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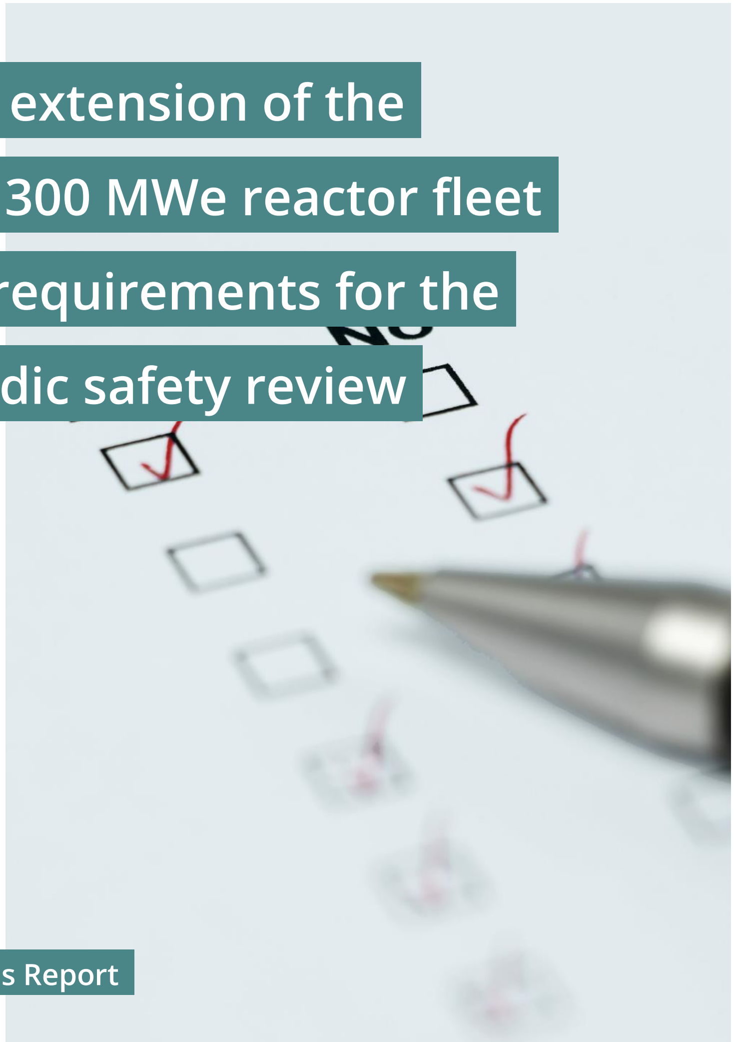
Lifetime extension of the French 1300 MWe reactor fleet generic requirements for the 4th periodic safety review



Task 3: Hazards Report

Federal Ministry
Republic of Austria
Climate Action, Environment,
Energy, Mobility,
Innovation and Technology

Lifetime extension of the French 1300 MWe reactor fleet generic requirements for the 4th periodic safety review

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Oda Becker
Kurt Decker
Yves Marignac

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Project Manager Franz Meister

Authors Oda Becker
Kurt Decker
Yves Marignac

Layout Felix Eisenmenger

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SUMMARY

Twenty nuclear reactors of 1300 MWe installed capacity in France are now approaching forty years of operation, the end of their design life. The operator EDF intends to extend the lifetime of those plants. In France, once the design lifetime of 40 years is reached, and the utility plans extending operation of a nuclear power plant (NPP) beyond its design lifetime, a comprehensive reassessment of the status of the plant is needed within the fourth periodical safety review (PSR4).

The French High Committee for Transparency and Information on Nuclear Safety (HCTISN) is organizing a public consultation process with the possibility to provide opinions on the generic phase of the PSR4, which covers topics relevant to all the 1300 MWe reactors. In case of a severe accident in a French NPP, significant impacts on Austria cannot be excluded. Therefore, Austria is participating in this consultation. For this participation, four task reports and a synthesis report have been prepared. The report at hand is task report no.3 focusing on hazards.

Hazard assessment: Regulatory requirements

The regulatory requirements for the assessment of natural hazards are not regarded to be fully in line with WENRA Reference Levels and guidance. For **earthquake** France followed a deterministic approach for determining design parameters while WENRA requires definitions of design basis events for an occurrence probability of 10^{-4} per year. Defining the Design Basis Earthquake (DBE) on deterministic methods is no longer state of the art. Already in the Stress Tests in 2012 ENSREG recommended introducing Probabilistic Seismic Hazard Assessment (PSHA) to determine the DBE. It seems that this recommendation is still not fully implemented although PSHA was used in a number of pilot studies to develop methodology to be used in the PSR4 of the 1,300 MWe fleet and to define requirements for the Hardened Safety Core (HCS) which must sustain earthquakes with a 20,000 year recurrence interval. Detailed results of the PSHA studies are not available to the Authors of this report. It appears, however, that PSHA revealed ground shaking values for DBEs with occurrence probabilities of 10^{-4} per year well in excess of the deterministically derived values. Therefore, strict application of the WENRA (2014; 2021) requirements is expected to lead to DBE values that are higher than the deterministically derived ground shaking parameters for many nuclear sites.

Flooding is a risk that was taken into account in the design of French plants. The partial flooding of the Blayais NPP during the storm on December 27, 1999 revealed significant deficiencies in the determination of potential water levels and the risks of external flooding. In response to the Blayais flooding, in 2013, the ASN published the new Guide No. 13, which deals with the risk of external flooding. It was developed from 2005-2012 and must now be considered out of date. The guide does not take into account the related WENRA documents developed after the Fukushima accident. The regulations are not complete in line

with WENRA (2014; 2021). Although the French regulation account for all major phenomena and processes that combine to the flooding hazards at sites located at river or at the Atlantic coast, some of the phenomena are only considered for very short recurrence periods (e.g., local rainfall and waves 100 years; wind waves, 1000 years).

The ASN guide No. 13 for the protection against external flooding should be updated. The relevant WENRA documents developed after the Fukushima accident should be systematically taken into account. The determination of the phenomena should be based on scientific analysis rather than on expert judgment. For all relevant flooding phenomena, exceedance probabilities of 10^{-4} should be assumed. In addition, phenomena due to climate change should be adequately taken into account.

Regulatory basis for safety assessments with respect to **extreme weather** is provided by national standards that existed at the time of the construction of each plant series (i.e., in the 1070s and 1980s). There is no corresponding directive in the French regulations.

In view of the increasing relevance of extreme weather events for the safety of NPPs, it would be relevant to safety if legally binding regulations for protection against extreme weather events also existed in France. **Thus, it is recommended to develop a guide on the protection of nuclear installations against extreme weather events that reflects the current scientific knowledge of extreme weather events. This new Guide should be applied within the framework of the PSR4 for existing NPPs.**

The WENRA RHWG review of the transposition of the 2014 SRL into the national legal framework showed that only four of the 19 RL of issue T (external hazards) had been transposed into national regulations in France by October 31, 2015. **There should be a systematic review of the implementation of the WENRA RL in the regulations in France, including its implementation in the corresponding guidelines for protection against external events.**

For **man-made external hazards,** the standard RFS I-2.d sets safety objectives by defining criteria for unacceptable release of radioactive substances at the site boundary and limits of the probability of occurrence of events. The approach is regarded to be in line with WENRA (2021).

External hazards in PSR

The contents and procedures of **PSR** are only loosely defined in the French legal framework leaving it to the nuclear regulator to specify conditions and contents of the review. The objectives of the PSR4 of the 1300 MWe fleet were defined by ASN in a process that involved a proposal by EDF, a review and conclusive guidelines issued by ASN. With respect to external hazards ASN stipulates that definitions of design basis events and design extension considerations must follow the requirements set by WENRA. The main implication of the objective for **earthquake** is that the deterministic approaches for hazard assessments, which are current French standards, are to be supplemented by PSHA.

ASN specifications for the PSR4 do not make sufficiently clear if PSHA shall lead to the definition of new design basis parameters and, subsequently, updated requirements for plant protection. With respect to design extension conditions ASN defines the objective for the PSR4 to “integrate all the provisions of the Hardened Safety Core which have been prescribed to [EDF] by the ASN”. **It is concluded that implementation of the "noyau dur" at the 1300 MWe sites has not been completed by now.**

As part of the PSR4 1300, EDF intends to check the robustness of the 1300 MWe plants against the **external flooding hazards** described in “ASN Guideline No. 13” (ASN 2013g) It is noted that this review has already been carried out for the Cattenom and Paluel sites as part of the 3rd PSR 1300, and that studies will therefore not be carried out again. In general, reference is made to the post-Fukushima analyses already carried out. **The studies for all sites should be updated according to the state-of-the-art.**

As part of the PSR4 1300 it is to check whether the water stops, which are a key element of the Volumetric Protection (VP) are not affected by different settlements, thus demonstrating that earthquake-induced flooding has no impact on safety. To this purpose, it is very important that the strength of the potentially occurring earthquakes has been determined with sufficient certainty. As already explained, this is not the case. In addition, other elements of the VP must be comprehensively checked. **Since protection against extreme external flooding is essentially based on the VP and, on the other hand, there have been considerable deficiencies in the implementation and analysis of the VP to date, extensive analyses and conformity checks should be carried out as part of the PSR4.**

With respect to **extreme weather**, several hazard types are considered in the PSR4. **It is recommended to require for the PSR4 that the selection of design basis events for extreme weather conditions complies with WENRA (2014; 2021) by (1) demonstrating that the selected event leads to a level of safety equivalent to WENRA target (occurrence probability of 10^{-4} per year) (2) the design basis parameters are developed on a conservative basis.**

The reassessment of industrial risks as part of the PSR4 1300 is apparently only to be carried out after the VD4 inspections. The risks relating to accidental aircraft crashes are only to be reassessed to a limited extent. **It is recommended that the reassessment of man-made hazards as part of the PSR4 1300 should be appropriate in scope and timeframe. All inspections and any resulting retrofits should be carried out during the shutdown period.**

Design basis of the 1300 MW reactors and protection measures

In addition to the inadequate earthquake analyses, the design of the 1300 MW reactors showed a number of weaknesses with regard to **protection against a design basis earthquake (DBE)**. In addition, significant failure of the earthquake protection has already been identified during targeted investigations in some safety relevant components. It cannot be excluded that further deficits exist in other components or systems. **Thus, it is recommended that in order to**

prevent similar defects concerning the seismic protection, a comprehensive inspection of all safety systems would have to be carried out.

In connection with the existing design deficits against external hazards, it is referred to the planned backfitting of the Hardened Safety Core (HSC). However, the envisaged reinforcement of the existing SSCs associated with the HSC is limited. **Thus, it is recommended that EDF should reinforce the existing SSCs associated with the HSC to demonstrate their resistance to the SND using standard design methods.** IRSN recommends for all new hard core equipment to carry out checks on 100% of welds in order to ensure that this equipment is highly robust to hazards. **In addition, a 100% test of the welds of the existing components belonging to the HSC should be carried out.**

The flood event at the Blayais NPP in France in 1999 showed that the **potential risk of external flooding** was not adequately determined, furthermore probabilistic analyses were missing. The now envisaged probabilistic analyses of external flooding considers only five scenarios calculated for specific NPP sites. The scope of these probabilistic analyses is not adequate given the increasing risk of external flooding. **A comprehensive PSA for external flooding should be conducted in accordance with WENRA recommendation. Scenarios should not be excluded due to the lack of information.**

The Blayais flooding in 1999 also has revealed weaknesses in the **site protection against external flooding**. The platform can be flooded at several NPP sites, and spot checks of the VP have repeatedly shown deficits. The appropriate protection against external flooding is very important because the analysis carried out by IRSN as part of the stress tests showed that cliff-edge effects set in shortly after the design basis flood levels (DBF) were exceeded.

IRSN (2012) assessed the methodology for determining the necessary protection of HSC against external flooding by the EDF. IRSN sees several deficits that lead to the conclusion that the implemented protection against external flooding is not sufficient. As far as can be seen from the very general EDF documents on the subject of protection of the HSC against external flooding, EDF seems to be of the opinion that the VP already installed after the stress test provides sufficient safety margins and thus also meets the increased protection requirements of the HSC.

EDF should follow the recommendation by IRSN concerning the protection of the HSC against external flooding. In particular EDF should reassess the precipitation levels especially the duration of rain; the runoff coefficient for the upstream catchments to take soil behavior during extreme rainfall events into account, the behavior of the hydraulic structures (e.g. dikes, reservoirs upstream of the sites) as well as the water level for sea and rivers. **Most important, EDF should consider extending the safety margins for the protections of the HSC against external flooding.**

Extreme weather events are to be analyzed as part of the PSR4. The hazards to be analyzed include strong winds, extreme temperatures and hazards threatening the availability of cooling water. **It is recommended that also biological**

influences on the cooling water inlets should also be considered as an external hazard. The possible entry of neobiota should be investigated and, if necessary, measures for protection should be implemented.

The protection against extreme external impacts, in particular an **airplane crash**, does not correspond to the state-of-the-art protection for both in new plants in France and in existing plants abroad. Based on current knowledge, a deliberate crash of an airplane into a nuclear power plant cannot be excluded. Such scenarios are generally not covered by the probabilistic approach used for the design of the 1300 MW reactors. The buildings for spent fuel pools are a "weak point" at the French reactors and the ASN has concluded that a deficiency will remain in any case compared to next-generation plants. Russia's attack on Ukraine has led to scenarios that were previously hardly considered realistic. **The residual heat removal from the reactor core and the spent fuel pool should also be ensured in the event of a crash of a commercial airplane. All practical improvements for appropriate protection should be taken. The new need for protection resulting from the war situation in Ukraine in terms of weapons used and attack scenarios should also be considered in the frame of the PSR4 1300.**

Examples of hazard assessments and protection

Earthquake. Information on hazard assessment, DBE and DEC earthquakes considered by the HSC for the sites Saint-Alban and Flamanville, which were selected as examples for seismic hazard assessments and protection, suggest the following:

- The PSHA approach for defining site-specific design basis earthquakes with occurrence probabilities of 10^{-4} per year in line with WENRA was heavily disputed between EDF, IRSN and ASN. It appears that EDF repeatedly chose parameters, models and assumptions which led to too low hazard values. It is unclear if a commonly accepted PSHA methodology and approach is available for the PSR4 of the 1300 MWe fleet at present.
- It is unclear if the deterministically derived design basis values for Saint-Alban and Flamanville can be defended against PSHA-derived results for earthquake occurrence probabilities of 10^{-4} per year (10,000 years average recurrence interval). The same applies to the design of the HSC which is required to sustain a 20,000-years earthquake.
- Different design basis values are apparently in force for the Flamanville site: 0.15 g for Flamanville 1 & 2 and 0.25 g for the EPR. Taking these values at face may lead to conclude that the DBE for Flamanville 1 & 2 is severely underestimated. The HCS of Flamanville 1 & 2 is designed for 0.25 g. Comparison of the value with the DBE of the EPR suggests that installation of the HCS at Flamanville 1 & 2 may only ensure safety up the 10,000 years earthquake and not for DEC earthquakes.
- It seems that seismic hazard assessments of both, Saint-Alban and Flamanville, do not account for active tectonics and active faults, although methodology and active fault data is well established in France. Both sites are located near active faults.

Flooding. The St. Alban site is located on the River Rhone, in an area with a high risk of flooding. Due to climate change, more frequent and more intense precipitation days in winter and an increase in extreme precipitation events are highly likely. It is expected that the current hazard level will increase in the future due to the effects of climate change. For the St. Alban site, IRSN (2012) considers it necessary to review the flood levels to ensure a significant and sustainable margin. All in all, neither the flooding analyses carried out nor the safety margins used are sufficient, as already explained. **It is important to define appropriate requirements in the generic PSR4 1300 in order to be able to adequately assess the site hazard in the context of the site-specific PSR.**

The Flamanville NPP is located on the English Channel. To protect coastal sites, IRSN (2012) recommended that EDF reevaluate the sea level used for the HSC so that it is well above the level previously chosen as a reference and use this re-evaluated level to account for the impact of waves. According to EDF, the probabilistic analysis of the impact of flooding (due to wave overtopping, wind and high sea levels) for the Flamanville site has shown that initial flooding that the overall risk of meltdown is sufficiently low. However, EDF used a too low water level for the analyses. In addition, EDF refers to the effectiveness of the measures taken at the site after Fukushima to deal with external flooding situations. But the inspections revealed that, due to maintenance deficiencies and handling difficulties, there is no guarantee that the necessary equipment will be ready for use in the event of external flooding.

In a statement published in December 2019, IRSN described the situation at the Flamanville NPP as "very worrying", particularly in view of the significant deviations found in various safety-relevant systems during the last ASN inspections. Even though the deficiencies found were rectified, the lack of safety-oriented behaviour was evident during an ASN inspection of the implemented post-Fukushima measures.

Comprehensive inspection and maintenance of the VP should be carried out as part of the PSR4 1300. Building's leak tightness should be inspected and maintained for walls, floors, joints, conduits, sumps and drainages related to potential flooding issues. Maintenance, with adequate frequency, planning, training and review, is important for flooding protection. **At the very least, the monitoring and maintenance of the VP to ensure flood protection should be comprehensively regulated as part of the PSR4 1300.**

1 INTRODUCTION

The life time extension of the French 1300 MWe reactors is linked to the 4th Periodic Safety Review (PSR) of the reactors.

Contents and objectives of the PSR4 defined on the basis of a proposal by EDF (2017) which was sanctioned and amended by ASN (2019a). Accordingly, the PSR4 is planned to be carried out in two phases (ASN 2019a):

- a generic PSR phase covering subjects common to all 1300 MWe reactors. The generic approach takes advantage of the standardized nature of the reactors and allows to pool certain studies such as aging control, obsolescence, compliance of the installation, reassessment and design studies of possible modifications.
- a specific PSR phase, which will focus on each reactor individually. The specific phase makes it possible to integrate the individual characteristics of the installations and sites such as, for example, the level of natural hazards to be considered and the condition of the installation. The specific phase will take place between 2027 and 2035 (Table 1).

Table 1: Timeline of the PSR4 for the 1300 MWe reactors (Data by ASN 2024a).

1300 MWE site	Unit	PSR
Cattenom	1	2027
Paluel	1+2	2027
Saint-Alban	1+2	2029
Belleville	2	2030
Cattenom	2	2030
Flamanville	1+2	2030
Nogent-sur-Seine	1+2	2030
Paluel	3+4	2030
Belleville	1	2031
Cattenom	3	2031
Penly	1	2031
Cattenom	4	2033
Golfech	1	2033
Penly	2	2034
Golfech	2	2035

The 20 reactors of the 1,300 MW fleet are located at eight locations in France. Basically, these locations can be distinguished between coastal locations (Paluel, Penly and Flamanville) and inland locations (Cattenom, Nogent-sur-Seine, Belleville, Saint-Alban, Golfech).

For Task 3, events from the past and events that could be estimated to be relevant in the immediate future are researched. The types of hazards that EDF wants to investigate as "hazards[1]" are compiled and based on the most recent findings possible, and these are recorded as a reference for site-specific investigations.

Until 2011, the methodology used in France to assess natural hazards was based on a deterministic approach. The strongest historical event was considered on the basis of a specific observation period - usually one hundred or one thousand years - to which safety margins were added. A PSA for external events was not carried out. The external hazards are reassessed at regular intervals as part of the periodic safety reviews carried out every ten years. In addition, external hazards, in particular earthquakes and floods, were subject to a targeted reassessment as part of the stress tests carried out in France in 2011.

For the purposes of the 4th Periodic Safety Review (PSR) of the 1300 MW reactors, the hazard assessments should be updated. According to EDF (2023a), external hazards[2] (comprising of natural and human-made hazards) include: earthquake, external flooding, extreme weather conditions (flooding, snowfall, heat wave, extreme cold, extreme wind, hurricane), hazards specifically threatening cooling water intake systems and related structures (frost, icing, blockage, siltation, low water), lightning and electromagnetic interference, and hazards arising from nearby industrial facilities (explosions, hazardous substances), aircraft crash and malicious acts.

Task 3 elaborates on the hazards to which the 1300 MW reactors are exposed according to the current state of knowledge. This takes into account (1) the extent to which the issue has already been covered by the EU Stress Tests, (2) hazards investigations that are still pending, (3) measures that have not yet been implemented or (4) planned measures no longer being pursued.

Chapter 2 begins by summarizing the relevant French regulatory requirements and compares these national requirements with the most important requirements of WENRA. Chapter 3 explains, as far as possible, which investigations and measures should be carried out as part of the PSR. These are compared to the corresponding WENRA requirements. Chapter 4 discusses the design basis of the 1300 MW reactors and the protective measures already taken and planned. The approaches to analysing external hazards are illustrated for a coastal site (Flamanville) and an inland site (Saint-Alban) in Chapter 5.

Due to the limited scope of this report, it is not possible to assess in equal depth whether and how all different types of external hazards, comprising of natural and man-made hazards[3], are taken into account in the French regulations and the PSR4 of the 1300 MWe reactor fleet. At this background the authors decided

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[1] According to EDF, hazards are events or situations that can cause direct or indirect damage to SSCs important to safety, i.e., SSCs necessary to fulfil the basic safety functions.

[2] Internal hazards are not considered in this task. According to EDF, internal hazards include: fire, explosion, internal flooding, failure of pressure equipment, collision and load drop, electromagnetic interference, emissions of dangerous substances, malicious acts.

[3] The WENRA (2020a) hazard list comprises of 73 natural hazards types and 18 human-made hazard types.

to focus on earthquake, external flooding, some extreme weather events and certain types of human-made hazards which are regarded most important for the safety of the reactors. This is because:

- it appeared questionable if French regulations and approaches to analyse seismic hazards are up to date;
- lessons learned from previous events show that external flooding is a relevant threat to the French NPP fleet;
- contrary to earthquake and flooding, some hazards related to extreme weather allowing to forecast extreme events and mitigate their consequences by human intervention.

2 HAZARD ASSESSMENT: REGULATORY REQUIREMENTS

2.1 WENRA Reference Levels and Guidance

In 2014 WENRA published commonly agreed Safety Reference Levels (SRL) and guidelines for the consideration of natural hazards in the safety demonstration for existing reactors (WENRA 2014). The corresponding Reference Levels were developed in the aftermath of the Fukushima Daiichi accident with a clear focus on hazards in connection with earthquake, flooding and extreme weather (WENRA 2014, Issue T, Natural Hazards). The WENRA Reference Levels apply to existing reactors such as the fleet of the French 1300 MWe reactors and are regarded binding by all WENRA member states including France. In a later stage WENRA enlarged the scope of the concerned Reference Levels to also include external human-made hazards such as external explosion, fire or airplane crash (WENRA 2021, Issue TU, External Hazards), and internal hazards arising from inside of the NPP (WENRA 2021, Issue SV, Internal hazards). WENRA (2020a-d) further provide detailed guidance on how to apply the Safety Reference Levels for natural earthquake, external flooding and extreme weather.

