1 has a special emergency system which, in the event of external threats, ensures that the reactor remains in hot shutdown for 10 hours without manual actions after an emergency shutdown. After this period, staff have to manually further cool the reactor, and proceed to cold shutdown.
Specific actions such as '*Feed-and-bleed*' cooling in the event of an accident can only be activated manually.

5. Conclusion

The safety requirements for nuclear reactors are a national competence and therefore vary between countries. A comparison between countries is complex and must take into account the specific context, the national legal framework and the historical situation for each country. The comparison already shows that **all countries have regulations that demand a high level of safety**, but also that there are differences that are sometimes impossible or difficult to compare, due to different standards, assumptions and calculation methods used.

Within Europe, WENRA decided to harmonise the safety level by publishing Safety Reference Levels (WENRA SRLs). These SRLs have been set as minimum requirements for existing reactors, with each country still free to adopt its **own approach.** All members of WENRA have undertaken to transpose these SRLs into their regulatory framework and ensure they are implemented in the field. However, the approach to transposing the SRLs varies between countries.

Since the previous regulatory framework did not explicitly include such safety requirements, Belgium opted in 2011 to include the SRLs in a **new royal decree, the RD SRNI** (RD of 30/11/2011 on the safety requirements for nuclear installations). The safety requirements of the RD SRNI apply in full to both new and existing reactors. For existing reactors, several requirements from transitional provisions do not apply until later, for example not before a subsequent PSR (10-year safety review) has been conducted. As a result, reactors that will be permanently shut down by 2025 are exempt from some of the requirements added during the most recent revisions to the RD SRNI.

Several countries have chosen to transpose the WENRA SRLs **through non-binding guidelines** used by the nuclear safety authority as a basis for evaluating licence applications for new reactors, and as a benchmark to compare against in the PSR for existing reactors. This gives more freedom to the national safety authority to assess the implementation on the ground.

Not all countries have already fully transposed the WENRA SRLs, as Belgium has already done. Several countries are still working on it, primarily on changes from the most recent revision of the WENRA SRLs.

Consequently, because the WENRA SRLs represent a set of common minimum requirements, there are **aspects where countries go further**. Indeed, in some cases, national requirements were already being applied before the publication of the WENRA SRLs and the harmonisation through WENRA is not intended to ease rules that were already in force. For example, several countries apply a 10-hour autonomy in the event of external threats, which is more than what is stipulated in the WENRA SRLs and the Belgian regulations.
When the 2014 revision of the WENRA SRLs was transposed into Belgian regulations, additional and specifically Belgian safety requirements and clarifications were included, such as resistance to aircraft crashes, shared systems and automatic/autonomous operation. These topics, along with earthquake resistance, are all important, well-known design concerns for the potential Long Term Operation of the Doel 1&2 and Tihange 1 NPPS, and were therefore selected as 'key topics' in this report.

For three of these topics (aircraft crashes, shared systems and automatic/autonomous operation), Belgium therefore opted to be more stringent or specific than the WENRA SRLs. These are conscious choices, for two reasons:

- The **specific Belgian situation** was taken into account. The location of the nuclear power plants is an example: the sites in Belgium are located in a major port area, a few kilometres from densely populated, urban agglomerations, or near an airport. Some of the choices made in the (initial) design are also specific to Belgium. For example, the topic of 'shared systems' is quite unique to our country, with the 'twin reactors' Doel 1&2. Since this feature does not apply to other reactor designs, it is not an issue for the other countries in this report.
- The FANC assumes that the regulations must evolve according to the principle of continuous improvement, to ensure the highest possible level of safety. Indeed, the purpose of the regulations and the FANC is to protect the population and the environment against the risks of ionizing radiation. That is why, in transposing the 2014 WENRA SRLs, which resulted from lessons learned from the Fukushima-Daiichi accident, the FANC pursued an additional goal: the safety level of Belgian reactors, if they remain in operation after 2025, must evolve to get closer to the **safety level of Belgium's most recent reactors, Doel 4 and Tihange 3.**

When the SRLs were transposed, the FANC envisaged that the reactors had to meet the updated requirements by the next PSR, if an LTO was envisaged after that. As a result, the reactors could still be operated for several years, i.e. until 2025.

Aside from the key topics considered in this report, most of the WENRA SRLs were transposed in Belgium without additional or more stringent requirements. As a result, the **safety requirements in Belgium are similar and equivalent to those applied in other European countries in many aspects**.

A comparison with regulations in other countries shows that **different choices can be made in terms of content as how to carry out the safety demonstration**, and this in full compliance with the general expectations of the WENRA SRLs.
For example, for **aircraft crashes,** a probabilistic approach can be used, whereby the type of aircraft which the reactor has to withstand can be determined based on probability. In Belgium, a deterministic (regardless of probabilities) approach is imposed for buildings to withstand a crash of both a typical commercial and a typical military aircraft. In other countries, a deterministic approach or a combination of deterministic/probabilistic approach has been used to set a reference aircraft (i.e. impact of a military aircraft).

As far as the **actual application of these requirements at the NPPs** is concerned, Doel 1&2 and Tihange 1 currently have shortcomings in complying with Belgian regulations, should they remain operational after 2025. Doel 1&2 does not meet the WENRA SRLs' relating to earthquake resistance, nor the additional Belgian requirements concerning the other topics. Tihange 1 does not meet the additional Belgian requirements for aircraft crashes and automatic/autonomous operation.
Doel 4 and Tihange 3 already largely comply with Belgian regulations for operation after 2025 and will fully comply through the implementation of their LTO programme.
The design safety level of Doel 1&2 and Tihange 1 does not yet approach the safety level of Doel 4 and Tihange 3 or of new reactors that would be built today.

If the intention is to keep Doel 1&2 and/or Tihange 1 in operation beyond 2025, then the operator has to conduct a PSR. This involves a systematic evaluation of the nuclear safety of the reactor and **additional studies**, which include comparing the safety level with the latest regulations and current standards and practices. These additional studies will result in the definition of actions necessary to enable long-term operation. A PSR also includes various other issues that are not part of the scope of this report (e.g., ageing management, sufficient skilled operating staff). It is the responsibility of the operator to conduct these studies and propose actions, which will be assessed by the FANC and its subsidiary Bel V. **Only a PSR will enable**

the FANC to determine whether any operation after 2025 is acceptable in terms of safety.

Annex A – Characteristics of the considered reactors

Reactor	*Type*	*Electric capacity*	*1st use*	*Status*
Doel 1	PWR 2-loop	445 MW	15/02/1975	Permanent shutdown *14/02/2025*
Doel 2	PWR 2-loop	445 MW	01/12/1975	In operation *LTO 50 years*
Tihange 1	PWR 3-loop	962 MW	01/10/1975	In operation *LTO 50 years*
Doel 4	PWR 3-loop	1026 MW	01/07/1985	In operation *LTO 50 years*
Tihange 3	PWR 3-loop	1030 MW	01/09/1985	In operation *LTO 50 years*
Gravelines 1	PWR 3-loop	910 MW	25/11/1980	In operation *no end date*
Borssele	PWR 2-loop	482 MW	26/10/1973	In operation *LTO 60 years*
Beznau 1	PWR 2-loop	365 MW	09/12/1969	In operation *no end date*