The Reference Levels and accompanying guidance on their application cover the identification and assessment of external hazards, the definition of design basis events, the protection against design basis events, and the consideration of events more severe than the design basis (WENRA 2014; 2020a-d; 2021). The Reference Levels particularly stipulate that, for all hazards that apply to a site, design basis events shall be defined based on site-specific hazard assessment. The occurrence probability of these design basis events shall not exceed 10^{-4} per year in order to ensure a high level of protection against external hazards (WENRA 2014, Issue T4.; WENRA 2021, Issue TU4.)[4]. The definition of design basis events and the related design basis parameters (e.g., ground motion values for earthquake; water levels for floods; wind speed) is consequently to be based on probabilistic assessments that provide relations between the hazard severities and their occurrence probability.

WENRA (2014, Issue T5.; 2021, Issue TU5.) further requires existing reactors being protected from design basis events. During design basis accidents, protection shall be sufficiently reliable to conservatively ensure that the plant is able to fulfil the fundamental safety functions[5]. This is to be achieved by applying reasonable conservatism providing safety margins in the design WENRA (2014; 2021, Issue E8.).

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[4] Requirements for the definition of the design basis have to be read in conjunction with Issue E, Design Basis Envelope for Existing Reactors.

[5] Control of reactivity, cooling of the reactor core and spent fuel, confinement of radioactive material.

Consideration of phenomena more severe than the design basis events are stipulated in Issue T6. and TU6., respectively (WENRA 2014; 2021)[6]. Such events and phenomena are summarized under Design Extension Conditions (DEC). The Reference Levels require identifying and assessing the effects of events not covered by the design basis. Analyses shall include the assessment of hazard severity as a function of the related occurrence probability (when practicable) along with the impact of such events on the plant. The overall goal is to identify reasonably practicable improvements to increase the robustness and resilience of a plant that can be implemented for the prevention of severe accidents[7].

In sum, WENRA's stipulations on design extension conditions do not require setting concrete values for events in terms of their severity (e.g., seismic ground motion) or occurrence probability (e.g., once in 20,000 years as applied in the case of the French "noyau dur") that must not lead to severe accidents. WENRA rather requires to increase the robustness and resilience of a plant as far as "*reasonably practicable*". Unfortunately, WENRA does not provide commonly agreed explanation on how to decide on the "*reasonable practicability*" or just "*practicability*" of possible measures to increase safety leaving the judgement to the national regulators.

Issues T and TU of WENRA (2014) and (2021), respectively, clearly express that the design basis of a plant may change during its lifetime, e.g., due to a new hazard assessment that identifies higher severities of the design basis event (e.g., in terms of seismic ground motion or flood height)[8]. The same applies to DEC considerations. WENRA consequently requires that the design basis and DEC shall regularly be reviewed using both, a deterministic and probabilistic approach (WENRA, 2014; 2021; SRL E11.1 and F5.1). It is explained that "regularly" is understood as ongoing activity supported Periodic Safety Reviews on a longer perspective[9].

Periodic hazard reviews with respect to the earthquake, flooding and extreme weather are also addressed by WENRA (2020a-d), although not in the rank of binding Reference Levels. WENRA (2020b) suggests "*Seismic hazard assessment should be reviewed thoroughly and periodically. The reviewers should consider conducting independent hazard assessments involving different groups of experts and considering all relevant interpretations in order to improve and strengthen the bases for regulatory decisions.*" The authors of this report regard this WENRA suggestion particularly important for the PSR4 of the French 1300 MWe fleet.

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6 Requirements for the definition of the design basis have to be read in conjunction with Issue F, Design Extension of Existing Reactors.

7 Issue F of WENRA (2014; 2021) has the same requirement.

8 WENRA (2014), Reference Level E1.1, Footnote 16: *„The design basis shall be reviewed and updated during the lifetime of the plant*"

9 WENRA, 2014; 2021; SRL A2.3

Implementation of the WENRA Reference Levels in the French Regulations.

The WENRA RHWG performed a formalized review to follow-up the implementation of the 2014 SRL in WENRA countries' national regulatory framework (i.e. legally binding requirement established in laws and regulations, publicly available license conditions repeated in each and every NPP license, publicly available regulatory guidance). This review focused on the 101 RLs which were revised or newly formulated such as the SRL in the new Issue T on natural hazards. As of the 31 October 2015, only four of the 19 RLs of Issue T were implemented in the national regulations in France. France subsequently want to implement the remaining SRL by the Guide „Reactor (PWR) design" and a new ASN Guide on natural hazards. (WENRA 2018b)

The implementation of the WENRA RLs in France was characterized by considerable delays: As of 1 January 2018, the implementation of 123 of the 342 RLs were still missing. (WENRA 2018a) According to WENRA (2021a), as of 1 January 2021, 73 RLs were still not implemented.

It is not clear to the Authors, which of these SRL were implemented in the French regulations at what time. In any case, it is clear that the WENRA RLs Issue T were not implemented in the regulations at the time the new Flood Risk Assessment Guidance was established (see below).

2.2 French regulations

2.2.1 Earthquake

The regulatory requirements for natural hazards to be considered in the design of French nuclear facilities are stipulated in RFS 1.2.C (1981)[10] and a revision thereof, RFS 2001-01[11]. Both safety standards require French nuclear installations to be designed and built to withstand – without jeopardising their safety - the most severe natural phenomena (earthquake effects) that have already occurred in the surrounding area, with an additional safety margin (ASN 2011a).

The Safe Shutdown Earthquakes (SMS) and Design Basis Earthquakes (DBE) for the 1300 MWe reactors commissioned in the late 1970s and 1980s were consequently determined using deterministic methods based on the strongest recorded earthquakes ("*Séisme maximal historiquement vraisemblable*"; largest probable historical earthquake). The approach determines earthquakes equivalent to those for which historical records exist and which are liable to recur at an epicentre causing the most penalising effects (in terms of intensity) at the site. The

[10] Règle fondamentale de sûreté - RFS 1.2.c of 1st October 1981 concerning the determination of the seismic motion to be taken into account for the safety of the facilities

[11] Règle fondamentale de sûreté - RFS 2001-01 of 31st May 2001 concerning the determination of the seismic risk for the safety of surface basic nuclear installation

corresponding earthquake is referred to as MCE (Maximum Credible Earthquake) or "Maximum Historically Probable Earthquake". The MCE is taken as the strongest earthquake that occurred in the seismotectonic zone which also contains the site. It is determined from the historical period covered by SISFRANCE earthquake catalogue, i.e., roughly the last 1000 years (FORNER & BOULAIGUE 2001). Determining the MCE also accounts for paleo-earthquakes (ASN 2011a).

The Safe Shutdown Earthquake (SMS) is calculated from the MCE as follows:

$Intensity_{SMS} = Intensity_{MCE} + 1$

This 1-degree intensity safety margin above the strongest historical earthquake is conventionally said to correspond to a safety margin of 0.5 magnitude units (FORMER & BOULAINGUE 2001).

The Design Basis Earthquake (DBE) is consequently evaluated from the SMS and defined by an enveloping design spectrum normalized to the site-specific ground acceleration values. The seismic ground motion (mean acceleration response spectra only) is determined by the ground motion prediction equation by BERGE-THIERRY et al. (2003). Detailed descriptions of the process to obtain response spectra for the DBE are provided by FORMER & BOULAINGUE (2001) and SCOTTI et al. (2014).

Defining the Design Basis Earthquake on deterministic methods is no longer state of the art. ENSREG (2012b) therefore recommended introducing probabilistic methods (PSHA) in order to provide a more meaningful basis for determining the design earthquake. The recommendation is reflected in the French National Action Plan (NAcP) and ASN (2014) announced that probabilistic methods are to be used to determine the site-specific seismic hazard as part of the 3rd PSR of the 1300 MWe fleet. The aim was to apply the methods used in a pilot study for the Saint-Alban site first and roll it out to other sites as part of the PSR4.

2.2.2 External flooding

Flooding is a risk that was taken into account in the design of French plants and reassessed during regular safety reviews or after certain exceptional events. The partial flooding of the Blayais NPP during the storm on December 27, 1999 led to a reassessment of all plants with additional safety requirements. Lessons learnt from the Blayais flooding for the characterization of flooding hazards was the necessity to identify all the phenomena which may cause or take part in the flood of the sites. This resulted in the review of the protection of all NPPs against external flooding ("REX Blayais methodology" in 2001). ASN and IRSN declared in 2011 as part of the EU stress test that the methodology used at the time could not calculate the 10,000-year flood with sufficient certainty[12] (ENSREG 2012b).

Excursus: The flooding of the Blayais NPP

At the Blayais site four 900 MWe reactors are in operation. During the night of 27-28 December 1999, a flood caused by the confluence of the rising tide with exceptionally strong winds resulted in the partial submergence of the Blayais site. The winds pushed the water over the protective dike.[13] The water infiltrated into the duct cover slabs, flooding the sub-levels of the administrative buildings and common auxiliaries building. Then, the water propagated into the rooms of Units 1 and 2 through doors and openings, reaching the sub-levels of the electrical buildings, the connection galleries of the water pumping station, the sub-levels of the peripheral and fuel buildings. It has to be noted that, during the first hours of the incident, the arrival of the additional teams from outside the NPP was impossible owing to the damage resulting from the storm (flooding of the access routes, many tree falls…).

Lessons Learned: *Severe weather conditions caused a flooding of the reactor building basement and thus the simultaneous failure of major safety systems. The event showed that events affecting more than one unit on a site could result in additional difficulties as some auxiliary systems are common to all units on the site. It has revealed also some weaknesses in the site protection against external flooding. The French standard safety rule contained two criteria for flood protection: (1) placing the platform that supports safety-relevant equipment at a level at least as high as the maximum water level; and (2) blocking any possible routes through which external waters could reach reactor safety equipment located below the level of the site platform. At Blayais, both criteria were not met: the platform was 1.5 meter too low; and the resistance of the fire doors in the tunnels to the underground safety equipment was miscalculated: the waters surged into the tunnels and simply broke through the doors. The event is an example of several units affected at the same time by one external hazard. It was classified as Level 2 in the INES scale. (BECKER et al. 2020).*

New guide No. 13

The original assessment basis for flood protection was defined in the RFS I.2.e rule of April 12, 1984. The Blayais flooding showed the need for a new guide on protection of nuclear installations against external flooding, which was developed from 2005-2012. In 2013, the ASN published the new Guide No. 13 "Protection of Basic Nuclear Installations Against External Flooding". (ASN 2013g)

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12 ENSREG recommended carrying out a comparative assessment between the DBF level defined in accordance with ASN requirements and the methods used in other European countries. As part of ETSON, a comparison of the methods used in Europe to define the hazard was carried out in 2014-2015. (ASN 2020f)

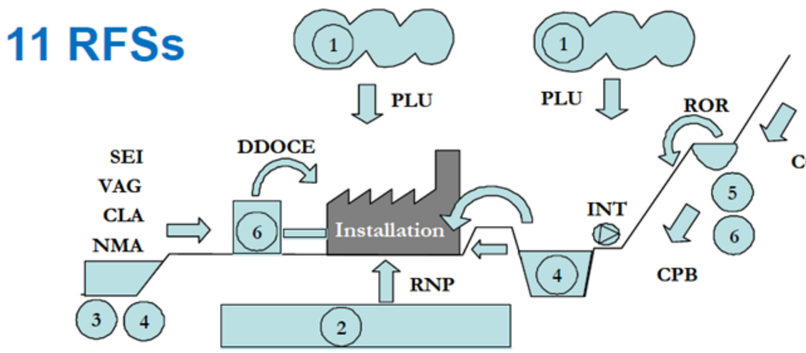
13 Before the floods, EDF had been planning to raise the dike around Blayais by 50 cm, to 5.70 m, as required by the 1998 safety analysis report. This work had been delayed. Furthermore, the waves rose to more than a meter above the dike level of 5.20 m to 6.20 m.

The guide should be used for installations already in operation during PSR (article L.593-18 of the Environment Code).

The principles adopted for the development follow those of RFS I.2.e and experience feedback from the Blayais site flooding in 1999. The guide provided the definition of "Reference Flooding Situations (RFS)" and the methods for the characterization of these 11 RFSs (Figure 1). In the following paragraphs, these RFSs are described.

*Figure 1: Reference situation for flooding risk according to the Guide no. 13 (**PLU** Local rainfall, **CPB** Small watershed flooding, **CGB** Large watershed flooding; **DDOCE** Deterioration or malfunctioning of structures, circuits or equipment; **INT** Mechanically induced wave – Malfunctioning of hydraulic structures; **RNP** High groundwater level; **ROR** Failure of a water-retaining structure; **CLA** Local wind waves; **NMA** Sea level; **VAG** Ocean waves; **SEI** Seiche) (ASN 2013g)*

Reference situation for flooding risk according to the Guide no. 13



Source: ASN 2013g

umweltbundesamt

Five RFSs should be taken into account for all sites:

1 Local rainfall: The reference rainfall events are defined by the upper bound of the 95% confidence interval for the 100 year return period rainfall events calculated from the data of a weather station that is representative of the site conditions. To take account firstly of the potential for obstruction of the stormwater drainage system during extreme events, and secondly for events rarer than those defined in the reference rainfall events, the installation shall be able to cope with a surface water runoff scenario when its local stormwater drainage system is completely blocked. This reference surface water runoff scenario is defined by the 100-year return period rainfall event (upper bound of the 95% confidence interval) lasting 1 hour.

2 Small watershed flooding: The reference small watershed flooding is defined by an instantaneous peak flow rate, for a 10,000-year return period. For watersheds with a surface area of between 10 and 100 km², the flow rate associated with this RFS can be calculated from the 100-year return period rainfall events (upper bound of the 95% confidence interval) by multiplying the resulting flow rate by a factor of 2.

<u>3 Deterioration or malfunctioning of structures, circuits or equipment:</u> The types of structures, circuits and equipment to be taken into consideration include: basins, reservoirs, ponds, tanks, the circuits, pipes, filling and discharge structures, water-retaining structures, dykes along watercourses and canals and the associated hydraulic structures, except for the structures considered in the "failure of a water-retaining structure" RFS. To assess the effect of the discharged volume, it is usually necessary to characterize the potential resulting water height. The volumes of water that could enter the rooms to be protected are quantified on the basis of this water height.

<u>4 Mechanically induced wave:</u> The reference mechanically induced wave is characterized by its intensity and its duration. The reference situation is chosen considering the initial level and flow rate conditions leading to the worst-case mechanically induced wave situation. When characterizing the initial level, no situation less probable than the flood or sea level RFSs defined in this guide shall be taken into consideration. It is necessary to seek the worst-case scenario, taking into account the structure operating instructions.

<u>5 High groundwater level:</u> The reference groundwater level is characterized on the basis of a hydrogeological study of the site, depending on the available data, using one of the two methods. The combination of an "initial level" and the rise effect caused by an "initiating event" is to be considered. Hydrogeological data collected from public organizations shall be supplemented by in-situ measurements. More specifically, piezometric measurements shall be taken over a continuous period that shall never be less than 1 year and shall preferably exceed 3 years, with a sufficiently small time step to characterize the amplitude and speed of fluctuations in groundwater level.

Three RFSs should be taken into account for river sites:

<u>6 Large watershed flooding:</u> A large watershed generally covers an area larger than 5,000 km². The reference flow rate corresponds to the peak flow rate associated with the 1000-year flood, taking the upper bound of the 70% confidence interval, and increased by 15%. The model for the flood plain is calibrated on the basis of the available data relative to severe floods, paying particular attention to head losses at particular features: when the study is based on a previously established height, the validity of this calibration shall be verified. When calibration is impossible due to a shortage of data, particularly concerning the flood plain, the values of the parameter(s) of the model which cannot be adjusted, such as the Strickler coefficient, can be characterized by appraisal.

<u>7 Failure of a water-retaining structure:</u> The analysis of the failure scenarios concerns water-retaining structures that lie across watercourses.

<u>8 Local wind waves:</u> The reference local wind waves are the field of waves resulting from a 100-year return period wind (upper bound of the 70% confidence interval) propagated over a 1000-year return period flood (upper bound of the 70% confidence interval.

These three RFSs should be taken into account for coastal sites:

9 Sea level: The reference high sea level is the sum of:

- the maximum level of the theoretical tide,
- the 1,000 year return period storm surge (upper bound of the 70% confidence interval), increased to take into account uncertainties associated to the evaluation of the rare storm surges, and resulting from outliers,
- the change in mean sea level extrapolated to the next PSR.

Extreme storm surges are characterized from data on the sea high water storm surges, using a statistical study on the local or regional scale. The calculation of 1000-year return period storm surges on a local scale using the conventional extrapolation laws is at present unable to take satisfactory account of exceptional events (outliers) observed at several monitoring stations. An additional increase in reference sea level of 1 m is applied to allow for this.

10 Waves (ocean waves and local wind waves): The reference waves are characterized from the 100-year return period significant height wave conditions (upper bound of the 70% confidence interval) determined offshore of the site and propagated over the reference sea level. If the effects of the local wind are found to be predominant over the ocean waves due to the site configuration or existing structures, reference local wind waves are used. This is defined by the local wind waves resulting from a 100-years wind (upper bound of the 70% confidence interval) propagated over the reference sea level. When waves cause the overtopping of protective structures, the overtopping water volumes shall be estimated.

11 Seiche: The seiche hazard is analyzed on the basis of available experience feedback, for example through the operation of an existing installation or measurements of the water level.

The guide also discussed the potential threat of **tsunamis**. It is explained that no geological structure that could cause a major tsunami has been identified near the Atlantic coast of metropolitan France (more specifically the coasts of the Atlantic Ocean, the English Channel and the North Sea). In the last 50 years of seismic and sea-level monitoring, no rise in sea level on the Atlantic coast of France has been linked with any certainty to an Atlantic tsunami. Witness reports compiled from the 18th century record about fifteen events attributed to tsunamis with varying degrees of uncertainty. In none of the cases do the effects go beyond the flooding of gently sloping coastal areas[14]. Moreover, tsunamis are independent of high tides and storms. The probability of a tsunami and the sea level RFS occurring together is therefore very low. The joint occurrence of these two events has therefore been ruled out (ASN 2013g).

The RFSs are characterized first and foremost by an expert appraisal. This appraisal takes into **consideration the identified uncertainties** in the current state of knowledge. In the paragraphs specific to each RFS, the guide proposes a

[14] The conclusion is supported by far field modelling of the tsunami triggered by the 1755 Lisbon earthquake (BARKAN ET AL. 2009)

method for taking certain particular uncertainties into account. It is also explained how other uncertainties can be addressed.

It is explained that the **combinations of events** have been chosen inter alia where there is a proven or presumed dependency between events likely to cause flooding. In addition, when the potential for concomitance has been identified in the light of the duration and frequency of any one of the events, their combination has been included.

The RFSs definition is based **on engineering judgment** with a probabilistic target. It is using statistical and deterministic methods and the probability of exceedance of 10^{-4} per year to cover associated uncertainties. It also required to evaluate the hazard with time concerning climate change and to monitor "influence factors" (i.e. dyke modification upstream the site).

Climate change effects have to take into account if the state of knowledge so allows. Based on the current state of knowledge, only the development of the average sea level is taken into account, which is extrapolated at least until the next PSR. IRSN explained with regard to the influence of climate change, it is considered that there is no obvious trend for extreme events (extreme wind, precipitation, river flooding), which is why they are not taken into account. But there is a surveillance of factors whose modification may impact significantly RFS characteristics, and a periodical reassessment should be performed (REBOUR & MENAGE 2012).

2.2.3 Extreme weather

Regulatory basis for safety assessments with respect to extreme meteorological conditions is provided by national standards that existed at the time of the construction of each plant series (i.e., in the 1070s and 1980s). Information on the meteorological events or combinations of events taken into account for the design of the facilities are described in ASN (2011a) as follows:

- High wind and snow: Structures were designed in accordance with the latest revision of the "*Snow and Wind 65*". During the Stress Tests the licensee further checked conformity of the robustness of buildings and SSCs important to safety with updates of the Snow and Wind rules including amendments made in 2000.
- Hail was not considered in the design.
- Lightning: Protection of the facilities conforms with the ministerial order of 15th January 2008 (lightning protection of classified facilities) abrogated and replaced by the order of 19th July 2011.
- Tornado: Buildings and SSCs important to safety are protected against a "reference tornado" of Intensity 2 on the Enhanced Fujita Scale, independently from the site (EDF 2023c).

No design requirements seem to exist with respect to extreme temperature, low water level and frazil which, however, are considered in the safety demonstration in addition to the listed weather phenomena (ENSREG 2012b). Protection requirements for extreme temperature were only developed following cold winters in the 1980s and heat waves in the 2000s (EDF 2023c).

It is concluded that no design basis requirements for extreme meteorological conditions have yet been developed.

2.2.4 Man-made external hazards

The standard RFS I-2.d ("Integration of risks related to the industrial environment and communication routes") defines, among other things, the list of industrial facilities and communication paths that can cause risks for nuclear reactors. The safety case is based on a deterministic approach and a probabilistic approach when the deterministic approach cannot exclude the risk. According to RFS I-2.d, the probability of an unacceptable release of radioactive substances at the site boundary must be less than 10^{-6} per year for all hazards of external origin associated with human activities. In order to take into account the sum of the probabilities of accidents of different origins, RFS I-2.d sets an order of magnitude for the probability of occurrence of an event of 10^{-7} per year for each group of hazard sources considered. (ASN 2022a)

The air risk analysis is based on the application of the fundamental safety rule RFS 1-2.a ("Integration of risks related to airplane crashes"). In accordance with this RFS, the probability of an unacceptable release of radioactive substances at the site boundary must be less than 10^{-6} per year and for each of the following "safety functions": shutdown of the reactor and removal of residual heat; storage of spent fuel and treatment of radioactive substances. To take into account the sum of the probabilities of accidents of different origins but with similar consequences, RFS I-2.a sets, for each group of these external event (general aviation, commercial and military) considered an order of the probability of occurrence of the event of 10^{-7} per year and per reactor. (EDF 2023a)

2.3 Conclusions and recommendations

The regulatory requirements for the assessment of natural hazards in France are not regarded to be fully in line with WENRA Reference Levels and guidance. This is particularly true for **earthquakes**, where France so far followed a purely deterministic approach for determining design parameters while WENRA (2014; 2021) requires definitions of design basis events for an occurrence probability of 10^{-4} per year. Already in 2012 ENSREG (2012b) therefore recommended introducing Probabilistic Seismic Hazard Assessment (PSHA) to determine the design earthquake. It seems that this recommendation is not yet fully implemented although it is duly reflected in the French National Action Plan (ASN 2012a).

The regulations concerning (ASN 2013g) the protection of **external flooding** are not completely in line with WENRA (2014; 2021). Although the French practices account for all major phenomena and processes that combine to the flooding hazards at sites located at river or at the Atlantic coast, some of the phenomena are only considered for very short recurrence periods (e.g., local rainfall and waves 100 years; wind waves, 1000 years). In any case, it is clear that at the time of publication of ASN Guide No. 13 in 2013, WENRA Safety Reference Levels and Guidance, published in 2014 and 2015, could not be included in the French regulations.

Regulatory basis for safety assessments with respect to **extreme weather** is provided by national standards that existed at the time of the construction of each plant series (i.e., in the 1070s and 1980s). Within the scope of this report, it could not be conclusively clarified whether binding regulations for the assessment of meteorological hazards that meet the requirements of WENRA have been implemented. However, there is no corresponding directive in the French regulations.

For **man-made external hazards**, the ASN standard RFS I-2.d[15] sets safety objectives by defining criteria for unacceptable release of radioactive substances at the site boundary and limits of the probability of occurrence of events. It therefore refers to both, hazards (defined by severity and occurrence probability) and the response of the plant. The approach also provides lists of hazard sources to be considered and the assessment of hazards. It is consequently regarded in line with WENRA (2021).

2.3.1 Recommendations

2.3.1.1 Application of the requirements of the WENRA Safety Reference Levels in the PSR4

Relates to EDF NRO (2023a) chapter I.2.2.2.1

Motivation/Observation:

The WENRA Safety Reference Levels (SRLs; WENRA, 2014; 2021) provide European common ground for the consideration of external hazards in nuclear safety. Of central importance in this context are Issue T (Natural Hazards; WENRA 2014) in conjunction with the Issues E and F (Design Basis Envelope for Existing Reactors and Design Extension of Existing Reactors, respectively). The Authors of this report assume that most, if not all, of the 2014 SRLs have been

[15] Objectifs de sûreté et bases de conception pour les centres de surface destinés au stockage à long terme de déchets radioactifs solides de période courte ou moyenne et de faible ou moyenne activité massique (8 novembre 1982) ; révision 1 (19 juin 1984).

implemented into the French national regulatory framework and expect that Issue TU of the 2021 SRLs (External Hazards) will be implemented in due course[16]. The SRLs of Issue T (2014) and TU (2021) are accompanied by Guidance Documents addressing the application of the SRLs. French experts from both, ASN and IRSN contributed significantly to the consensual development of the aforementioned documents by WENRA.

Recommendation:

It is recommended to strictly apply the contents and requirements of WENRA Safety Reference Levels relevant to external hazards and the protection against such hazards in the PSR4, in particular Issues E, F and TU. Where there is room for interpretation of the rules, ASN should give preference to interpretations that result in higher levels of safety.

2.3.1.2 Update the Guide for protection against external flooding.

Relates to EDF NRO (2023a) chapter I.2.2.2.1.4 "External Flooding"

Motivation/Observation:

In 2013, the ASN published Guide No. 13 (ASN 2013g), which deals with the risk of external flooding. This guideline was developed in response to the flooding of the Blayais NPP site in 1999, which revealed significant deficiencies in the determination of potential water levels and the risks of external flooding. It was developed from 2005-2012 and must now be considered out of date. The guide does not take into account the related WENRA documents developed after the Fukushima accident. The assessment is based on deterministic methods considering margins and hazard combinations, with a "probabilistic" exceedance target of less than 10^{-4} per year, but mainly using expert judgment. For many relevant flooding events too low exceedance probabilities are considered, climate changes are only considered to a limited extent.

In the (outdated) ASN Guideline No. 13 on the protection against external flooding, only the rise in sea level is taken into account as a variable value that is increasing due to climate change. However, heavy rainfall events represent a significant and increasing risk for the external flood risk. Due to climate change persistent weather conditions are being observed more and more frequently in the northern hemisphere in the summer months. The long duration of specific meteorological conditions can lead to extreme results. The summer of 2016

[16] Benchmarking of the implementation of the WENRA (2021) Safety Reference Levels of Issues TU (External Hazards) and SV (Internal Hazards) into the national regulatory framework is currently ongoing in WENRA-RHWG.

showed that a single weather pattern can trigger both localized heavy precipitation with flash floods and regional precipitation with river flooding.[17] (BECKER et al. 2020)

Recommendation:

The ASN guide No. 13 for the protection against external flooding should be updated. The relevant WENRA documents developed after the Fukushima accident should be systematically taken into account (WENRA 2021; 2020c). Where possible, the determination of the phenomena should be based on scientific analysis rather than expert judgment. For relevant flooding events, exceedance probabilities of 10^{-4} should be assumed. In addition, extreme weather phenomena due to climate change should be adequately taken into account. These are, in particular, local heavy rainfall events.

2.3.1.3 Development of a Guide on the protection against extreme weather events

Relates to EDF NRO (2023a) chapter I.2.2.2.1.8 “Heat Waves”, I.2.2.2.1.9 “Extreme cold”, I.2.2.2.1.11 “Storms and debris”, I.2.2.2.1.12 “Tornado” and I.2.2.2.1.14 “Snowfall”

Motivation/Observation:

In France, rules and guidelines exist for various external hazards. In view of the increasing relevance of extreme weather events for the safety of NPPs, it would be relevant to safety if legally binding regulations for protection against extreme weather events also existed in France.

Recommendation:

It is recommended to develop a guide on the protection of nuclear installations against extreme weather events that reflects the current scientific status and that must be applied within the framework of the PSR4 of the 1300 MWe NPPs. Climate change phenomena should be adequately addressed.

[17] From the end of May to mid-June 2016, a persistent large-scale weather situation with thunderstorms and intense rainfall caused both local flash floods and widespread flooding in Central Europe. The floods occurred in many places without warning. Almost at the same time, storms caused floods in France: initially only small rivers were affected, but later the Loire and the Seine also overflowed their banks.

3 EXTERNAL HAZARDS IN PSR

3.1 WENRA Reference Levels and Guidance

WENRA (2021, Issue P, Periodic Safety Review) provides, on a high level, definitions of the scope and content of PSR. Reference Level P2.2 stipulates that the scope of the review shall be clearly defined and as comprehensive as reasonably practicable with regard to significant safety aspects. P2.2 contains an enumerative list of 14 safety factors to be covered. Among these, equipment qualification, deterministic safety assessment, probabilistic safety assessment, hazard analysis and safety performance are of prime importance for the assessment of a plant's safety with respect to external hazards.

Complementing Issue P, Issues E and F of the WENRA Safety Reference Levels (WENRA 2021) stipulate that design basis and design extension conditions of existing reactors shall be reviewed and updated regularly[18] (reference levels E11.1 and F5.1). Reviews of natural hazards are not addressed on the level of the Reference Levels but in WENRA's so-called guidance documents on external hazards. WENRA (2020a) specifies that "the site specific hazards and the protection concepts against external hazards should be reviewed at least as part of the PSR" and that the results of hazard reviews should be used in the reviews of both, the design basis and design extension conditions (WENRA 2020a, 2020b). The cited guidance documents on natural hazards give more detailed direction to hazard reviews. For earthquake, hazard reviews should account, inter alia, for novel data on seismic sources, newly discovered active or capable faults, new data on ground motion attenuation, and site effects (WENRA 2020b). Reviews of flooding hazards should particularly address man-made changes of physical geography and climate change (WENRA 2020c). Reviews of hazards by extreme weather should pay attention to non-stationary effects including climate change (WENRA 2020d).

In sum, WENRA requires that external hazards be addressed as part of the PSR. The design basis of existing plants is not considered fixed by the initial plant design but rather as a "floating" value that can change over the life of a reactor. The same applies to design extension conditions (DEC).

[18] WENRA understands "regular" as an ongoing activity in which PSR is a complementary tool to follow up this activity on a longer perspective (WENRA RHWG 2021, Reference Level A2.3)

3.2 French regulations and approach

Article 3 of the 2006 Law on Nuclear Transparency and Safety introduces the principle of PSR in the French legislation[19]. Prior to this PSR was practiced for reactors, but on a not-so-regular basis and at time intervals between 9 to 12 or even 13 years, depending on the individual reactors. Article 3 therefore made PSR compulsory for all nuclear facilities and introduced the strict 10-years periodicity. The contents of PSR are only defined in very general wording ("*This review must make it possible to assess the situation of the installation with regard to the rules applicable to it and to update the assessment of the risks or disadvantages that the installation presents for the interests mentioned in I of Article 28*.").

The Environment Code, Article L. 593-18, stipulates an amended requirement[20] (Partie legislative 2023). The article states that the licensee of a basic nuclear installation performs periodic safety reviews of its installation taking the best international practices into consideration. "*This review must allow […] updating of the assessment of the risks or drawbacks presented by the installation […], taking into account more specifically the state of the installation, the experience acquired during operation, the development of knowledge and of the rules applicable to similar installations*". Pursuant to this article, the external hazards must be reassessed as part of PSR, taking the development of knowledge into account and updating the SARs accordingly. As regards external hazards, the article only specifies the content of the PSR to the extent that "*the risk assessment takes into account the consequences of climate change on external hazards to be taken into consideration in this context*." Other contents of the PSR are not explicitly mentioned.

With respect to the contents of PSR, the corresponding regulatory basis for the PSR, as defined in the order-based part of the Environment Code, in Article R. 593-62 (initially introduced by the article 24 of Order 2007-1557, in application of the 2006 law) adds the following[21]: "*The conditions for carrying out the periodic review as well as the questions to be addressed in the report may be specified, for all basic nuclear installations or by categories of installations, by the authority.*" ASN

[19] Loi n° 2006-686 du 13 juin 2006 relative à la transparence et à la sécurité en matière nucléaire (1). Titre IV : Les installations nucléaires de base et le transport des substances radioactive (Articles 28 à 54) Chapitre Ier : Règles applicables aux installations nucléaires de base et au transport de substances radioactives. (Articles 28 à 36).

[20] Code de l'environnement Partie législative (Articles L110-1 à L713-9) Livre V : Prévention des pollutions, des risques et des nuisances (Articles L501-1 à L597-46) Titre IX : La sécurité nucléaire et les installations nucléaires de base (Articles L591-1 à L597-46) Chapitre III : Installations nucléaires de base (Articles L593-1 à L593-43) Section 3 : Fonctionnement (Articles L593-18 à L593-24)

[21] Code de l'environnement Partie réglementaire (Articles R121-1 à R714-2) Livre V : Prévention des pollutions, des risques et des nuisances (Articles R501-1 à R597-5) Titre IX : La sécurité nucléaire et les installations nucléaires de base (Articles R592-1 à R597-5) Chapitre III : Installations nucléaires de base (Articles R593-1 à R593-123) Sous-Section 9 : Réexamens périodiques (Articles R593-62 à R593-63) Sous-section 1 : Réexamens périodiques prévus à l'article L. 593-18 (Articles R593-62 à R593-62-1)

consequently can publish decisions on contents and practice of PSR that are legally binding, although not at the rank as articles of law or governmental decrees.

The objectives of the PSR4 of the 1300 MWe reactors (referred to as "RP4-1300") were developed on the basis of a proposal provided by EDF (2017). ASN (2019a) generally accepted the proposal by EDF requiring additional contents. The provisions formulated by ASN closely follow the report STANDING GROUP OF EXPERTS (2019) which provided an in-depth review of the EDF (2017) proposal. Accordingly, the PSR4 is structured in a "generic" phase covering subjects common to all 1300 MWe reactors and a "specific" phase, which will focus on each reactor individually. The specific phase is scheduled for the period 2027 - 2035 (Table 1). The specific phase should notably "*integrate the particular characteristics of the installation and its environment, such as, for example, the level of natural hazards to be considered*" (ASN 2019a).

For the generic phase of the PSR4, ASN (2019a) defines the following objectives:

1. Verification of the compliance of installations with applicable safety requirements.
2. Move towards the safety objectives set for Generation III reactors with the EPR Flamanville 3 reference reactor. This objective should lead to:
   a. for design basis accidents, to "*aim for radiological consequences below the threshold for implementing population protection measures*";
   b. for design basis hazards, "*bring back and maintain the reactor in a safe state for hazard levels reassessed during the review and integrate the hazards into the assessment of the overall risk of core melt*";
   c. for severe accidents leading to core melt in the reactor, to "*tend towards population protection measures limited in space and time*";
   d. for accidents in the SFP, "*limit the risk of uncovering spent fuel assemblies*".
3. Integrate all the provisions of the hard core which have been prescribed by the ASN.

With respect to natural hazards ASN requires to:

- "*verify the absence of a cliff edge effect for natural hazards corresponding to a target value of annual frequency of exceedance less than* 10^{-4}*/year, or, when it is not possible to calculate the probabilities associated with hazards of natural origin with an acceptable degree of confidence, for events chosen and justified while aiming for an equivalent objective*". The objective clearly refers to Reference Levels T4.2 and T6.3 of WENRA (2014) which are stated verbatim by ASN (2019a p. 6)[22];
- update or develop new Level 1 PSA of fire, flooding, explosion and to carry out a screening of all plausible hazards for each site to determine hazards and sites for which probabilistic analyses could be made (p. 45);

[22] Referred to as WENRA T4 and WENRA T6 by EDF and ASN

- develop Level 1 and level 2 seismic PSA[23] for "*one of the sites considered to be most subject to earthquake risk*". PSAs for other sites should be completed one year before specific PSR (c.f. Table 1).
- identify, based on PSA, provisions aimed at reducing the probability of core melt and uncovering of fuel in the spent fuel pool;
- verify that the concerned installations comply with the updated WENRA (2021) Reference Levels on internal and external hazards (Issues SV and TU, respectively) and the management of ageing (Issue I; ASN 2019a, p. 9);
- compare hazard levels including seismic hazards obtained for the PSR4 to the recommended target set by WENRA (2014) and to specify the levels corresponding to the probabilistic target of 10^{-4}/year "*when this assessment is relevant*" (ASN 2019 p. 32);
- update the levels of meteorological hazards based on the most recent scientific knowledge. ASN specifically mentions extreme temperatures, the combination of high temperature and station blackout, lightning, solar storm and storm (ASN 2019 p. 39-40).

EDF (2023a) takes position on the objectives of the PSR4. With respect to the consideration of WENRA requirements EDF (2023a p. 73) states that "*EDF has verified that the RP4 1300 installations comply with these updated reference levels, known as "WENRA 2020*" adding that some of the hazards listed in WENRA (2020a) were not relevant to the 1300 MWe sites. These hazards were consequently screened out. According to probabilistic studies or "*exploratory post screening analyses*" were carried out: earthquake, river flood, high sea level (tide, storm surge, wave and wind), heat wave, extreme winds and associated phenomena, and tornado including associated phenomena (EDF 2023a p. 130-131). Airplane crash, explosion pressure wave, and explosion pressure wave combined with toxic, flammable, asphyxiating gas or liquid releases it is claimed that the hazards were already subject to sufficient probabilistic and will not be the subject of additional analyses.

3.2.1 Earthquake

For earthquake, EDF claims that the PSR4 of the 1300 MWe fleet accounts for the deterministic reassessment of the level of hazard expressed by the SMS ("Enhanced Safety Earthquake") resulting from the application of RFS 2001-01 and the consideration of site effects. Comparison of the SMS hazard levels derived in the 3rd and PSR4 revealed that hazard spectra are identical for all other sites except Belleville and Saint-Albin (EDF 2023a, p. 102). For Belleville, the new hazard level exceeds the value established in the 3rd PSR (SMS 3 spectrum). EDF announced to evaluate existing safety margins and implement necessary measures if required by seismic re-evaluation (EDF 2023a, p. 102). For Saint-Alban EDF states that the new hazard spectra derived for the PSR4 is covered by the robustness of SSCs as determined during the 3rd PSR. EDF further carried

[23] To be completed by March 2022.

out a “positioning analysis” of the deterministically derived SMS levels in relation to the so-called “WENRA T4 target level”. The latter corresponds to the probabilistically derived Design Basis Earthquake with a return period of 10,000 years. EDF concluded “*that the SMS are correctly positioned in relation to the target level and/or that the installations are justified in relation to the target level due to the seismic levels previously considered (for example the SDD).”* This is not valid for the Saint-Alban site. It appears that the PSHA-derived DBE for the Saint-Albin site exceeds the deterministically derived SMS level. EDF consequently regards “sensitivity studies” to be necessary (EDF 2023a, p. 102).

Actions to be carried out in the PSR4 and for LTO also foresee Level 1 and Level 2 Seismic Probabilistic Safety Analyses (SPSA; EDF 2023a p. 137-138). By 2023 the Level 1 SPSA for Flamanville was completed letting EDF conclude that the probability of core melt associated with seismic loads corresponding to a return period of less than 150,000 years is very low and that 95% of the calculated risk derives from seismic accelerations higher than the “Hardened Safety Core earthquake”.

3.2.2 External flooding

As part of the PSR4 1300, EDF is verifying the robustness of 1300 MWe facilities against the hazards described in “ASN Guide No. 13” concerning the protection against external flooding following the updating of studies and verification of the behaviour of volumetric protection (VP). It is mentioned that the ASN guide, published in 2013 was applied to all 1300 MWe sites prior to the PSR4. (EDF 2023a)

Studies of the eleven reference flooding situations (RFSs) described in ASN Guide No. 13 have already been carried out for the Cattenom and Paluel sites as part of the 3rd PSR 1300, and remain valid for the PSR4. For the other sites, studies are underway or will be carried out in the near future.

River flooding in areas over 5,000 km2 (CGB) - sites concerned[24]: Belleville, Cattenom, Golfech, Nogent and Saint-Alban: The studies carried out to adapt this scenario take into account the phenomenon of dike breach formation and the search for the most important parameter, and justify the modeling used for all river sites. This scenario has no impact on the Cattenom site, since the site is located quite far (around 3.5 km) and above (around 22 m) the Moselle riverbed.

Dam-break wave propagation (ROR) - sites concerned: Belleville, Cattenom, Golfech, Nogent and Saint-Alban: The scenario studies take into account the 15% increase over the entire hydrograph resulting from the propagation of the wave caused by dam failure. This scenario has no impact in terms of modification on the Cattenom site, which is not vulnerable to this scenario given its geographical location as described above.

[24] River flooding in areas with an area between 10 and 5,000 km^2 (CPB) – no site with 1300 MWe reactors concerned.

Sudden transient and localized variation in water level near the site due to a hydraulic structure malfunction or pump station circulation pump stoppage (INT) - all 1300 MWe sites concerned: ASN guide No. 13 recommends studying this scenario by considering the initial level and flow conditions leading to the most penalizing intumescence. The initial water level does not consider any rarer situation than those of flood (CGB) or sea level (NMA). This scenario does not have any impact in terms of modification on the Cattenom site, which is not vulnerable to this scenario given the distance from the Moselle. As regards the Paluel site, the analysis shows an upward re-evaluation of the water level reached in the pumping station, which necessitated an increase in the VP in premises in permanent contact with the heat sink before the PSR4.

Behavior of the rainwater drainage network in the event of heavy rain; runoff phenomena (PLU) - all 1300 MWe sites concerned: As part of the post-Fukushima studies, EDF has carried out rainfall and tank rupture studies following an earthquake at all its sites, and deployed protective measures in this context before the PSR4 1300.[25] Depending on the results of the studies, other provisions may be added to the site's protection. For the Cattenom site, the analysis showed that the measures already in place ensure the site's robustness. As regards the Paluel site, following the analysis carried out, an anti-rain wall was installed in the southern zone to block runoff from the catchment areas of this zone and from outside the site before the PSR4. In addition, organizational provisions for closing bypass valves have been added. With regard to provisions already in place, additional protection thresholds have also been installed.

Breakage of tanks or piping outside buildings housing safety-related SSCs (DDOCE) – all sites in the 1300 MWe level concerned: Additional protection provisions were installed following the conclusions of the Post-Fukushima studies. Concerning the Cattenom site, the analysis showed that the provisions already in place make it possible to ensure the robustness of the site. Concerning the Paluel site, following the analysis carried out, existing organizational provisions and additional protection thresholds were valued (identical to the scenario PLU).

Rise of the water table (RNP) – all sites in the 1300 MWe level concerned: EDF takes into account updated input data as part of the study and also piezometric chronicles and historical data for the characterization of this scenario. This scenario does not generate any impact in terms of modification on the Cattenom site, which is protected by the existing VP and by organizational provisions. Concerning the Paluel site, following the analysis carried out, an increase in the VP at the pumping station was carried out to protect against the phenomenon of rising water tables in the event of higher sea level before the PSR4 1300.

[25] These measures consist in protecting access to premises containing the equipment needed to withdraw and maintain the plant in a safe state, by raising their elevation using sills or cofferdams, combined with reinforced concrete walls to ensure continuity with the wall of the building to be protected. Any hoppers (pipe or cable penetrations) located in the lower part of buildings are sealed.

Local wind waves (CLA) – sites concerned: Belleville, Cattenom, Golfech, Nogent and Saint-Alban: Concerning the Cattenom site, the analysis of the SRI CLA has no impact given the configuration of Lake Mirgenbach.

Sea level (NMA) and Ocean waves (AGW) - sites concerned: Flamanville, Paluel and Penly[26]: As part of the Post-Fukushima studies, EDF carried out sea level and wave studies on the seaside sites, which significantly exceeded the levels required by the reference standards, without the need to implement additional provisions on the three 1300 MWe sites. In particular, the updating of the NMA and VAG scenario studies is covered by the existing provisions following the post-Fukushima studies. Depending on the results of the studies underway for the Flamanville and Penly sites, other provisions may be added to the site's protection. As regards the Paluel site, following the analysis carried out, the VP at the pumping station has been raised (identical to the INT SRI) prior to the PSR4. It was noted that the consequences of this scenario depend heavily on the sea level selected.

Behaviour of VP: all sites with 1300 MWe level reactors: As part of the PSR4 1300, the objective is to verify the absence of impact of differential settlements on the waterstop forming part of the perimeter of the VP, and to demonstrate that there is no safety impact of a seismic flood. In addition, a study on joint sealants was carried out for the Paluel and Cattenom sites. This study demonstrates the integrity of the sealants used on these sites. For other sites, the results of the study as well as any resulting provisions will be presented in the SAR.

The analysis relating to operator delay does not generate any impact on the Cattenom and Paluel sites. The operator actions valued for external flooding scenarios are only preventive actions against the hazards and they are therefore not affected by the application of the operator delay sensitivity approach. (EDF 2023a)

3.2.3 Extreme weather

EDF (2023a, p. 72) informs that design basis events corresponding to occurrence probabilities of 10^{-4} per year as required by WENRA (2014; 2021) could only be determined for few hazards (external flooding, icing, low water level and tornado). Design basis requirements for hazards for which only short historical records exist were derived by adding margins to the severity of events for which reasonably accurate recurrence times can be determined (e.g., a centennial return period). With respect to extreme weather, the following hazard types are considered in the PSR4:

- heat waves considering water and air temperature and climate monitoring. EDF considers temperatures corresponding to exceedance probabilities of 10^{-2} per year and 70% confidence;

[26] Seiche (SEI) - no site concerned

- extremely low temperature;
- phenomena endangering the availability of the ultimate hat sink: frazil ice, ice barriers, low water level, clogging of the water intake and pollution of cooling water by hydrocarbons;
- high wind including re-assessment of wind speeds to be taken into account;
- tornado accounting for dynamic wind pressure and pressure difference for a reference tornado of intensity 2 on the Enhanced Fujita scale with an occurrence probability $<10^{-4}$ per year;
- lightning and electromagnetic interference;
- snow.

Extreme winds are part of the hazards which were retained at the screening stage of relevant attacks for carrying out probabilistic analyzes in the PSR4 1300. The extreme winds PSA is developed for the first time on a PSR on the French fleet. A first extreme wind PSA was carried out on the Cattenom site and made it possible to verify the feasibility of such a study. It also made it possible to conclude that the design was highly robust with respect to the risk induced by wind on this site: The risk of core meltdown following an extreme wind event is very low. Most of the calculated risk (around 55%) is due to wind levels associated with return periods in excess of 1000 years, the characterization of which is highly uncertain. The study highlights the Cattenom facility's robustness with regard to extreme wind hazards and the associated residual risk.

An extension of this study was undertaken for the case of seaside sites associated with the most severe hazards and for which the extreme winds can cause clogging of the heat sink. For sites at the Atlantic coast (Flamanville, Paluel) the risk of core meltdown following an extreme wind event is considered low. In general, these calculated overall risk values should be used with caution, as most of this risk is connected to wind levels with a return period of over 200 years, for which the frequency of occurrence is characterized with considerable uncertainty. It was concluded that the risk induced by extreme wind on seaside sites is acceptable in the context of the PSR4. (EDF 2023a)

3.2.4 Man-made external hazards

Industrial risks are subject to a periodic review because they can change over time. The industrial risk analysis is based on the application of the fundamental safety rule RFS I-2.d. The potential sources of hazards considered are:

- external industrial installations such as storage and production units;
- external transport of dangerous goods by pipelines and by road, rail, river or sea;

The reassessment of industrial risks as part of the PSR4 1300 is carried out for each NPP, during the VD4 shutdown of the first unit of the site. These studies will be carried out as close as possible to the ten-yearly inspections of the first reactor of the NPP concerned.

During periodic reviews, **accidental aircraft crashes** are reassessed according to RSF I-2.a, which is based on a probabilistic approach in order to assess the risk of unacceptable release of radioactive substances at the site boundary. In order to verify compliance with the high-level safety objective which is to guarantee the prevention of fuel melting in the core and in the spent fuel pools and to limit radioactive releases, the probabilities are reassessed during the studies of PSR4 1300 with updated data concerning accidents and data specific to the environment of each site. Thus for each site, a probabilistic approach to the risks due to air traffic is established based on data specific to the site considered and the target surfaces. The following data were updated as part of the PSR4 1300.

- Accident parameter values.
- Data specific to the environment of each site: location of airports/airfields, air traffic data.
- Surface values (surfaces of structures exposed to risk of falling aircraft).

It was concluded that no active equipment and no operator action is necessary to guarantee control of air risk.

Studies demonstrate the very low contribution of helicopters to aerial risk and therefore during the probabilistic reassessment of the studies carried out under RFS I-2.a. EDF (2023a

According to EDF (2023a), for the Paluel and Cattenom sites, the risk linked to air traffic respects the probabilistic benchmark values defined in RFS I-2.a.

As already mentioned above the following external events or combinations of correlated external events are already the subject of probabilistic analyzes which are considered sufficient and will not be the subject of additional analyses:

- Airplane crash,
- Pressure wave,
- Airplane crash and pressure wave,
- Airplane crash, pressure wave and release of toxic, flammable, aspirating gases or liquids.

3.3 Conclusions and recommendations

The contents and procedures of PSRs are only loosely defined in the French legal framework leaving it to the nuclear regulator to specify conditions and contents of the review. The objectives of the PSR4 of the 1300 MWe fleet were consequently defined by ASN in a process that involved a proposal by EDF (2017), a review of the proposed objectives by STANDING GROUP OF EXPERTS (2019) and conclusive guidelines issued by ASN (2019a). With respect to external hazards

ASN stipulates that definitions of design basis events and design extension considerations must follow the requirements set by WENRA (2014; 2021; referred to as “WENRA T4” and “WENRA T6” in ASN and EDF documents). The main implication of the objective is that the deterministic approaches for hazard assessments, which are current French standards, are supplemented by probabilistic analyses. Specifications by ASN, however, do not make sufficiently clear if the probabilistic analyses shall lead to the definition of new design basis parameters and, subsequently, updated requirements for plant protection. With respect to design extension conditions ASN defines the objective for the PSR4 to “integrate all the provisions of the Hardened Safety Core which have been prescribed to [EDF] by the ASN”. (ASN 2019a) It is concluded that implementation of the HSC ("noyau dur") at the 1300 MWe sites has not been completed by now.

Earthquake. The Response to Objectives Note by EDF (2023a) informs that at least some probabilistic studies have already been completed, including the assessment of seismic hazards by PSHA for all 1300 MWe sites and a Level 1 PSHA for the Flamanville site. Concrete results are not reported. Based on the available documents, it cannot be estimated whether the PSR requirements have already been satisfied with these analyses or whether further assessments are planned in the second, specific, phase of the PSR. The specific phase should notably “integrate the particular characteristics of the installation and its environment, such as, for example, the level of natural hazards to be considered” (ASN 2019a).

External flooding. As part of the PSR4, EDF intends to check the robustness of the 1300 MWe plants against the external flooding hazards described in “ASN Guideline No. 13”. (ASN 2013g) It is noted that this review has already been carried out for the Cattenom and Paluel sites as part of the 3rd PSR 1300, and that studies will therefore not be carried out again. Overall, reference is essentially made to the studies already carried out in the aftermath of Fukushima and any protective measures installed. The Authors of this report regard this approach not sufficient to ensure a high degree of safety. The studies for all sites should be updated; this is particularly important as the ASN Guideline No. 13, which was used in past assessments, does not represent the current state of the art.

Extreme weather. Based on the information presented, it is not clear whether extreme weather events (meteorological hazards) with probabilities of occurrence of 10^{-4} per year have been determined with an acceptable degree of certainty or this is scheduled for the PSR4. For the PSR4, the selection of the design basis for extreme weather conditions must comply with WENRA (2014; 2021; 2020d) by (1) demonstrating that the selected event leads to a level of safety that meets the WENRA target (probability of occurrence of 10^{-4} per year or, where it is not possible to calculate these probabilities with an acceptable degree of certainty, an equivalent level of safety), (2) developing the design basis parameters on a conservative basis.

Human-made hazards. The reassessment of industrial risks as part of the PSR4 is carried out for each NPP, but it is explained that these studies will be carried out “as close as possible to the ten-yearly inspections” of the first reactor of the NPP site. During PSR4, hazards by accidental aircraft crashes will be reassessed. However, it is also mentioned that airplane crashes have been already the subject of PSAs which are considered sufficient and will not be the subject of additional analyses.

3.3.1 Recommendations

3.3.1.1 Hazard screening including hazard combinations

Relates to EDF NRO (2023a) chapter I.2.2.2.1 “Ensure the resilience of installations at all levels of internal and external event reassessed during the re-analysis under consideration of international recommendations (WENRA)”

Motivation/Observation:

Hazard types stated in the various documents defining the objectives for the PSR4 are limited to comparably low number of hazards. This particularly applies to meteorological hazards where only extreme temperature, high wind, tornado, snow, hail and lightning are mentioned. Reference to hazard combinations is only rarely made. This calls into question if all natural and human-made hazards and hazard combinations that might affect the 1300 MWe sites were comprehensively identified and a hazard screening as required by the WENRA Reference Levels TU2 and TU3 (WENRA 2021) has been performed.

Recommendation:

It is recommended to require for the PSR4 a demonstration that all hazards and combinations of hazard that apply to the individual 1300 MWe sites have been identified by comprehensive site-specific hazard screening. WENRA (2020a) provides a non-exhaustive, yet extensive, list of natural and human-made hazards to be used as a starting point for screening. DECKER & BRINKMAN (2017) provide detailed information on hazard combinations.

3.3.1.2 Definition of design basis events and protection against design basis events

Relates to EDF NRO (2023a) chapter I.2.2.2.1 “Ensure the resilience of installations at all levels of internal and external event reassessed during the re-analysis under consideration of international recommendations (WENRA)”

Motivation/Observation:

For design basis hazards EDF (2017) and ASN (2019a) formulated the following objective for the PSR4: “bring back and maintain the reactor in a safe state for hazard levels reassessed during the review” etc. This formulation does not seem equivalent to the WENRA (2014)[27] requirement that "protection shall be provided for design basis events" (Reference Level T5.1) and "protection … shall be of sufficient reliability that the fundamental safety functions are conservatively ensured for … effects of the design basis event." (Reference Level T5.2)

Recommendation:

It is recommended to require for the PSR4 (1) the definition of design basis events with occurrence probability of 10^{-4} per year in accordance with WENRA (2014; 2021) and (2) a demonstration that the fundamental safety functions of the reactors are conservatively ensured for the effects of these design basis event. The requirement should apply to all natural hazards for which the required probability can be calculated with sufficient accuracy, in particular to earthquake and external flooding.

3.3.1.3 Analysis and protection against external flooding

Relates to EDF NRO (2023a) chapter I.2.2.2.1.4 "External Flooding"

Motivation/Observation:

As part of the PSR4, EDF intends to review the robustness of the 1300 Mwe plants with respect to external flooding hazards as described in "ASN Guideline

No. 13" (ASN 2013g). It is noted that this review has already been carried out for the Cattenom and Paluel sites in the 3rd PSR 1300, and that studies will therefore not be carried out again. In general, reference is made to the post-Fukushima analyses already carried out and the subsequent protective measures taken with regard to the described scope of the analyses of the external flooding risk.

Recommendation

As part of the PSR4, studies to evaluate the hazard of external flooding should be updated for all sites. This is particularly important as the ASN Guideline No. 13 does not represent the state of the art.

Comprehensive inspection and maintenance of the Volumetric Protection (VP) should be carried out as part of the PSR4. Building's leak tightness should be inspected and maintained for walls, floors, joints, conduits, sumps and drainages related to potential flooding issues. Maintenance, with adequate frequency, planning, training and review, is important for flooding protection. At the very least, the monitoring and maintenance of the VP to ensure flood protection should be comprehensively regulated as part of the PSR4.

[27] WENRA (2021) stipulates the same requirements in Issue TU (TU5.1 and TU5.2).

3.3.1.4 Earthquake-induced flooding and seismic resistance of Volumetric Protection against external flooding

Relates to EDF NRO (2023a) chapter I.2.2.2.1.4 "External Flooding" and I.2.2.2.1.5 "Earthquakes"

Motivation/Observation:

For all sites with 1300 MWe reactors, the PSR4 is to check whether the water stops and barriers, which are a key element of the Volumetric Protection (VP), are not affected by earthquake, thus demonstrating that earthquake-induced flooding has no impact on safety. To this purpose, it is important that the ground shaking parameters of possible earthquakes and related earthquake induced effects such as damage to civil structures, dynamic compaction, ground settlement or liquefaction/lateral spreading have been determined with sufficient certainty. Sufficient leeway should be applied with regard to the assumed ground shaking parameters in order to take into account the existing deficits in the analysis of the earthquake studies.

Recommendation

Earthquake induced flooding scenarios, which have an impact on safety should be thoroughly studied and relevant protection measures should be implemented as part of the PSR4.

In addition, other elements of the VP should be comprehensively checked. Since protection against extreme external flooding is essentially based on VP and, on-the other hand, there have so far been considerable deficiencies in the implementation and analysis of the VP, extensive investigations and conformity tests should be required.

3.3.1.5 Protection against effects of extreme weather

Relates to EDF NRO (2023a) chapter I.2.2.2.1.8 "Heat Waves", I.2.2.2.1.9 "Extreme cold", I.2.2.2.1.11 "Storms and debris", I.2.2.2.1.12 "Tornado" and I.2.2.2.1.14 "Snowfall"

Motivation/Observation:

For many, if not most, of the meteorological hazards calculation of design basis events with occurrence probabilities of 10^{-4} per year cannot be achieved with an acceptable degree of certainty. This is due to short observation periods (reports typically covering much less than 100 years) and methodological limitations. For such hazards WENRA (2014; 2021) requires that "an event shall be chosen and justified to reach an equivalent level of safety" (SRL T4.2, TU4.2). WENRA further stipulates that "design basis events shall be compared to relevant historical data to verify that historical extreme events are enveloped with a sufficient margin" and "design basis parameter values shall be developed on a conservative basis"

(SRL T4.3, T4.4; TU4.3, TU4.4). It is not clear if the required justification and conservatism has been demonstrated.

Recommendation:

It is recommended to require for the PSR4 that the selection of design basis events for extreme weather conditions complies with WENRA (2014; 2021) by (1) demonstrating that the selected event leads to a level of safety equivalent to WENRA target (occurrence probability of 10^{-4} per year) and (2) the design basis parameters are developed on a conservative basis.

3.3.1.6 Scope and timetable for re-assessing-man-made hazards

Relates to EDF NRO (2023a) chapter I.2.2.2.2 “Learnings from PSAs”

Motivation/Observation:

The reassessment of industrial risks as part of the PSR4 is apparently only to be carried out after the VD4 inspections. A probabilistic safety analyses (PSA) in this regard is not to be carried out (again).

Recommendation:

The reassessment of man-made hazards as part of the PSR4 should be appropriate in scope and timeframe to the possible consequences. Inspections and resulting retrofits should be carried out during VD4. In addition, updated PSAs should also be carried out to determine the possible risks.

4 DESIGN BASIS, DESIGN EXTENSION CONDITIONS AND PROTECTION MEASURES OF THE 1300 MWE REACTORS

4.1 Earthquake

Desing basis: Design basis ground motion values for the 1300 MWe reactors were established by the deterministic approach. The fact that the deterministic approach was originally stipulated in RFS 1.2.C (1981)[28] suggests that design basis values were only established after the start of construction of most of the 1300 MWe units (Table 2; see ASN 2011a for more details).

At the background of the standardized reactor series operated in France, EDF introduced the notion to define the DBE as the envelope spectrum of the various SMS spectra associated with the different sites of the same plant series (ASN 2011a). This approach allowed pooling the design studies for the reactors on the respective nuclear islands. All plants of a specific series consequently share the same seismic design. Other structures, referred to as "site structures", were specifically designed for each site (Table 2).

Table 2: Design basis ground motions (peak ground acceleration) of the 1300 MWe reactors. Transition from RFS 1.2.c to RSF 2001-01 caused reduction of the DBE values for several plants (data ASN 2011a)

NPP	Start of construction	Start of operation	DBE (g) Nuclear island	DBE (g) Site structure
Belleville	1980	1988-1989	0,15/0,1	0,1
Cattenom	1979-1983	1986-1991	0,15	0,15
Flamanville	1979-1980	1985-1986	0,15	0,15
Flamanville (EPR)	2007		0,25	0,2
Golfech	1982-1984	1991-1994	0,15	0,15
Nogent-sur-Seine	1981-1982	1987-1988	0,15/0,1	0,15
Paluel	1978-1980	1984-1985	0,2/0,15	0,2/0,15
Penly	1982-1984	1990-1992	0,15	0,15
Saint-Alban	1979	1985-1986	0,15 (*1)	0,1/0,132

In 2001 the requirements stipulated in RFS 1.2.C (1981) were replaced by RFS 2001-01[29]. The replacement retained the general deterministic approach. The main changes concerned:

[28] Règle fondamentale de sûreté - RFS 1.2.c of 1st October 1981 concerning the determination of the seismic motion to be taken into account for the safety of the facilities.

[29] Règle fondamentale de sûreté - RFS 2001-01 of 31st May 2001 concerning the determination of the seismic risk for the safety of surface basic nuclear installation.

- New definitions of seismotectonic zones
- Intensity-magnitude correlations
- Replacement of a fixed response spectrum by a site spectrum set at 0,1g.
- Consideration of site effects
- Account for paleo-earthquakes in addition to historical/instrumental earthquakes of the SISFRANCE earthquake catalogue.

In addition, it was required that the DBE is higher than a minimum level that encompasses a M=4 earthquake at a distance of 10 km from the site, and a M=6.6 event at 40 km distance (ASN 2011a).

RFS 2001-01 formed the basis to verify the design of the plants during the PSR4s. For the majority of the plants the transition from RFS 1.2.C (1981) to RFS 2001-01 did not lead to design modifications (ASN 2011a; EDF 2023c). For Belleville EDF (2023c) notes that the new response spectrum exceeds the one of the 3rd PSR. EDF consequently initiated a "Seismic Reassessment Approach for Equipment" (EDF 2023c, p. 101). For Saint-Alban EDF (2023c) states that the updated ground motion values are covered based on a study performed in the 3rd PSR.

Defining the Design Basis Earthquake on deterministic methods is no longer state of the art and does not conform with the WENRA Reference Levels (WENRA 2014; 2021). In the Stress Tests ENSREG (2012b) therefore recommended introducing probabilistic methods (PSHA) to determine design basis earthquakes. The French National Action Plan (NAcP) consequently announced that probabilistic methods are to be used to determine the site-specific seismic hazard as part of the third PSR of the 1,300 MWe fleet ASN (2014). The aim was to apply the methods used in a pilot study for the Saint-Alban site to other sites as part of the PSR4. This pilot study, referred to as "experimental seismic probabilistic safety assessment (EPS)" for Saint Alban was already reported in the Stress Tests (ASN 2011a). According to information obtained during the Stress Tests review, the calculated ground motion for the occurrence probability of 10^{-4} per year (i.e., corresponding to the DBE requirement by WENRA 2014) was higher than the hazard level derived from deterministic approach.

DUROUCHOUX et al. (2014) describe the PSHA methodology applied to all French nuclear sites in more deal. The PSHA aims at return periods between 10,000 and 50,000 years[30]. By 2014, the approach was tested for three sites with different seismicity. The author's description identifies a standard PSHA procedure with a logic tree-approach based on historical earthquakes (SISFRANCE earthquake catalogue). Remarkable details are a relatively high minimum magnitude of M=5 and CAV (Cumulative Absolute Velocity) filtering. Both tendentially decrease the calculated hazard values. SCOTTI et al. (2014) particularly noted that calculated hazard values increase significantly by reducing the minimum magnitude from M=5 to M=4. The approach of CAV filtering was later rejected by ASN (2016). In 2013, the methodology was reviewed by meetings of an

[30] It should be noted that state-of-the-art PSA and Seismic PSA also considers earthquakes with occurrence probabilities down to 10^{-6} or 10^{-7} per year.

Advisory Committee, which concluded that work needed to be continued to achieve a method that was usable for the forthcoming PSRs. In the updated NAcP 2014, ASN adopted the following position on the procedure proposed by EDF for the probabilistic seismic safety studies (ASN 2014): *"The methodological developments must be continued so that such a study can be implemented in the framework of forthcoming periodic safety reviews."*

DEC and Hardened Safety Core: After the Fukushima accident ASN requested EDF to carry out safety assessments in order to study the safety of nuclear installations under so-called *"extreme natural hazards*" with hazard severities significantly exceeding the design of the plants (ASN 2011b). DEC conditions to be investigated match the topics of the European Stress Tests, i.e. earthquake, flooding, extreme winds, lightning, hail and tornado.

In 2012 ASN asked EDF to propose organizational and physical provisions to prevent accidents with core melt or mitigate their consequences, limit radioactive releases and enable the operator to manage severe accidents (ASN 2012a). The higher safety level for DEC conditions shall be ensured by a "Hardened Safety Core" (HSC; "*noyau dur*") that remains functional in DEC conditions including under situations of station blackout, loss of the heat sink, and in the status of the reactors after the occurrence an "extreme natural event".

With respect to earthquake, EDF (2023a) defined that the seismic hazard taken in account for the SSCs of the HSC ("*noyau dur*") shall be defined by a response spectrum that must:

- envelope the deterministically derived SMS spectra increased by 50%;
- envelope probabilistically defined site spectra with a return period of 20,000 years;
- take into account site effects.

The French approach consequently sets concrete ground motion values for the design of the HSC.

French regulations do not envisage technical specification concerning probabilistic seismic hazard studies. It was thus necessary to draw up "specifications" for probabilistic studies which were carried out to produce the probabilistic UHS spectra at 20,000 years return period. These specifications were written by EDF according to technical exchanges that took place in 2013 between the ASN, the IRSN (technical support of the safety authority) and EDF. The approach is said to be in line with IAEA guidance (IAEA SSG-9; DUROUCHOUX et al. 2014). To determine the SND earthquake, hazard analyses were carried out for all locations in 2013-2014 using PSHA methodology (DUROUCHOUX et al. 2014). The studies were based on existing data at the time; no new data was collected (DUROUCHOUX et al. 2014). However, the analyses are said to correspond to the guidelines of the IAEA (2010) (DUROUCHOUX et al. 2014).

The current ground motion values applicable to the HSC could not be researched with certainty. IRSN (2013) lists ground motion values for the 1300 MWe reactor sites shown (as of 2013) in Table 3.

Table 3: Design basis ground motions (peak ground acceleration) of the 1300 MWe reactors according to RSF 2001-01 and ground motion levels for the Hardened Safety Core (SND, Séisme Noyau Dur) (data from IRSN 2012; 2013)

NPP	DBE (g) SMS 2001-01	SND (g)
Belleville	0,14	0,2
Cattenom	0,12	0,2
Flamanville	0,16	0,25
Golfech	0,12	0,2
Nogent-sur-Seine	0,1	0,15
Paluel	0,15	0,25
Penly	0,13	0,2
Saint-Alban	0,15	0,3

The PGA values for HSC – termed SND (Séisme Noyau Dur) - shown Table 3. are calculated by increasing the deterministically derived design basis earthquake levels (SMS - Séismé Majoré de Sécurité) by a selected constant margin (mostly 50% as required by ASN). According to IRSN (2012), EDF did not associate a return period return to the SND levels of each site (ASN requires the HCS to withstand a 20,000-year earthquake). However, according to EDF, PSHA studies carried out on the St-Alban, Civaux and Flamanville sites show that the levels retained for the HSC are higher than those obtained at a return period of 10,000 years. The return periods estimated for the PGA of the SND for Saint-Alban, Flamanville and Civaux are 167,000, 39,000 and 65,000 years, respectively.

IRSN (2012, p. 163 - 175) regards the approach not state-of-the-art and questions the PSHA results because:

- It is not considering seismic scenarios such as site characteristics, nearby faults etc.).
- probabilistic studies for Civaux and St-Alban do not take into account magnitudes greater than those observed historically (no Mmax defined)
- the choice to apply a truncation to the predictions of seismic movement equal to two standard deviations can lead to underestimating the seismic hazard (by around 20% at 10,000 years)

IRSN (2012) additionally pointed out that the SND response spectrum retained for Saint-Alban has no significant margins above a spectrum established for a 10,000-year recurrence interval. Accelerations derived for 20,000 years and low frequencies of the spectrum are even below the acceleration derived for 10,000 years (i.e., the design basis value) when a higher level of confidence (85 percentile) of the hazard curve is considered.

ASN (2016) reviewed the seismic ground motion values obtained for HSC concluding that the deterministic component of the HSC spectra were acceptable. For the PSHA derived spectra ASN concluded that the approach chosen by EDF could lead to underestimated hazard values[31]. This essentially led ASN to reject the hazard results for Belleville and Saint-Alban. ASN further ordered that CAV

[31] The cited document does not provide numeric ground motion values for the 1300 MWe sites.

(Cumulative Absolute Velocity) filtering, which typically leads to lower hazard values, must be excluded for all sites because its "*relevance for the definition of a reference hazard has not been established*". As for the consideration of site effects, ASN noted that data existing by 2016 for Belleville and Golfech were inadequate for calculating spectra to be used for the HSC. Finally, for Saint-Alban, ASN noted severe discrepancies between the hazard opinions of IRSN and EDF concluding that it was necessary to continue investigations and work on databases.

Protection against earthquake

The original design of the 1300 MWe reactors showed a number of weaknesses with regard to protection against a design basis earthquake (DBE). In case of a DBE the following impact was to be expected:

- In the area of the intercooling circuit, there would have been a pipe failure with a loss of the pool cooling system and a loss of one line of the reactor cooling system.
- Due to a failure of the piping of the fire extinguishing system, a cross-redundancy flooding of rooms of the secondary cooling water system and thus a complete failure of the system function of residual heat removal from both the reactor and the storage pool was to be assumed.
- For parts of the hydrogen distribution piping system, a failure and resulting release of hydrogen was to be assumed. This can lead to corresponding hydrogen burns or even hydrogen explosions, which can impair safety-related equipment. (e.g. the single storage tank for coolant storage and the steam generator supply)

Even if these weak points should now be remedied by retrofitting, it should be noted that retrofits often do not achieve the same level of safety as a safety level already implemented by design. In addition, retrofits often result in the use of components that do not comply with specifications or failures of the installation occur. All in all, therefore, it cannot be assumed that the required protection against a DBE has been fully achieved.

In addition to the design weaknesses, several significant safety-related incidents regarding the seismic resistance have been occurred. The insufficient seismic resistance of an emergency diesel generator set auxiliary system (cooling system surge tank) was initially detected by EDF in March 2017 in the Golfech NPP and then on all the 1300 MWe reactors. On 20 June 2017, EDF informed ASN that both emergency diesel generator sets of twenty 1300 MWe reactors are concerned. Given the potential consequences for the safety of the NPPs in the event of an earthquake, this event is rated level 2 on the INES scale for the 1300 MWe reactors of Belleville, Cattenom, Flamanville, Golfech, Nogent, Paluel, Penly and Saint-Alban.

If off-site electrical power is lost as a result of an earthquake, the operation of the emergency diesel generator sets could no longer be guaranteed as a result of the failure of their auxiliary systems.32 The significant event concerns the lack of demonstration of the ability of the civil engineering anchors to withstand an earthquake. It covers both design problems, which are generic to all the 1300 MWe reactors, and local problems relating to the condition or assembly of the anchors. (ASN 2017c)

Further significant safety event concerning seismic resistance of the emergency diesel generator sets were identified during the inspections stipulated by ASN, as reaction to the defects of the anchors of the auxiliary systems. On 31 January 2020, EDF reported a significant safety event concerning seismic resistance defects of its 1300 MWe reactors. These defects, identified are of three types:

- incorrect installation of piping elastomer couplings,
- corrosion of certain parts of the pipes or their supports,
- connection faults in certain electrical cabinets.

Given the potential consequences of a malfunction of the two emergency diesel generator sets of a given reactor in the event of an earthquake, this event is rated level 2 on the INES scale for the following eight reactors: Flamanville unit 1 and 2, Paluel unit 1, 3 and 4, Belleville-sur-Loire unit 1, Nogent unit 1 and Penly unit 2. The event is rated level 1 on the INES scale for eight other reactors, where the scope of the flaws was lesser and would not have led to the loss of the two emergency diesel generator sets in the event of an earthquake.[33]For the reactors concerned, all of the defects detected were repaired or, with regard to the incorrect installation of certain elastomer couplings, were subject to reinforced monitoring until the next reactor outage, when they will be replaced. (ASN 2020a)

A significant safety-related event has occurred 2017 due to the lack of appropriate maintenance: a risk of heat sink loss for ten 1300 MWe reactors. The insufficient earthquake resistance of a pipe was initially detected by EDF in the Belleville NPP. Additional investigations in early June 2017 revealed that several sections of these pipes were degraded, with thicknesses less than the minimum thickness required for earthquake resistance. This degradation is the result of corrosion which may have developed because of a lack of appropriate preventive maintenance.[34] In total 29 of the 900 MWe and 1300 MWe reactors are concerned by this event. After thickness measurements on piping sections and the earthquake resistance analysis of the piping concerned, EDF declared on 10th October 2017 that 20 reactors were concerned by a risk of total loss of heat

[32] Each 1300 MWe reactor has two emergency diesel generator sets, which should provide redundant electrical power supply to certain safety systems in the event of the failure of off-site electrical power supplies, more particularly in the wake of an earthquake.

[33] Paluel unit 2, Saint-Alban unit 2, Belleville-sur-Loire unit 2, Cattenom unit 1 und 3 and Penly unit 1

[34] The heat sink could be lost owing to the unavailability of the pumps of the essential service water system (SEC) as a result of internal flooding following an earthquake-induced rupture of the piping supplying water to the fire protection network and the raw water filtration network.

sink. This event is therefore rated level 2 on the INES scale.35 The following ten 1300 MWe Reactors subject to the INES 2 rating: Belleville-sur-Loire unit 1 and 2; Cattenom unit 1-4; Golfech unit 1 and 2; Nogent-sur-Seine NPP unit 1 and 2. ASN required that the repairs to ensure total availability of the SEC system in the event of an earthquake must be initiated as early as possible. (ASN 2017b)

This considerable damage was noticed and repaired during targeted investigations. They had been present in the plant since the start of construction and became more serious as a result of ageing and maintenance deficiencies. In order to prevent similar faults from occurring in the plant, a comprehensive inspection of the entire plant would have to be carried out and these faults rectified.

Again recently, on the May 13, 2024, EDF notified the ASN of a safety incident relating to deficiencies in the structural anchoring of certain safety-critical equipment. These deficiencies also affect Belleville 1 and 2. As part of the monitoring of the condition of its installations, EDF checks the conformity of the anchorages with the structural conditions of the safety-critical installations (e.g. piping, electrical equipment, motors, pumps). During these inspections, discrepancies were found in certain anchors, particularly with regard to the number, diameter and position of the anchors. These discrepancies are due to the construction of the reactors and could jeopardize the performance of the supported installations in the event of an earthquake. The discrepancies identified have been corrected. EDF continues to carry out inspections on its other reactors. (ASN 2024b)

Protection of the HSC

In the opinion of IRSN, the seismic behavior of existing SSC belonging to the HSC is not justified yet: The assessment of the IRSN with regard to the LTE for the 900 MWe reactors is presented below. It must be assumed that the same deficits are also valid for the 1300 MWe reactors. IRSN (2020a) explained that for some parts of the civil engineering structures and equipment of the hard core compliance with design criteria will have been demonstrated in the hard core earthquake, while for the other parts, robustness in the hard core earthquake will have been assessed using non-conventional methods. The level of confidence that the expected functions will be ensured in the event of a SND will be lower for structures and equipment in the second group. IRSN considers that EDF's priority should be to reinforce existing equipment and structures associated with the hard core, in order to demonstrate their resistance to the hard core earthquake using standard design methods. (IRSN2020a)

For civil engineering structures, EDF aims to deviate from current safety review practices by assuming "admissible" damage greater than that assumed in the design basis, an increase in structural damping and the introduction of ductility coefficients for reinforced concrete and steel structures. IRSN considers that the

[35] Nine other 1300 MW reactors are for their part concerned by a risk of partial loss of heat sink, which is a situation rated level 0 on the INES scale: Paluel unit 3 and 4, Saint Alban unit 1 and 2.

use of complementary or alternative non-linear analyses should not be considered to reassess the seismic behavior of civil engineering structures. According to IRSN, the method planned by EDF is acceptable only in certain cases, and subject to the prior completion of studies using standard methods and the provision of substantiated justifications, particularly with regard to the data and criteria used. (IRSN2020a)

EDF has drawn up methodological guides for justifying the extreme seismic resistance of existing components of the HSC. IRSN considers that EDF should amend several points in its methodological guide relating to the SND resistance of existing anchors. Furthermore, EDF should give priority to the use of dimensioning criteria that guarantee the elastic behavior of rotating machine structures, with a requirement for tightness or functional capacity. In the case of piping lines, IRSN considers that EDF should retain the criteria used for the initial design. (IRSN 2020a)

4.2 External Flooding

Design basis: ASN (2013g) explained that Guide no. 13 have been developed from the point of view of the design of a new installation. For an existing installation whose design does not take these recommendations into account, it is necessary to check whether it is possible to achieve an adequate level of protection for the interests referred to in Article L.593-1 of the Environmental Code. A robust protective measure to be preferred is to set the installation platform at a level above the maximum water level taking into account all relevant RFS.

Platform: Not all sites have the platform at a level above the maximum water level determined for the area covered by the installation, taking into account all relevant RFS.

The following table presents the Design Basis Flood (DBF) level valid in 2011 with regard to the altimetry of the nuclear island platform. (ASN 2011a) The elevation of the platform of two sites (Belleville and Saint Alban are lower as the DBF.

Table 4: DBF level with regard to the altimetry of the nuclear island platform (ASN 2011a)

NPP site	Design DBF level	Elevation of the nuclear island platform	Elevation of lowest access threshold for buildings classified important for safety	Existing protection
Belleville	**142.06 (+0.47)[36]**	141.55	141.73	Peripheral embankments
Cattenom	155.61	171.00	170.90	Platform elevation
Golfech	61.38	62.22	62.17	Platform elevation
Nogent	66.07	68.15	68.05	Platform elevation
Saint Alban	**147.46**	147.00	147.05	North and East wall

Protected volume approach: Following the flooding of the Blayais site in 1999, EDF set up volumetric protection (VP) on all sites to prevent water from entering an area that includes the buildings housing the components required for reactor safety.[37] The VP essentially consists of walls, floors and ceilings. These walls may have openings that could affect the functioning of the VP if they are not watertight (doors, openings, hatches); appropriate measures are therefore taken to ensure their watertightness. (ASN 2011a)

Conformity of the plants with the current safety requirements: Following the accident in Fukushima, the ASN carried out a series of targeted inspections to check the conformity of this VP. During the inspections conducted in June and October 2011, ASN observed numerous anomalies regarding the monitoring, maintenance and perimeter of the VP.38 (ASN 2011a) For example:

- the conformity work decided on subsequent to the Blayais experience feedback, which was to have been completed in 2007, was not finished on all the sites;
- some sites notified discrepancies observed between the VP perimeter identified in the EDF report and the actual situation on the site[39];

[36] The Belleville DBF considered by EDF does not cover the significant influence of the Strickler coefficient. If the calculation does take account of this influence, then it leads to a higher water level, estimated at 47 cm. ASN asked EDF to update the Belleville DBF value to take account of the uncertainty surrounding the Strickler coefficient.

[37] The ENSREG Peer Review also recommended the use of a volumetric protection concept for flood protection for certain rooms or areas. (ENSREG 2012b)

[38] Given that VP plays a key role in protecting the plants against the off-site flooding risk, ASN required that EDF implement rapid conformity remediation work.

[39] In particular, ASN noted the vulnerability of the diesel buildings to flooding at certain locations. For example, EDF claims that in some locations there are curbs about ten centimetres high in front of the entrances to the diesel buildings. However, ASN has established on site that these curbs are not always present.

- some sites notified the fact that it was impossible to test the "waterstop"[40] seals, which are a key part of the VP;[41] (ASN considers that EDF did not take account of seal ageing in its approach)
- the identification of equipment and structures at the VP limits is absent on some sites;
- the day-to-day management and monitoring of the VP are not always carried out correctly, sometimes even not at all.

Following the stress tests, ASN had set the prescriptions ECS–4 (Completion of work in connection with the Blayais experience report)[42] and ECS–5 (Conformity of the scope of protection). The work to restore the conformity of the VP was completed on 30.06.2012. (ASN 2020f)

Probabilistic Analyses

The probabilistic analyses related to the external flooding are applied in the PSR4 1300 according to the defined work program by integrating the phenomena from ASN Guide No. 13, but also some of their combinations. However, instead of a comprehensive analysis, only five scenarios are calculated for specific installations. The PSA are developed for the following phenomena (EDF 2023a).

<u>River flooding for the Belleville and Golfech sites:</u> A probabilistic river flood analysis was carried out for the Belleville site. The risk of a core melt, apart from hypothetical situations associated with a higher flood level than that used for the hard core design (CM3 level), is sufficiently low and is considered acceptable. The scenario with a flood level higher than that used for the HSC design shows a low level of knowledge in assessing the frequency of such an external flood trigger. Therefore, the numerical assessment performed for this scenario is not considered relevant. The integration of post-Fukushima provisions (DUS, refill of the ASG by the SEG system, provisions to protect the hard core from flooding (solution currently being defined) significantly reduces the risk of core melt. The probabilistic analysis for the Golfech site has to be evaluated.

<u>River flooding combined with waves for the Belleville, Golfech and Saint-Alban sites:</u> For Belleville site, the characterization of the hazard showed that the first water spills on the site platform occur for hazards with a frequency of around a few 10^{-8} per year. The associated risk of core melt is therefore seen as negligible. The results of the probabilistic analyzes for the Golfech and Saint-Alban sites are not completed yet.

<u>Seaside crossing for the Flamanville site (see chapter 5):</u>

<u>Damage or malfunction of structures, circuits or equipment (DDOCE), for the Flamanville, Paluel, Penly and Saint-Alban sites:</u> Due to the detection systems in

[40] Tightness of the expansion joints in the concrete walls (water stop strip)

[41] For example, the Cattenom site declared a significant safety-related event (ESS) regarding flooding of the fuel oil tank room, partly owing to a loss of tightness of the "waterstop" seals.

[42] The work was completed at the Penly site by 31/12/2014. Note: *Not less than 15 years after the event at the Blayais NPP*.

place and the time available to stop the pumps, the risk of water entering the protected buildings from the machine room is very low for the Flamanville and Penly sites, and considered negligible for the Paluel site. It should be noted that no ingress of water is possible when the PRB is in place. At the Saint-Alban site, given the limited time available to stop the pumps before water overflows onto the platform, it was decided to implement an automatic shutdown of the pumps in the event of a leak being detected in the machine room.

Protection against external flooding higher than DBF

The stress tests showed that the consequences of the analyzed beyond design scenarios for the flood levels are very different. At some locations, the platforms of the nuclear islands would remain above the water level. (ASN 2011a) At others, flooding could reach up to two meters on the platforms. (IRSN 2012)

The analysis carried out by IRSN as part of the stress test revealed cliff-edge effects in the close to of the flood levels. ASN considers that the approach initially presented by EDF does not provide a satisfactory response to the requirements and that the prevention of cliff edge effects needs to be reinforced. Thus, ASN believes that a sufficient increase in VP would be able to prevent cliff edge effects in most cases. ASN requires to reinforce the protection of the facilities against the risk of flooding beyond the baseline requirement in effect on 1 January 2012, for example by raising the protection volume…., for the beyond design-basis scenarios, such as maximum rainfall and flooding resulting from failure of on-site equipment under the effects of an earthquake (ECS-6). (ASN 2012a)

Following the post-Fukushima studies, some of the protection measures have already been put in place before the PSR4 at all 1300 MWe sites. The remaining provisions will be deployed as part of the external flooding hard core.

For the determination of HSC two external flooding phenomena are considered by EDF (2023a):

- external flooding associated with the rise in the level of the water source,
- flooding by direct discharge onto the platform linked to Heavy Intensity Rainfall (PFI) or following the failure of water structures on the platform (as a result of the effects induced by an earthquake).

For external flooding associated with the rise in the level of the water source (river or sea), the following situations are taken into account for the sizing of the HSC SSC protections:

- River flood whose flow rate would be 30% higher than that of the Greater Millenial Flood (CMM) defined as part of the "REX Blayais" approach.
- For seaside sites, sea level resulting from a fixed increase in the reference level determined in application of ASN guide no. 13, taking into account the effects of a 100-year swell propagated on the static level thus obtained.
- Multiple failures of dams upstream of the site under the effect of an earthquake.

For flooding by direct spillage on the platform, the following situations are taken into account for the sizing of the HSC SSC protections:

- High Intensity Rainfall (PFI) whose intensity is doubled (2x PFI) compared to the centennial PFIs considered in the "REX Blayais" reference system,
- Heavy rains associated with the total obstruction of the drains of the rain-water evacuation network (PFI + clogged SEO),
- Flooding Induced by an SND leading to the damage of water structures located on the platform.

IRSN criticized the methodology for the calculation of the increased sea-side flooding: IRSN (2012) point out that extreme surges call into question the accuracy of estimates of extreme surges by current statistical analyses and that a better consideration of exceptional surges is necessary to estimate millennial surges. Initial results using new approaches tend to show that current millennial surges may be underestimated by up to 1 metre on the Atlantic coast. Thus, IRSN considers that the increased sea level used by EDF to protect the hard core (CMS+1m) is below the sea level scenario defined by the flooding guide. In order to provide a margin, IRSN considers it necessary to retain, for the protection of the hard core, a sea level significantly higher than that retained by EDF. IRSN recommends that EDF reassess the sea level used for the hard core so that it is significantly higher than the level corresponding to "CMS + 1 m", and take this reassessed level into account to take account of the effects of waves.

IRSN criticized the methodology for the calculation of the increased river flooding: IRSN (2012) considers that EDF must justify that the selected fixed levels, cover an increase in flood levels calculated for a penalizing value of the influential parameter (defined by the flood guide) in the scenario corresponding to 1.3 times the increased millennial flood (i.e. "CMM+30%"). IRSN considers that the appraisal approach adopted is pragmatic and acceptable for defining the levels retained for hard core protection provisions. However, the information provided does not enable IRSN to take a position on the conclusions presented by EDF on the basis of its "expert judgments". In particular, IRSN cannot assess whether the checks carried out by the operator to identify the need to update the models are sufficient, or whether the assumptions concerning the behavior of singularities and hydraulic structures affecting the modeling results (dikes, reservoirs located upstream of the sites) are acceptable. (IRSN 2012)

After the Fukushima accident, one focus of the German Reactor Safety Commission[43] 's review in May 2011 with regard to the robustness of nuclear power plants was to recognize an abrupt deterioration in the course of events (cliff edges) and, if necessary, to derive measures to avoid it. If a water level at which there is a risk to vital safety functions cannot be ruled out due to the site-specific conditions, the criteria from the safety review for at least Level 1 must be

[43] The German Reactor Safety Commission consult the Federal Ministry for the Environment and Nuclear Safety concerning the safety of nuclear facilities.

applied.[44] Level 1 is defined as follows: Design reserves are shown in relation to the design flood defined in the base level[45] in such a way that, in the event of a discharge that **is 1.5 times higher than the design flood** and in the event of assumed failure of barrages, insofar as their failure is due to a common cause dikes, etc. and the resulting water level, the preservation of vital safety functions is ensured in order to meet the protection objectives. Effective emergency measures can also be taken into account.[46](RSK 2011, 2012)

Even if it is not possible within the scope of this statement to compare the assessment scale and method, the criticism of the IRSN that a 1.3-fold increase does not indicate sufficient robustness (safety margin) against extreme flooding events must be supported.

IRSN criticized the methodology for the calculation of the increased local rainfall: IRSN (2012) had indicated that the two scenarios[47] evaluated by EDF did indeed go significantly beyond the REX Blayais methodology. However, IRSN pointed out that the PFI duration adopted in the PFI x 2 scenario was not a priori the most penalizing. Indeed, given the saturation of rainwater networks, it is highly likely that rainfall durations longer than the network's concentration times (of the order of ten minutes) will lead to higher water levels. IRSN's analysis of the scenario of heavy rainfall ("PFI x2") identify several unsatisfactory choices by EDF. IRSN considers that the elements presented for the "2 x PFI" scenario are not sufficient to define the levels to be retained for the dimensioning of HSC protection provisions on the nuclear island platform.

However, it has to considered that for every 1°C of warming, experts say the atmosphere is able to hold 7 percent more water vapor. This increases the chance of heavy rainfall.[48] Several climate model projections showed that these extreme weather events could become more frequent and intense in the future,

[44] Alternatively, it can be demonstrated on a site-specific basis that a postulated discharge volume determined by extrapolating existing probabilistic curves to a frequency of occurrence of 10^{-5}/a does not lead to the loss of vital safety functions.

[45] The safety of the system has been verified for the design flood to be considered for the site according to the state of the art in science and technology.

[46] There are two further levels defined: Level 2: design reserves are shown in relation to the design flood defined in the base level in such a way that, if the discharge is 2 times higher than the design flood and the resulting level, the maintenance of vital safety functions is ensured in order to meet the protection objectives. Level 3: Due to the topography or the system design, the possibility of flooding resulting in the failure of vital safety functions is practically ruled out. Temporary measures are not taken into account.

[47] EDF evaluated two scenarios:

- high intensity rainfall (PFI) plus: this scenario involves doubling the intensity of the PFI rainfall used for design purposes, over a period corresponding to the saturation time of the rainwater systems,
- 60-minute PFI combined with clogging of the stormwater network's downspouts: this scenario consists of considering a high-intensity rainfall of 60 minutes duration, combined with complete clogging of the site's stormwater network's downspout

[48] https://www.euronews.com/green/2024/01/05/why-are-france-germany-and-england-flooded-and-is-climate-change-to-blame

because of climate change linked to greenhouse gas (GHG) emissions in the atmosphere.[49]

IRSN notes that the runoff coefficient chosen for the upstream catchment areas (a coefficient of 0.30), which has a very strong influence on runoff flow and flood levels, does not appear to take account of soil behavior during extreme rainfall events, as recommended by the flooding guide. IRSN considers that a higher runoff assumption would be more plausible in the extreme scenarios studied. Induced flood levels could be significantly higher than those calculated.

Protection of the HSC

Buildings containing Hard Core SSCs are protected according EDF (2023a):

- from flooding due to direct spillage onto the platform by means of "low-lying close protection" (PRB),
- from flooding due to rising water source: either by the "high close protection" (PRH) which protects the buildings or by peripheral protection (e.g. dykes) to protect sites.

The PRB involves protecting the openings of the nuclear island and pumping stations located between the 0.00m platform level and the water levels assessed for each site. Their scope is adapted to the specific features of each site and to the provisions set out in ASN Guide 13. In response to requirement ECS-6, these protections were deployed in advance, as part of the "permanent means" phase of the "Post Fukushima" project.

PRH relies on Volumetric Protection (VP) outside pumping stations and diesel buildings. It consists in sealing the periphery of the nuclear island:

- by justifying or treating the resistance of existing joint sealing systems and penetrations of the VP to the water column of the PRH.
- by sealing the new infrastructure interfaces, which were part of the VP.
- by waterproofing the means of access (0.00m platform) (by installing cofferdams, watertight partitions, etc.).
- if necessary, adding isolating devices to eliminate the risk of bypassing the PRH.

Phenomena leading to a rise in the level of the water source can be predicted with a 72-hour forecasting capability, and the flooding generated by the overflow of the cold spring at "Noyau Dur CM3" level can last several days. Removable protections designed to prevent massive water ingress into the PRH perimeter of the nuclear island will be installed before water reaches the platform.

The Cattenom, Nogent, Saint-Alban, Penly, Flamanville and Paluel sites cannot be flooded by rising the water source. There are no related crossings for the Hard Core facilities. For the Belleville site, the implementation of protections for

[49] https://lemag.ird.fr/en/news/towards-intensification-extreme-rainfall-events-southern-europe

ND facilities against the risk of external flooding level CM3 (PRH-type solution or peripheral protection currently being defined). Studies are underway for the Golfech site.

4.3 Extreme weather events

The original **design** of the 1300 MWe reactors against extreme weather conditions was based on the requirements of conventional regulations in various areas. As the conventional regulations require a significantly lower level of safety than is required for nuclear plants, the design did not achieve the level of safety required internationally today at the level of an exceedance probability of 10^{-4} per year, taking appropriate account of the uncertainties.

In 2012, the ENSREG peer review confirmed the ASN's conclusion that further studies need to be carried out in order to obtain a complete and systematic design basis and assessment of the safety margin with regard to extreme weather conditions. As part of the stress tests, EDF examined the margins in the event of extreme meteorological conditions such as wind, lightning, hail and their combination, in the event of a loss of the heat sink and the electrical power supply. The analysis of the additional studies has led ASN to define requirements. ASN letter to EDF (ASN CODEP-DCN-2011-00677 of May 3) defining the guidelines for the 3rd of the 1300 MWe reactors: Prevention of the effects of climatic hazards: (heat waves, lowest safe water level, broken ice, extreme winds, extreme flooding, tornadoes etc.). (ASN 2012a)

DEC and Hardened Safety Core: Available documents do not provide sufficient information on the French DEC approach with respect to meteorological hazards. ASN (2016) requires to consider the following hazards in the design of the HSC: flooding by heavy rain, tornado, extreme winds, hail, snow, extreme temperatures and lightning.

According to (ASN 2014), the hazard assumptions underlying the other external impacts vary in terms of their frequency. ASN has therefore asked EDF to carry out further studies with regard to snow loads, wind, hail and lightning. Notably, the levels of meteorological hazards should be updated in the frame of the PSR4 (ASN 2019a).

Existing operational experience in Europe shows that extreme weather events were mostly related to very low ambient temperatures or were caused by strong winds or precipitation. (JCR 2013)

Extreme weather events are to be analysed during the PSR4. Hazards to be studied include high wind, extreme temperature (high/low), and hazards threatening the availability of cooling water (frazil, freezing, low water level, hydrocarbon pollution, sanding, flotsam; EDF 2023c).

Protection against extreme weather

Topics under scrutiny in the generic phase of the 3rd PSR of 1300 MWe reactors have been among others external hazards. (FERON 2015) According to the ASN (2022a), until 2025, the 20 reactors of the 1300 MWe series will have undergone their third ten-yearly outage and will have integrated the modifications decided during the 3rd PSR. The studies carried out in this context lead to modifications, with regard to the objectives of better take into account certain external hazards, especially:

- protection of equipment important to safety from projectiles generated by high winds[50];
- increasing the capacity of air-conditioning systems in order to maintain, in a heat wave, a temperature in the premises compatible with the operation of equipment important to safety;
- prevention of the risks of explosion induced in the event of an earthquake by reinforcing the resistance of the hydrogen circuits in the nuclear island.

Furthermore, EDF has taken operational measures to protect the sites from extreme meteorological conditions (flooding, extreme heat, extreme cold, low water, etc.) more specifically including alert systems in the event of a foreseeable hazard[51] and agreements with outside organizations such as Météo France and the Prefecture. (ASN 2012a)

Protection of the HSC against extreme weather events

The Hardened Safety Core is designed to withstand "ND" tornado levels, well above the levels required for plant design. The associated provisions are specific to each piece of equipment to be protected or structure to be reinforced. New outdoor SSC Noyau Dur are designed to withstand the effects of an ND tornado. (EDF 2023a)

<u>Winds associated with ND external flooding:</u> Winds corresponding to situations of external flooding of ND are regional in nature, lasting a few hours, with speeds of up to 200 km/h at their peak. In practice, the verification of the SSCs of the Hard Core with regard to winds associated with external flooding ND can be based on the verification carried out for the tornado risk.

<u>Lightning:</u> For all sites, the functions of the Hard Core are verified by considering a lightning risk with the following characteristics: (Maximum current: 300 kA; Specific energy: 45 MJ/Ω; charge quantity: 700 C, time derivative: 200 kA/µs). The chosen maximum current of 300 kA includes a significant margin of 50% compared with the highest level for standards design protection. These verifications

[50] With regard to extreme winds, it was determined that the intake pipes of the emergency feed pump outside buildings, the air cooling of the emergency diesel generators, other pipes of the emergency diesel generators, the connecting pipes and fittings and other safety-relevant equipment could be affected by projectiles.

[51] high temperatures, riverside or coastal flooding, possibly combined with extremely high winds, rainfall.

led to the identification of the need to implement lightning risk prevention measures.

Hail: For all sites, the functions of the Hard Core are verified by considering a risk of hail of the following characteristics and provisions are implemented if necessary: Diameter: 50 mm, Speed: 32 m/s, Density: around 0.9 g/cm³. The "hail projectiles" risk analysis can be covered by the "tornado projectiles" risk analysis, as the protection installed on a case-by-case basis to protect against projectiles also provides sufficient protection against hailstones. In addition to the direct effects of projectiles, hail is also taken into account indirectly in the analysis of the risk of pluvial flooding (taking into account blocking the drainage networks).

Clogging of the UHS

None of the French reactors is equipped with an alternative ultimate heat sink (UHS). But the vulnerability of the UHS was highlighted by the events of clogging and (partial) loss of the heat sink (see Task 2). A situation with threaten the function of UHS will affect all units at a site. In those cases, the core could become uncovered in just a few hours. ASN requires the heat sink design review (ECS–15). EDF submitted ASN an overall review of the design of the UHS and proposed several changes. However, the ASN considers that further improvements are needed, in particular in the identification of hazards and their combinations. EDF has carried out studies and has proposed several changes. According to ASN (2020f), this measure is closed, but it is not mentioned when these necessary improvements will be implemented.

Emergency cooling functions can be compromised if abnormal conditions exist in the ultimate heat sink. These abnormal conditions may be caused by high or low temperature or by high or low water level. However, the review of the operational experience has shown that most safety significant events were related to low temperatures of the heat sink with ice buildup and eventually water intake clogging or malfunctioning. In France, the fouling events were the most frequent (36%), followed by extreme heat sink conditions (17%). The combination of those two types of events clearly emphasizes the high exposure of the heat sink to external factors, and the need to ensure its protection in order to avoid common cause failures with potential very significant consequences. (JCR 2013)

Biological impacts on the cooling water supply must also be taken into account as natural external influences. So-called invasive species, their immigration routes and their influence on natural ecosystems are increasingly the subject of research. Freshwater systems are considered to be particularly vulnerable to invasion by neobiota. The immigrating species are apparently more resistant to salinity, temperature, organic pollution and flow conditions than native species, which is why they sometimes reproduce explosively. With regard to potential impacts on NPPs, the effects of impurity entering the cooling water intake of nuclear power plants, such as agitated leaves etc., have been considered to date. In the case of biological impacts, the input may be more difficult to remove from the cooling water areas, as adhesions and biological films can develop.

The entry is also more complex, as the neobiota can reach the cooling water inlets protected by screens in the comparatively small larval stage and can clog heat exchangers or fittings as they grow. The Moselle and especially the cooling water inlets at Cattenom NPP, for example, have already been colonized by neobiota. (PISTNER et al. 2018)

ASN requested EDF to present modifications for installing technical backup devices for long-term heat removal from the reactor and the spent fuel pool in the event of loss of UHS. These devices must meet the requirements for the hardened safety core. (ECS–16) According to the 2020 NAcP, EDF presented the modifications (new shafts, basins or tanks depending on the site), as well as their requirements. As part of the implementation of a hardened safety core, EDF will build an alternate heat sink, based on either artesian wells or existing tanks, whose seismic behaviour will be verified for earthquakes beyond the initial design-basis of the facilities. The new emergency water supplies (alternate heat sink) have the potential to reduce the risk of a core melt accident. (ASN 2020f)

4.4 Hardened Safety Core

As one of the most important requirements after the stress tests, ASN requires to define of the structures and components of the "hardened safety core", including the premises for emergency management (ECS – 1). To define these requirements, EDF is adopting margins compared to the requirements in force on January 1, 2012. ASN issued Decisions no. 2012-DC-0274 to 2012-DC-0292, dated June 26, 2012, requiring EDF to put in place "robust material and organizational provisions ("hard core", noted ND)" aimed at managing an accident situation involving the total loss of power supplies and the heat sink affecting all the reactors on a site following an extreme event (known as an ND event) of the type of earthquake, flood, extreme wind, lightning, hail or tornado. (ASN 2020f)

In a "ND situation", the hard core is set up to prevent fuel meltdown or limit its progress, to limit radioactive releases that could nevertheless result from fuel meltdown, and to enable the operator to carry out his crisis management duties. The hard core is made up of a set of resources robust to ND situations, which can be supplemented by mobile resources brought in by the nuclear rapid action force (FARN). (ASN 2020f)

In connection with the existing design deficits against external hazards, it is referred to the planned backfitting of the Hardened Safety Core (HSC). However, the HSC is classified as a 4th safety level system. The 4th safety level is required as an additional and independent level compared to the 3rd safety level. HSC can therefore not be used to compensate for existing deficits in terms of diversity, redundancy, independence and decoupling of the safety systems of the 3rd safety level. In addition, these components are not yet available. (PISTNER et al. 2018)

Interface with existing system: As far as is known, it is not ensured that the HSC meets the requirements for resistance to extreme hazards and their induced effects after implementation at the interface with the existing structures, systems and components (SSC).

Mechanical design requirements for new SSC-NDs: The IRSN (2023c) point out that the hard core must be designed in such a way as to provide a high level of confidence in its ability to perform its functions for the full duration of the hazard. This means that the SSCs making up the hard core must have requirements for their design, manufacture and operational monitoring. IRSN considers that welds are a sensitive point in the manufacture of equipment and its assembly on site, which could call into question the functionality of equipment after an ND earthquake. IRSN recommends that, for all new core equipment, EDF carry out checks on 100% of welds, ….., in order to ensure that this equipment is highly robust to hazards.

Time schedule for the implementation: A known deficit is the considerable time delay in implementing the "hardened core" concept (HSC) to control external hazards that exceed the design limits. The original plan was to be carried out by EDF in accordance with the National Action Plan by 2018. However, the implementation was postponed. The measures were scheduled for three phases: Phase 1 was to be carried out from 2012 to 2015, Phase 2 from 2015 to 2020 and Phase 3 from 2019 in connection with the next PSR of the specific plants. The measures based on temporary or mobile means or related to the rapid reaction force (FARN) were completed according to the original schedule. According to ENSREG is the implementation of the concept of the hardened safety core a challenge. (ENSREG 2015)

4.5 Protection against man-made hazards

With regard to the industrial risk analysis within the framework of the LTE for the 900 MWe reactors, IRSN pointed out that EDF should take into account a 10 km radius for the area around each nuclear power plant, to identify potential hazards. (IRSN 2020a)

Crash of an airplane

The reactor buildings of the 1300 MWe reactors are enclosed by a double-walled containment, but these walls are not very thick (about 90 cm). For theses NPPs, assumptions regarding accidental aircraft crashes were defined on a site-specific basis. In this respect, basic protection results only from the design against an accidental aircraft crash at the level of a small business aircraft. A targeted aircraft crash was not assumed for the design.

The impacts specified in the original design with a view to an accidental airplane crash do not meet the deterministic requirements specified for new plants in

France. According to ASN (2000), the accidental aircraft crash was determined deterministically for the EPR. The load-time diagrams correspond to the crash of a military aircraft (phantom, tornado). The containment of the EPR can also withstand the crash of a large airliner.

The risk of a targeted (terrorist) plane crash became apparent after the September 2001 attacks in New York. The scenario of a targeted plane crash was included in the security concept. For new NPPs in Europe, WENRA expects that a deliberate crash of an airliner will not lead to a core meltdown accident and therefore, according to the WENRA safety objective (O2), may only have minor radiological consequences. In order to demonstrate this, effects from direct and secondary impacts of the aircraft accident must be considered (vibrations/shocks, combustion and/or explosion of the aircraft fuel). In addition, buildings or parts of buildings containing nuclear fuel and safety-relevant safety equipment should be designed in such a way that no kerosene can penetrate. (WENRA 2013) The WENRA safety objectives should be applied for the PSR4 of the 1300 MWe reactors.

According to Pistner et al. (2018), the 1300 MWe reactors have relatively weak and less robust protection against mechanical impacts in the event of an airplane crash for safety-relevant building such, in particular, fuel pools. This applies also in particular to the single storage tanks for the coolant water and the steam generator feed. Like other safety-relevant equipment, these are located outside the reactor building and are therefore not particularly protected against mechanical or thermal impacts from an aircraft crash. In addition to the changed load assumptions, further conceptual developments can also be seen in the comparison of the plant areas protected against aircraft crashes. In contrast to the 1300 MWe reactors, the primary coolant supplies in the EPR are located inside the containment. In addition to the reactor building, the protected areas also include the storage pool building and buildings with safety-related equipment.

Protection of the spent fuel pools

The **spent fuel pools** are in a separate building that is not adequately protected against external hazards. These buildings at all sites have a thin metal roof and their concrete walls are not thick (30 cm). Available data about the spent fuel building show that the thickness of the wall in the area of the water basin is about 0.8 to 1 m. Thus, a severe damage of the spent fuel building by external hazards is possible.

The threat of a large breach of the spent fuel pool was highlighted during the Fukushima accident in 2011. An external event resulting in major damage to the building would cause cooling water loss. If the water drains off and refilling of water is not foreseen or possible, very severe radioactive releases would begin within hours. This leads to a dangerous challenge: As soon as the water has drained out of the pool, not only the cooling, but also the shielding effect of the water is lost. Fuel that has been reloaded only a short time earlier from the reactor would generate a relatively high amount of heat and can reach a temperature of 900 °C within a few hours. At that temperature, the fuel cladding made of zircaloy would burn in the air. The fire is very hot and cannot be extinguished with water. Within the cooling pool it could spread to all fuel assemblies. Thus, the entire inventory of the cooling pool could melt. About 75 percent (10-90 percent) percent of the caesium-137 inventory could be mobilized in the plume from the burning spent fuel pool. (HIPPEL 2016) In this situation, the population would have to be evacuated during an extremely short time period.

The spent fuel pools are also at risk when the reactor is not in operation, and to an even greater extent. The situation is most dangerous during refueling, when all the fuel has to be unloaded from the reactor core into the spent fuel pool. The spent fuel buildings at the French NPPs are highly visible and therefore relatively easy targets for an attack from the air. No studies about the consequences of a deliberate aircraft crash against a French NPP (reactor building or the building of the spent fuel pool) are available. It is, however, possible to draw conclusions from the results of studies carried out in other countries e.g. Germany and general considerations regarding the possible effects of such an aircraft crash. A generic study commissioned by the German Federal Environment Ministry (BMU) revealed that even a small commercial aircraft (e.g. an Airbus A320) would cause major damage to a building with a wall thickness of 0.6 to 1 meter. (BMU 2002)

In context of the LTE of the 900 MWe reactors, ASN criticized the limited target which was set for the intended safety level for the LTE. For accident situations due to explosions and leakage further studies and possible upgrades are expected. Also concerning fires, the safety level which was reached with upgrades does not fulfil currently required safety levels. ASN demanded further studies, however already limited the necessary upgrades by calling them “proportionate”. Whether those further upgrades will reach the safety goal defined by ASN is questionable at this point. However, the main weakness – the SFP’s vulnerability against extreme impact – would persist for the LTE, because no measures are foreseen to remedy this weakness. (UMWELTBUNDESAMT 2019a)

Further civilization-related impacts

Russia's attack on Ukraine has led to scenarios that were previously hardly considered realistic. For the first time, civilian nuclear facilities have become the direct and indirect target of armed conflict. Russia has made it clear that international rules prohibiting acts of war around nuclear power plants can only continue to apply as long as all actors feel bound by them. Nuclear facilities become a particular threat in such cases (BASE 2022).

For this reason, the additional potential threat must also be taken into account in an appropriate manner within the framework of the PSR, e.g.:

- Crash of a military aircraft loaded with weapons.
- Use of remote-controlled drones loaded with explosives.
- Use of more modern weapons with greater destructive power (thermobaric weapons) by terrorist.

Drone overflights are possible at French nuclear power plants: EDF announced in October 2014 that drones had been observed over several nuclear power plants since October 5. On October 19, for example, they had flown over four distant NPPs, indicating that this was a well-coordinated operation. According to media reports, the drones were sometimes two meters wide and could therefore possibly carry smaller quantities of explosives. In recent years, the use of drones for attack purposes has also developed considerably.

The Nuclear security index 2023 shows that France with a total score of 77 points ranked 20th out of 47 countries. The score for the section “security and control measures” with 57 of 100 points is low. Of particular concern are the low scores for the “Security culture” (25), “Cybersecurity” (63) and “Insider threat protection” (36). These low s cores indicate weaknesses in the protection. (NTI 2023) Sabotage is not just a potential threat, as the following incident at the Cattenom NPP shows: In December 2004, it was discovered that over 30 hoses from the plant's fire extinguishers had been scratched. The responsible gendarmerie in Thionville began an investigation into sabotage and the fire extinguishers were replaced.[52]

4.6 Conclusions and recommendations

Earthquake. France so far followed a deterministic approach for determining design parameters for seismic hazards. Defining the Design Basis Earthquake by deterministic methods is no longer state of the art. ENSREG (2012b) therefore recommended introducing Probabilistic Seismic Hazard Assessment (PSHA) for determining the design basis earthquake. A PSHA approach is also necessary to meet the requirements of WENRA (2014; 2021). PSHA was consequently used in pilot studies to develop methodology to be used in the PSR4 of the 1300 MWe fleet and to define the requirements for the Hardened Safety Core (HSC) which must resist the 20,000 years earthquake. The need for “methodological developments” seems surprising given that PSHA is a standard methodology and PSHA results for at least some nuclear sites were already available in 2004 (CLÉMENT et al. 2004a, b).

Detailed PSHA results for the 1300 MWe sites are not available to the authors of this report. It appears, however, that PSHA revealed ground shaking values for Design Basis Earthquakes (DBEs) with occurrence probabilities of 10^{-4} per year in excess of the deterministically derived values (SCOTTI et al. 2014). This is consistent with information obtained during the Stress Tests where ASN confirmed that PSHA revealed DBE values for Saint-Alban that exceed those obtained from deterministic analyses. Therefore, strict application of the WENRA (2014; 2021) requirements is expected to lead to DBE values that may be higher than the deterministically derived ground shaking parameters for many nuclear sites.

[52] https://antiatomnetz-trier.de/informier-dich/cattenom/

The PSHA methodology applied to all French nuclear sites in the course of determining design parameters for the HSC is partly described by DUROUCHOUX et al. (2014). The PSHA approach sketched by the authors is not regarded state of the art and compliant with WENRA (2020b) for two main reasons[53]:

- The use of a minimum magnitude as high as M=5 and Cumulative Average Velocity (CAV) filtering[54] do not account for WENRA's requirement to develop design basis parameters on a conservative basis (WENRA 2014, T4.4; WENRA 2021, TU4.4). CAV filtering was also rejected by ASN (2016).
- The PSHA approach seems to disregard relevant geological data.

Today scientific consensus exists that information on active faults and paleo earthquakes need to be introduced in PSHA. Such data is available for France (BAIZE et al. 2002; NEOPAL 2009; JOMARD et al., 2017; RITZ et al. 2021). PSHA models considering faulting[55]11 are well developed and were already applied to French nuclear sites (CLÉMENT et al. 2004b; CHARTIER et al. 2017; JOMARD et al. 2017)[56].

Figure 2 shows the locations of the 1300 MWe reactors on the background of the French active fault database. The importance of considering fault information is particularly evident for the sites Belleville, Flamanville, Golfech, Paluel and St. Alban, where Pliocene and/or Quaternary faults extend to distances of less than 25 km from the plants. It is noteworthy in this context that ASN has already prescribed how to incorporate fault data in the PSHAs for establishing the HSC of the 900 MWe reactors Fessenheim and Tricastin (ASN 2018).

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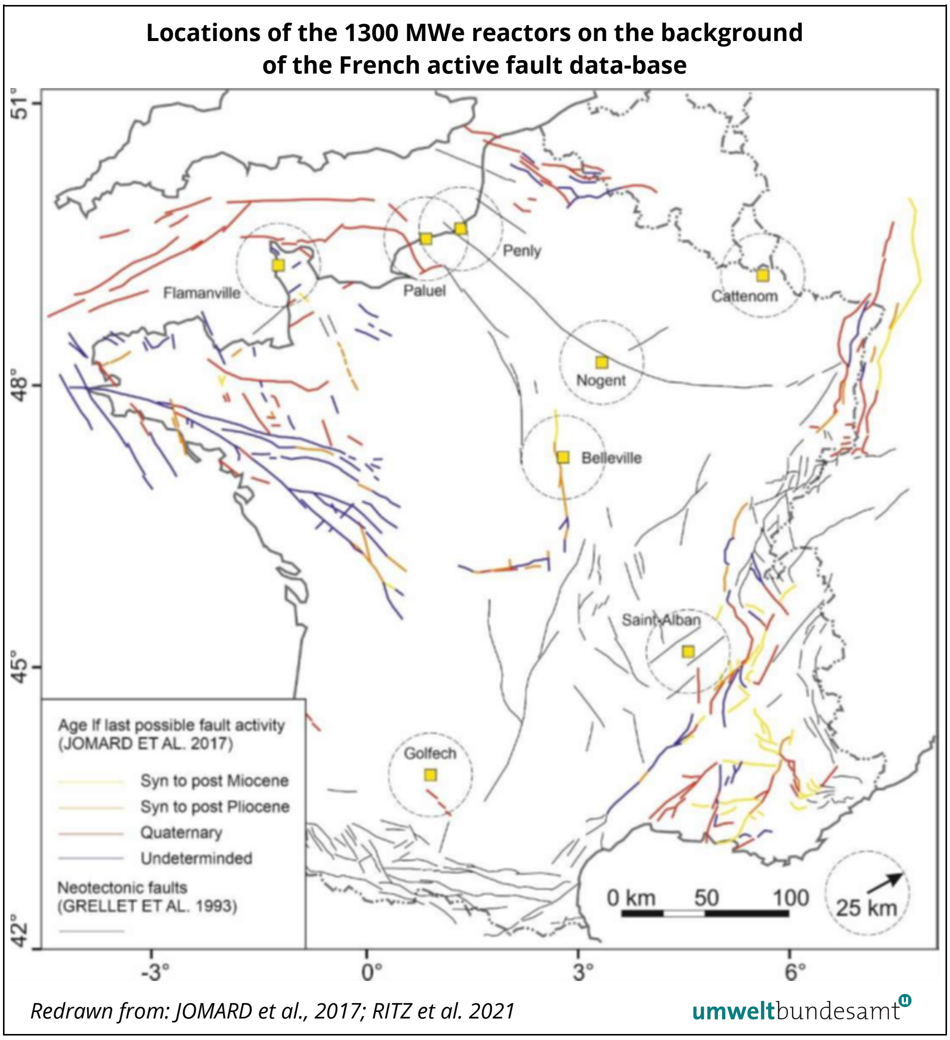
[53] It must, however, be noted that comprehensive information on the PSHA database and methodology used for assessing the French nuclear sites could not be obtained for this report.

[54] Both, the minimum magnitude approach and CAV filtering are based on arguments that certain earthquakes cannot lead to damage of a well-engineered NPP. Both approaches do not exactly relate to the estimation of the seismic hazard, but to a risk assessment because a joint calculation of hazard and vulnerability is made.

[55] E.g., Gutenberg-Richter or characteristic earthquake fault models

[56] Both, databases and methodology were developed in a continued effort by IRSN.

Figure 2: Locations of the 1300 MWe reactors on the background of the French active fault database



Seismic hazard assessments for Saint-Alban and Flamanville, which were researched by the Authors in more detail as examples, suggest the following:

- The PSHA approach for defining site-specific design basis earthquakes with occurrence probabilities of 10^{-4} per year in line with WENRA was heavily discussed between EDF, IRSN and ASN in the past. It appears that EDF repeatedly chose parameters, models and assumptions which lead to too low hazard values[57].
- It is unclear whether the deterministically derived DBEs for Saint-Alban and Flamanville can be defended against PSHA-derived DBEs with an average recurrence interval of 10,000 years. The same applies to the design of the HSC which is required to sustain a 20,000-years earthquake.

[57] Selection of source zones, seismicity rates, choice of minimum and maximum magnitude (Mmin, Mmax), consideration of site effects, CAV filtering, truncation of Ground Motion Prediction Equations.

- Different DBE values are apparently in force for the Flamanville site: 0.15 g for Flamanville 1 & 2 and 0.25 g for the EPR. Taking these values at face may lead to conclude that the design basis earthquake for Flamanville 1 & 2 is severely underestimated. The HSC of Flamanville 1 & 2 is designed for 0.25 g. Comparison of the value with the DBE of the EPR suggests that installation of the HCS at Flamanville 1 & 2 may only ensure safety up the 10,000 years earthquake and not for DEC earthquakes.

The aforementioned examples underline the prime importance of requiring state-of-the-art PSHA to update the seismic design bases of the 1300 MWe sites in the PSR4.

Protection against earthquake. In addition to the inadequate probabilistic seismic analyses, the design of the 1300 MWe reactors showed a number of weaknesses with regard to protection against the DBE (e.g., concerning the fire extinguishing system). In addition, significant failure to the earthquake protection has already been identified during targeted investigations for some safety relevant components (e.g., concerning the emergency diesel generator). In connection with the existing design deficits against external hazards, it is referred to the planned backfitting of the Hardened Safety Core (HSC). However, the envisaged reinforcement of the existing SSCs associated with the HSC to demonstrate their resistance to the Séisme Noyau Dur[58] (SND) is limited.

Flooding. The flood event at the Blayais NPP in France in 1999 showed that the external flooding hazard was not adequately determined, and probabilistic analyses were missing. As severe flooding does not occur frequently, probabilistic analyses are necessary to evaluate the potential flooding hazards. Probabilistic analyses of external flooding in the PSR4 consider only five scenarios calculated for specific NPP sites. The scope of these probabilistic analyses is not adequate given the risk of external flooding may increase due to climate change effects. (BECKER et al. 2020). A comprehensive PSA for external flooding should be conducted in accordance with WENRA (2021; 2020c).

IRSN (2012) assessed the methodology for determining the necessary protection of HSC against external flooding by the EDF. IRSN identified several deficits that lead to the conclusion that the implemented protection against external flooding is not sufficient.

Protection against external flooding. The Blayais flooding in 1999 has revealed weaknesses in the site protection against external flooding. The French standard safety rule contained two criteria for flood protection: (1) placing the platform that supports safety-relevant equipment at a level at least as high as the maximum water level; and (2) blocking any possible routes of water ingress to safety equipment located below the level of the site platform. At Blayais, both criteria were not met: The platform was not high enough; the resistance of fire doors in tunnels to underground safety equipment was miscalculated: the waters surged into the tunnels, broke through the doors, and caused flooding of the reactor building basement and simultaneous failure of safety systems. In

[58] SND = design basis earthquake for the HSC

the context of this expert statement, similar scenarios at other sites cannot be excluded. The platform can be flooded at several NPP sites, and spot checks of Volumetric Protection (VP) have repeatedly shown deficits. Appropriate flood protection is very important because analyses by IRSN for the Stress Tests showed that cliff-edge effects set in shortly after exceeding water level corresponding to the Design Basis Flood (DBF).

As far as can be seen from the very general EDF documents on the subject of protection of the HSC against external flooding, EDF seems to assume that VP already installed after the Stress Test provides sufficient safety margins and thus also meets the increased protection requirements of the HSC.

According to the results of the PSA for external flooding, the integration of post-Fukushima provisions (DUS, refill of the ASG by the SEG system, provisions to protect the hard core from flooding) significantly reduces the risk of core melt. However, spot checks by the ASN showed that the measures and equipment mentioned show a number of weaknesses.

For Saint-Alban and Flamanville, flood hazards and flood protection were researched by the Authors in more detail as examples.

The St. Alban site is located on the River Rhone in an area with a high risk of flooding. Due to climate change, more frequent and more intense precipitation days in winter and an increase in extreme precipitation events are highly likely. It is expected that the current hazard level will increase in the future due to the effects of climate change. IRSN considers that, in general, EDF must justify that the reference values it has chosen to cover an increase in flood levels calculated for a worst-case value of the impact parameter in the scenario corresponding to 1.3 times the increased thousand-year flood. For the St. Alban site, IRSN considers it necessary to review the flood levels to ensure a significant and adequate margin (IRSN 2012). All in all, neither the flooding analyses carried out nor the safety margins used are sufficient. **It is therefore important to define appropriate requirements in the generic PSR4 in order to be able to adequately assess the site hazard in the context of the site-specific PSR.**

The Flamanville NPP is located on the English Channel. To protect coastal sites, IRSN (2012) recommended that EDF re-evaluate the sea level used for the HSC so that it is well above the level previously chosen as a reference and use this re-evaluated level to account for the impact of waves. The probabilistic analysis of the impact of flooding (due to wave overtopping, wind and high sea levels) for the Flamanville site has shown that initial flooding of the site's platform occurs at a frequency of several 10^{-6} per year. It is concluded that the overall risk of meltdown is sufficiently low. However, EDF used too low water levels for the analyses. In addition, EDF refers to the effectiveness of the measures taken at the site after Fukushima to deal with external flooding situations. However, the inspections revealed that, due to maintenance deficiencies and handling difficulties, there is no guarantee that the necessary equipment will be ready for use in the event of external flooding.

In view of the operator's difficulties with maintenance, the ASN placed the plant under increased surveillance in September 2019. In a statement published in December 2019, IRSN described the situation as "very worrying", particularly in view of the significant deviations found in various safety-relevant systems during the last ASN inspections. Although the deficiencies identified at the time were rectified, an ASN inspection of the post-Fukushima measures in 2022 revealed a continuing lack of safety-oriented behaviour.

Extreme weather. Extreme weather events are to be analyzed as part of the PSR4. The hazards to be analyzed include strong winds, extreme temperatures and hazards threatening the availability of cooling water. But also indirect effects like the biological impact on the cooling water supply should be considered.

Human-made hazards. The protection against extreme external impacts, in particular an airplane crash, does not correspond to the state-of-the-art protection as implemented in the EPR.

4.6.1 Recommendations

4.6.1.1 Update of Design Basis Earthquakes and seismic design basis parameters

Relates to EDF NRO (2023a) chapter I.2.2.2.1.5 "Earthquakes" and I.2.2.2.2.5 "Seismic PSA"

Motivation/Observation:

Issue E of the WENRA Safety Reference Levels (WENRA 2021) stipulates that the Design Basis of existing reactors shall be reviewed and updated regularly (Reference Levels E1.1, E11.1) and at least as part of the PSR (WENRA 2020a, 2020b). Currently valid design basis parameters of the 1300 MWe fleet were determined by deterministic methods which were considered outdated already at the time of the European Stress Tests in 2011. The approach is not consistent with WENRA (2014) and (2021).

Recommendation:

It is recommended to define design basis earthquakes with exceedance frequencies not higher than 10^{-4} per year based on site-specific hazard assessments and an up-to-date PSHA methodology. Hazard curves should be calculated down to exceedance probabilities of 10^{-6} or beyond for DEC considerations and adequate considerations of seismic hazards in PSA. If the reassessments result in higher values for the design basis earthquakes, adequate retrofitting of SSCs important to safety would be required.

4.6.1.2 Use of active fault data and paleoseismological data in PSHA

Relates to EDF NRO (2023a) chapter I.2.2.2.2.5 "Seismic PSA"

Motivation/Observation:

Scientific approaches for seismic hazard assessment progressed rapidly since the PSHA pilot studies carried out in 2013-2014, e.g., by the ability to incorporate fault data. Hazard assessments should account, inter alia, for novel data on seismic sources, newly discovered active or capable faults, new data on ground motion attenuation, and site effects (WENRA 2020b). The latter is particularly important for Belleville, Flamanville, Golfech, Paluel and St. Alban, where Pliocene and/or Quaternary faults extend to distances smaller than 25 km from the plants. Notably, these data have been compiled by IRSN in the past and are well available (JOMARD et al. 2017; RITZ et al. 2021). The introduction of such data in PSHA, however, may result in additional uncertainties, particularly when accounting for weakly constrained fault data such as fault location, fault dimension and fault slip rate. The preferred way to reduce the related uncertainties[59] is to collect additional data by geophysical fault mapping, paleoseismological techniques including trenching, etc. (WENRA 2020b).

Recommendation:

PSHA updates should meet the requirements and specifications of the WENRA Reference Levels (2021, Issue TU) and the WENRA guidelines relevant to earthquakes (WENRA 2020a; WENRA 2020b, p. 11-13, guidance on Issue TU3.3). For the PSR4 it should be generally required that site-specific PSHA be carried out taking into account data on active faults (fault location, fault kinematics, fault dimension, slip rate etc.) and using methods that capable of using fault models. It is recommended to define an obligatory and standardized workflow to assess faults located near the sites of the 1300 MWe reactors to reduce uncertainties. Particular attention should be paid to Pliocene and post-Pliocene faults listed in the French active fault database (BDFA). Investigations should focus on fault location (distance from site), fault dimension and segmentation (for estimating maximum magnitude), fault kinematics, fault slip rates (to constrain PSHA fault models), and paleoseismological trenching (timing and magnitude of prehistorical earthquakes).

4.6.1.3 Protection against earthquake

Relates to EDF NRO (2023a) chapter I.2.2.2.1.5

[59] "An effective way to reduce uncertainties is to collect reliable geologic, paleoseismologic, seismologic and geotechnical data as complete as practicable. Expert judgement should not substitute the acquisition of new data." (WENRA 2020b, p. 10)

Motivation/Observation

In addition to the inadequate earthquake analyses, the design of the 1300 MWe reactors showed a number of weaknesses with regard to protection against a design basis earthquake (DBE) (e.g., the piping of the fire extinguishing system). (ASN 2012a) Furthermore, significant deficits to the earthquake protection has already been identified during targeted investigations in some safety relevant components. (e.g., emergency diesel generator) (ASN 2020a) It cannot be excluded that further deficits exist in other components or systems.

Recommendation:

In order to prevent similar defects concerning the seismic protection, a comprehensive inspection of the entire safety systems would have to be carried out.

4.6.1.4 Design extension conditions (DEC= considerations for seismic hazard)

Relates to EDF NRO (2023a) chapter I.2.7.6.1. "HSC Earthquake"

Motivation/Observation:

Issue F of the WENRA Safety Reference Levels (WENRA 2021) stipulates that "the analysis [of design extension conditions] shall identify reasonably practicable provisions that can be implemented for the prevention of severe accidents." WENRA does not introduce a concrete DEC level for which protection shall be foreseen (such as the 20,000 years earthquake for the Hardened Safety Core), but requires DEC analyses to be performed to identify reasonably practical measures for increasing safety further. Reference Levels F1.1 and F5.1 consequently stipulate that DEC conditions for existing reactors shall be reviewed and updated on a regular basis: "Based on these reviews, needs and opportunities for improvements shall be identified and relevant measures shall be implemented".

The French HSC approach takes account of the 20,000 years earthquake which corresponds to an occurrence probability of $10^{-4,3}$ per year. The resulting safety margin above the DBE, expressed by the occurrence probability, could be regarded small at the background that some European countries in low-seismicity regions similar to France require even lower occurrence probabilities for the DBE (10^{-5} per year).

Recommendation:

It is recommended to investigate whether the safety margins resulting from the design of the Hardened Safety Core for earthquakes with a return period of 20,000 years are sufficient and in line with the requirements of the WENRA Reference Levels for Design Extension Conditions (WENRA 2021, Issues F and TU). Depending on the results further reasonably practicable provisions could be identified and implemented.

4.6.1.5 Update of the seismic ground motion values to be taken into account for the Hardened Safety Core (HSC)

Relates to EDF NRO (2023a) chapter I.2.7.6.1. “HSC Earthquake”

Motivation/Observation:

Currently valid ground motion parameters taken into account for establishing the HSCs of the 1300 MWe fleet were determined by a combination of deterministic and probabilistic methods. The latter were used to determine ground motion values related to the 20,000 years earthquake. The PSHA-based values were seemingly determined in the 3rd PSR by an approach which deems outdated from today’s perspective. In addition, ground motion values of the 20,000 years earthquake were at least partly critically assessed by IRSN and ASN.

Recommendation:

It is recommended to base the probabilistic ground motion values taken into account for the design of the HSC on updated site-specific PSHAs.

4.6.1.6 Robustness of existing SSCs of the HSC with respect to earthquake

Relates to EDF NRO (2023a) chapter I.2.2.2.1.5

Motivation/Observation

IRSN (2022a) considers that the seismic behavior of the existing SSCs, which are part of the HSCs, is not sufficiently guaranteed. For example, the methodological approach regarding the resistance against the Séisme Noyau Dur (SND) of existing anchors, pipelines and the considered re-evaluation of the seismic behavior of engineering structures is not acceptable. IRSN explained that the HSC must be designed to provide a high level of confidence in its ability to perform its functions for the full period of the hazard.

Recommendation:

It is recommended to require demonstrating that the existing SSCs associated with the HSC are sufficiently qualified to resist the SND. Resistance should be demonstrated using standard design methods. Depending on the results measures should be identified to ensure the functionality of the SSCs during and after an SND.

4.6.1.7 Mechanical design requirements for new SSCs of the HSC

Relates to EDF NRO (2023a) chapter I.2.7.6.1. “HSC Earthquake”

Motivation/Observation

The IRSN (2023c) point out that the HSC must be designed in such a way as to provide a high level of confidence in its ability to perform its functions. The welds are a sensitive point in the manufacture of equipment and its assembly on site, which could call into question the functionality of equipment after an SND earthquake. IRSN recommends for all new HSC equipment to carry out checks on all welds in order to ensure that this equipment is highly robust to hazards.

Recommendation

For all new HSC equipment, systematic checks of welds should be carried out in order to ensure that this equipment is highly robust to hazards. In addition, a test of all of the welds of the existing components belonging to the HSC should be carried out.

4.6.1.8 Probabilistic analysis for external flooding

Relates to EDF NRO (2023a) chapter I.2.2.2.2.4 "PSA external Flooding"

Motivation/Observation

Until 2011, the methodology used in France to assess natural hazards like external flooding, was based on a deterministic approach. The strongest historical event was considered on the basis of a specific observation period - usually one hundred or one thousand years - to which safety margins were added. Probabilistic analyses were not performed. Probabilistic analyses of external flooding in the PSR4 are currently foreseen to only consider five scenarios calculated for specific NPP sites. The scope of these probabilistic analyses is not adequate given that the risk of external flooding may increase in the course of climate change. In addition, EDF (2023a) stated that for a scenario with a flood level higher than that used for the HSC design, there is a low level of knowledge to assess the frequency of such a flood event. Therefore, the numerical assessment carried out for this scenario is not considered relevant. However, this explanation is not justified from safety point of view.

Recommendation

A comprehensive PSA for external flooding should be conducted in accordance with WENRA (2014; 2021) and WENRA (2020c). Scenarios should not be excluded due to the lack of information. It is important to define appropriate requirements in the generic PSR4 in order to be able to adequately assess the site hazard in the context of the site-specific PSR.

4.6.1.9 Protection of the HSC against external flooding

Relates to EDF NRO (2023a) chapter I.2.7.6.2 "External Flooding HSC"

Motivation/Observation

IRSN (2012) evaluated the methodology to determine the necessary protection of the HSC against external flooding by EDF. IRSN point to some deficits, among others:

- The precipitation levels calculated for the "2 x PFI" scenario are not sufficient to define the HSC protection measures on the nuclear island platform.
- EDF's assumptions regarding the behavior of the hydraulic structures that affect the modeling results (dikes, reservoirs upstream of the sites) are only based on expert judgment.
- EDF must justify that the chosen fixed levels cover an increase in the calculated flood levels in the scenario corresponding to 1.3 times the increased millennial flood.
- The runoff coefficient selected for the upstream catchments by EDF does not take the soil behavior during extreme rainfall events into account. The induced flood levels could be significantly higher than the calculated values.
- The sea level used for the HSC does not have enough safety margins.

According to the results of the flooding PSA, the integration of post-Fukushima provisions including those to protect the HSC against flooding significantly reduces the risk of core melt. However, spot checks by the ASN showed that the measures and the equipment show a number of weaknesses. (ASN 2022b, c).

Recommendation

EDF should follow the recommendation by IRSN (2012) concerning the protection of the HSC against external flooding. In particular EDF should reassess the above mentioned issues. Most important, EDF should consider extending the safety margins for the protections of the HSC against external flooding. As the availability of HSC installations is crucial for the management of an external flooding situation, the relevant installations should be reviewed as part of the PSR4 and training should take place. In addition, a regular review of the HSC should be established.

4.6.1.10 Indirect effects of extreme weather events

Relates to EDF NRO (2023a) chapter I.2.2.2.1 "Ensure the resilience of installations at all levels of internal and external event reassessed during the re-analysis under consideration of international recommendations (WENRA)"

Motivation/Observation:

Biological influences on the cooling water supply should be taken into account as an external hazard. Freshwater systems are considered to be particularly susceptible to invasion by neobiota. Species introduced as a result of climate change can sometimes reproduce very rapidly. In the case of biological impacts, the input can be more difficult to remove from the cooling water areas than whirled-up leaves, as adhesions and biological films can form. The entry is also more complex, as the neobiota enter the cooling water inlets, which are protected by screens, even in the comparatively small larval stage and can clog heat exchangers or fittings as they grow. (PISTNER et al. 2018)

Recommendation

As part of the PSR4, biological hazards threatening cooling water inlets should be considered and assessed. The possible entry of neobiota should be investigated and, if necessary, measures for protection should be implemented.

4.6.1.11 Extreme external man-made hazards

Relates to EDF NRO (2023a) chapter I.2.2.2.1.16 “Risk from airplane crash”

Motivation/Observation:

The protection against extreme external impacts, in particular an airplane crash, does not correspond to the state-of-the-art protection as implemented in the EPR. Based on current knowledge, a deliberate crash of an airplane into a NPP

cannot be excluded. Such scenarios are generally not covered by the probabilistic approach used for the design of the 1300 MWe reactors. The buildings for spent fuel pools are a “weak point” at the French reactors and the ASN has concluded that a deficiency will remain in any case compared to next-generation plants. Russia's attack on Ukraine has led to scenarios that were previously hardly considered realistic. Nuclear facilities become a particular threat in such cases. For this reason, the PSR4 must also take the additional threat potential adequately into account.

Recommendation:

The residual heat removal from the reactor core and the spent fuel pool should also be ensured in the event of a crash of a commercial airplane. All practical improvements for appropriate protection should be taken. The new need for protection resulting from the war situation in Ukraine in terms of weapons used and attack scenarios should also be considered.

5 EXAMPLES OF HAZARD ASSESSMENTS AND PROTECTION

The selection of the NPPs described as examples is based on the scope and quality of the publicly accessible documents and by the specification to refer to both, a coastal and inland site.

5.1 NPP Saint-Alban: example for an inland site

The Saint-Alban nuclear power plant, operated in the department of Isère, on the territory of the municipalities of Saint-Alban-du-Rhône and Saint-Maurice-l'Exil, 50 km downstream from Lyon. Saint Alban-1 and -2 starts commercial operation in 1986 and 1987. The units belong to the P4 reactor type. A capacity factor of approx. 70 % shows the susceptibility to failures and the large number of technical issues during operation.

ASN (2024a) stated, the year 2023 was still marked by a significant number of significant events linked to non-compliance with the operating framework. ASN will remain watchful in 2024 on improving the strictness of reactor operation and on the actions that the site is committed to carrying out regarding the management of the equipment. Improvements are also expected in the content and depth of the analyzes of accidents and near-accidents to avoid their recurrence. However, on May 10, 2024, a configuration error was made at unit 2. As a result, too much water left the primary circuit to be sent to another circuit.

5.1.1 Earthquake

As for all other French NPP sites, the original seismic design basis for the Saint-Alban reactors is based on deterministic studies (see chapter 2.2.1). Accordingly, the design basis of the nuclear island was set to 0,15 g. The design basis for the site structure, originally set to 0.1 g, was later increased to 0.132 g (ASN 2011a).

EDF reassessed the seismic hazard for the Saint-Alban site during the 3rd PSR of the 1300 MWe reactors including a PSHA study. It appears that the PSHA-derived DBE for the Saint-Albin site exceeds the deterministically derived SMS level.

The PGA value of the DEC earthquake (SND; Séisme Noyau Dur) used for engineering the HSC of the Saint-Alban reactors was calculated with 0.3 g. The value was seemingly derived by adding a 100% safety margin to the deterministically derived design basis earthquake level. According to EDF, this SND level corresponds to an earthquake with an estimated return period of 167,000 years. IRSN (2012, p. 163 - 175) reviewed the PSHA critically concluding that it was not state-of-the-art and questioning its results because the study (i) was not considering seismic scenarios such as site characteristics and nearby faults, (ii) did not take into account magnitudes greater than those observed historically and (iii) applied a truncation to ground motion prediction equations equal to two standard deviations. IRSN (2012) further noted that the SND spectrum for the 20,000 years earthquake does not present margins for frequencies below 5 Hz with respect to a spectrum established for 10,000 years and a 85% confidence level. In fact, IRSN (2012, Fig. 13) shows that ground accelerations of the SND spectrum below 3 Hz are even lower than the accelerations shown for 10,000 years at 85% confidence.

In addition to the critical comments on the PSHA for Saint-Alban, there are further fundamental criticisms on the methodology raised by SCOTTI et al. (2014) and ASN (2016) who pointed out that the minimum magnitude of M=5 and CAV (Cumulative Absolute Velocity) filtering applied by EDF reduce the calculated hazard values significantly. ASN (2016) consequently rejected the SND proposed by EDF.

In 2017, ASN finally considered that the assessments of the seismic hazards determined by EDF for Saint-Alban were not acceptable. ASN (2017d, p. 347) consequently requested EDF to:

- reassess the seismic spectra;
- define a working programme to verify the strength of the equipment and civil engineering structures and make any seismic reinforcements for the PSR.

In 2018, ASN confirmed that the selection of several PSHA parameters by EDF lead EDF to underestimate the probabilistic spectrum of the SND. ASN (2018) specifically lists maximum magnitude, seismicity rate, seismotectonic zoning and hypotheses retained in fault models. ASN (2018, Appendix 2) consequently provides surprisingly detailed instructions and requirements how to modify the PSHA in order to arrive at acceptable hazard values.

It is unclear to this end if and how the PSHA approach applied to Saint-Alban accounts for account relevant geological data to the hazard assessment. WENRA (2020b) describes how geological information such as data on active faults and paleo-earthquakes should be integrated in PSHA. For Saint-Alban recent fault databases particularly highlight the "Faille de Valence" which offsets Pliocene sediments and should therefore be considered active in the sense of IAEA (2015). The fault extends to a minimum distance of ca. 25 km from the site (JOMARD et al., 2017; RITZ et al. 2021). It is noteworthy in this context that ASN previously required incorporating fault data (e.g., fault slip rates) in the PSHAs for the 900 MWe reactors Fessenheim and Tricastin (ASN 2018).

5.1.2 External flooding

The St. Alban site is located at the Rhone River. According to the modelling of "ThinkHazard!" tool the river flood hazard level is classified as high based on modeled flood information currently available for the area. This means that potentially damaging and life-threatening river floods are expected to occur at least once in the next 10 years. Project planning decisions, project design, and construction methods must take into account the level of river flood hazard. Concerning the climate change impacts it is stated: High confidence in more frequent and intense precipitation days in winter and an increase in the number of extreme rainfall events. The present hazard level is expected to increase in the future due to the effects of climate change. It would be prudent to design projects in this area to be robust to river flood hazard in the long-term.[60]

According to the EDF (2023a) the following seven reference flooding scenarios (RFSs) or their combination can cause external flooding situation for the St. Alban NPP:

- River flooding in areas over 5,000 km2 CGB),
- Dam-break wave propagation (ROR),
- Sudden transient and localized variation in water level near the site due to a hydraulic structure malfunction or stop of pump station (INT),
- Behavior of the rainwater drainage network in the event of heavy rain (PLU),
- Breakage of tanks or piping outside buildings housing safety related SSCs (DDOCE),
- Rise of the water table (RNP),
- Local wind waves (CLA).

IRSN (2012) notes that at the St Alban site, the scenario used to size the hard core protection provisions do not result in higher flows than those applied in accordance with RFS I.2.e (from 1984). For St Alban, pending studies resulting from the application of the flooding guide, and in order to guarantee a significant and lasting margin and the levels of the hard core, IRSN considers it necessary to review the flooding levels. (IRSN 2012)

For a number of river sites, IRSN stressed the need to verify the assumptions made concerning the behavior of hydraulic and protective structures in the range of flows covered by the “hard core” scenario, particularly for the Saint Alban site. IRSN considers that EDF must in general justify that the standard levels it has selected cover an increase in flood levels calculated for a worst-case value of the influential parameter in the scenario corresponding to 1.3 times the increased millennial flood. All in all, as already stated in chapter 4, the safety margins are not appropriate. (IRSN 2012)

[60] https://thinkhazard.org/en/report/1270-france-rhone-alpes/FL

5.1.3 Means of the Hardened Safety Core

Within the scope of the Nuclear Safety Authority's (ASN) concerning the control of nuclear facilities, an inspection took place on October 26, 2022, at the Saint Alban nuclear power plant on the subject of post-Fukushima safety improvements. The purpose of this inspection was to verify the integration of the organizational and material modifications to phase 2 of the safety improvement program following the nuclear accident at the Fukushima-Daiichi power plant, as well as the application of certain technical requirements resulting from ASN's review of the additional safety assessments submitted in 2012. (ASN 2022b)

The inspectors examined, on a test basis, the integration of modifications carried out at the site, as well as the testing of newly installed equipment. In particular, the inspectors checked the mobile compressed air production and pumping systems, the deployment of ultimate water sources and the ultimate emergency generator.

The inspectors also carried out a field inspection of certain equipment stored in the crisis management equipment building (BMGC), the routing of ultimate water replenishments (EWR) from the groundwater intake to the replenishment tap in the controlled zone, and a spot check of flood protection systems. The inspectors noted a number of specific deviations, which are the subject of requests.

- In order to supply compressed air to certain equipment in the event of a total loss of electrical power, autonomous mobile compressors are present on site to supply each of the reactors. In particular, these compressors enable compressed air to be re-supplied to the turbine-to-atmosphere bypass valves (GCTa), which are necessary for reactor cooling under these conditions. The inspectors revealed that the flow rate check on a compressor was not done, thus the performance is not guaranteed in an accident situation.
- In order to replenish the water supply to certain systems in the event of a total loss of electrical power, autonomous mobile pumps are available to replenish the water supply to each of the reactors. In particular, these pumps are used to replenish the water supply to the steam generator emergency supply reservoir (ASG reservoir), the fuel storage building (BK) pools and the pool cooling and treatment system (PTR) via the dedicated connections of the nuclear rapid action force (FARN). During the inspection, EDF´s personal were unable to provide calibration reports for the flowmeters used to check the characteristics of these pumps. Thus, the performance of the pumps could fail during an accident.
- The fuel tanks needed to operate autonomous systems (pumps, compressors, etc.) must be stored empty. But no procedures were currently available for filling these tanks, and that the equipment available for this purpose had not yet been directly identified. ASN requires to formalize in a memo the procedure and associated means for filling the empty fuel tanks.

5.2 NPP Flamanville: example for a costal site

The Flamanville NPP is near the village Flamanville, a French commune located in the Département of Manche in the Normandy region. The plant receives cooling water from the English Channel. After a seven-year construction phase, the two 1300 MWe reactors, Flamanville 1 and 2 began commercial operation in December 1986 and March 1987 respectively. Reactor 3, an EPR under construction since December 2007, is expected to start commercial operation in 2024 (after a 17-year construction phase).

Units 1 and 2 of Flamanville belong to the P4 reactor type. A capacity factor of approx. 70 % shows the susceptibility to failures and the large number of technical issues during operation.

Reactor 2 at the Flamanville nuclear power plant restarted on December 12, 2020, after numerous postponements and almost 2 years of shutdown. This was due to the ten-yearly inspection and refueling, as well as to refurbish the plant's equipment, some of which was a major cause for concern. Faced with the operator's difficulties in maintaining its site since mid-2018, ASN has placed the plant under enhanced surveillance in September 2019. Thirty-seven safety events, including five classified as level 1 and one classified as level 2 on the INES scale, were declared during the shutdown of Reactor 2, between January 10, 2019 and December 12, 2020. (RSN 2021)

In an opinion issued in December 2019, IRSN described the situation as “very worrying”. From a safety point of view, IRSN considers the situation at the Flamanville site to be very worrying, particularly in view of the major deviations in various safety-related equipment identified during the latest ASN inspections. IRSN considered that the Flamanville operator's primary objective must be to restore the conformity of its facilities, first and foremost all the equipment valued in the safety demonstration.

But also, before in 2017 and after this time periods there were several issues, related to non-compliance with general operating rules at the Flamanville units (see chapter 2).

5.2.1 Earthquake

The deterministic design basis earthquakes for both, the nuclear island and the site structures of the 1300 MWe reactors at Flamanville were originally fixed to 0.15 g (ASN 2011). Reassessment of the seismic hazard accounting for RSF 2001-01 modified this value to 0.16 g.

Remarkably, these values retained for the units 1 and 2 are significantly smaller than the value of 0.25 g stated for the design basis earthquake for the new-built Flamanville 3 EPR. The latter value is based on PSHA (ASN 2011). The background to this remarkable discrepancy between the design basis earthquake values could not be researched within the scope of this report.

The PGA value for HSC – termed SND (Séisme Noyau Dur) for Flamanville 1 & 2 was fixed to 0.25 g (Table 3) which is said to correspond to a recurrence interval 39,000 years (information by EDF cited in IRSN 2012). The value is again in strong contrast to the design basis value for the Flamanville 3 EPR, which must be assumed to have been calculated for a 10,000-years recurrence interval. The simple comparison of values can lead to the conclusion that both, the loads of the design basis earthquake and the earthquake retained for DEC considerations and the HSC of Flamanville 1 & 2 are significantly underestimated.

Recent geological data on neotectonics and active faults in the near-region of Flamanville highlight the Faille de La Hague or Faille de Jobourg (ca. 11 km from the site), the Flexure de Barfleur (35 km) and the Faille de Lessay (45 km; NEOPAL 2009; JOMARD et al. 2017; RITZ et al. 2021). These faults are referred to as Pliocene and Quaternary, respectively, show geomorphological evidence and should therefore be regarded active according to IAEA (2015). Given the date of publication of the fault data, it appears unlikely that the geological evidence was considered in the previous seismic hazard studies.

Flamanville is the only 1300 MWe reactors site for which a seismic PSA was carried out. This level 1 PSA led EDF to the following conclusions: (i) the probability of core melt subsequent to an earthquake with a return period of less than 150,000 years is very low. About 95% of this calculated risk is due to seismic accelerations greater than the SND retained for the HSC. (ii) The provisions of the HSC "make it possible to obtain a calculated residual risk for earthquakes up to the SND without a cliff edge effect". However, it must be taken into account that the seismic PSA results may be unreliable as they may be based on a faulty PSHA as shown by the discrepancies between the design basis earthquake levels and the SND earthquake obtained for Flamanville 1 & 2 on the one side, and the EPR on the other side (see above).

5.2.2 External Flooding

According to the EDF (2023a) the following six reference flooding scenarios (RFSs) or their combination can cause external flooding situation for the Flamanville NPP site:

- Sudden transient and localized variation in water level near the site due to a hydraulic structure malfunction or stop of pump station (INT),
- Behavior of the rainwater drainage network in the event of heavy rain (PLU),
- Breakage of tanks or piping outside buildings housing safety-related SSCs (DDOCE),
- Rise of the water table (RNP),
- Sea level rise (NMA),
- Ocean waves (AGW).

For the protection of the coastal sites, IRSN (2012) recommended EDF to reassess the sea level used for the hard core so that it is significantly higher than the level corresponding to "CMS + 1 m", and take this reassessed level into account to take account of the effects of waves.

The probabilistic analysis about the effect of seaside crossing (spillage of water on the site platform due to the effects of the tide, surge, swell and the wind) for the Flamanville site has shown that the first crossings on the site platform occur at a frequency of a few 10^{-6} per year. It is stated that the overall risk of core meltdown associated with the risk of crossings is sufficiently low. The majority of the core meltdown risk is due to a scenario involving water ingress into the nuclear island buildings, as a result of the site's flood protection being exceeded. EDF stated the analysis demonstrates the effectiveness of the post-Fukushima measures put in place on the site (DUS, refill of the ASG by the SEG, FARN) to manage external flooding situations. However, the inspections revealed that there is no guarantee that the required equipment will be operational in the event of external flooding due to maintenance deficiencies and handling difficulties. (see chapter 5.2.3)

The probabilistic analyses about a damage or malfunction of structures, circuits or equipment show according to EDF, that due to the detection systems in place and the time available to stop the pumps, the risk of water entering the protected buildings from the machine room is very low for the Flamanville site.

Flood hazards due to earthquake- or landslide-triggered tsunami for costal sites at the English Channel seem to be low as indicated by modelling results for the Lissabon – Galicia Banks tsunami of 1755 and the tsunami caused by the Storreaga landslide some 8000 years ago (BARKAN et al. 2009; WENINGER et al. 2008). Models for both events indicate only minor effects on the French coast. For the 1755 event this is supported by historical observation. (see also chapt. 2)

5.2.3 Means of the Hardened Safety Core (HSC)

As part of the responsibilities of the French Nuclear Safety Authority (ASN) concerning the control of basic nuclear installations, an inspection on the subject of safety improvements Post-Fukushima took place on July 13, 2022 at the Flamanville nuclear power plant. In the event of loss of the heat sink, devices for reactor water replenishment must meet the requirements relating to the HSC. (ASN 2022c)

The inspectors examined the compliance of local emergency equipment used to replenish water supplies to certain structures or circuits in the event of an accident involving the total loss of electrical power, which specifies the list of equipment and the necessary procedures.

With regard to mobile pumping equipment, the following points were noted:

- the water hose routes linking the pumps installed on the tanks to the make-up taps have to bypass a screened area, passing over an embankment strewn with holes and brambles for a distance of around 40 meters. The inspectors consider that this path will not be sufficiently practicable for team members in extreme situations;

- the indications of the two flowmeters could not be interpreted by the personal, who had no operating document for this purpose.

With regard to the means of gravity recharge from the SEA basins, and more specifically the SEG valves, the inspectors noted the following points:

- the construction of the structure (around 1 meter high) is such that connecting the pipes and operating the valves requires a person to crawl into a pit. In extreme conditions (flooding, snow, etc.), these operations will be difficult, if not impossible.
- the documents presented concerning the installation and use of the equipment contain numerous errors or lack of precision.

Prescriptions require that “before December 31, 2018, the operator [shall] set up, on each of the site's reactors, an additional means of power supply enabling, in particular, in the event of loss of other external and internal power supplies, the systems and components belonging to the hard core. In particular, this means consists of a diesel emergency power unit (DUS) and associated electrical installations for re-supplying the electrical system.

According to EDF´s declaration to the general operating rules dated June 24, 2022, concerning the extension of the repair time for the DUS at Reactor 2, an electrical device, known as a “FARN PLUG”, would be used to ensure “electrical re-supply by the crisis team”, i.e. via an emergency generator brought in and commissioned by the FARN based in Paluel.

The inspectors examined the equipment in question and noted that the “FARN PLUG” box, was used to connect power supply cables. However, the planned routing of these cables passes through a structure outside the building known as the “cable chimney”. Access to this chimney was obstructed by scaffolding and closed by a trapdoor with a non-functioning actuator. What's more, cable installation from the ground passes through a narrow opening in this chimney; this operation lacks ergonomics, without any apparent justification. Furthermore, the Paluel FARN, consulted for advice, told the inspectors that it had no equipment to connect to the “FARN PLUG”.

The volumetric protection management according to ECS-6 requires the implementation of volumetric protection (VP) measures to guard against the occurrence of situations involving the total loss of the heat sink or power supply. The inspectors noted that the two low close protection devices (PRB), permanent to install devices, at the entrance to the unit 1 pumping station premises were raised without this situation being justified or known to the control department.

5.3 Conclusions

Information on hazard assessment, design basis and DEC earthquakes considered by the HSC for the sites Saint-Alban and Flamanville, which were selected as examples for seismic hazard assessments and protection, suggest the following:

- The PSHA approach for defining site-specific design basis earthquakes with occurrence probabilities of 10^{-4} per year in line with WENRA was heavily discussed between EDF, IRSN and ASN in the past. It appears that EDF has repeatedly chosen parameters, models and assumptions in the development of PSHA that lead to too low hazard values[61]. Documents researched for this report do not provide information if a commonly accepted PSHA methodology and approach is available for the PSR4 of the 1300 MWe fleet at present.
- It is unclear if the deterministically derived design basis values for Saint-Alban and Flamanville can be defended against PSHA-derived design basis earthquakes with an average recurrence interval of 10,000 years. The same applies to the design of the HSC which is required to sustain a 20,000-years earthquake.
- Different design basis values are apparently in force for the Flamanville site: 0.15 g for Flamanville 1 & 2 and 0.25 g for the EPR. Taking these values at face may lead to conclude that the design basis earthquake for Flamanville 1 & 2 is severely underestimated. The HCS of Flamanville 1 & 2 is designed for 0.25 g. Comparison of the value with the DBE of the EPR suggests that installation of the HCS at Flamanville 1 & 2 may only ensure safety up the 10,000 years earthquake and not for DEC earthquakes.
- It seems that seismic hazard assessments of both, Saint-Alban and Flamanville, do not take advantage of recently published data on active tectonics and active faults, although the methodology to account for active fault data is well established in France.

The St. Alban site is located on the River Rhone, in an area with a high risk of flooding. Due to climate change, more frequent and more intense precipitation days in winter and an increase in extreme precipitation events are highly likely. It is expected that the current hazard level will increase in the future due to the effects of climate change. According to EDF (2023a), seven Reference Flood Scenarios (RFS) or their combination can cause an external flooding situation for the St. Alban NPP.

IRSN considers that, in general, EDF must justify that the reference values it has chosen cover an increase in flood levels calculated for a worst-case value of the impact parameter in the scenario corresponding to 1.3 times the increased thousand-year flood. For the St. Alban site, IRSN considers it necessary to review the flood levels to ensure a significant and sustainable margin. (IRSN 2012)

[61] Selection of source zones, seismicity rates, choice of minimum and maximum magnitude (Mmin, Mmax), consideration of site effects, CAV filtering, truncation of GMPEs.

All in all, neither the flooding analyses carried out nor the safety margins used are sufficient, as already explained in Chapter 4. It is important to define appropriate requirements in the generic PSR4 1300 in order to be able to adequately assess the site hazard in the context of the site-specific PSR.

The Flamanville NPP is located on the English Channel. According to EDF (2023a), six reference flooding scenarios (RFS) or their combination can cause an external flooding situation for the Flamanville NPP site. In addition to a blockage of the rainwater drainage network during heavy rainfall, a rise in the groundwater level and a rise in sea level combined with sea waves. To protect coastal sites, IRSN (2012) recommended that EDF re-evaluate the sea level used for the hard core so that it is well above the level previously chosen as a reference and use this re-evaluated level to account for the impact of waves.

The probabilistic analysis of the impact of flooding (due to wave overtopping, wind and high sea levels for the Flamanville site has shown that initial flooding of the site's platform occurs at a frequency of several 10^{-6} per year. It is concluded that the overall risk of meltdown is sufficiently low. However, EDF used too low a water level for the analyses. In addition, EDF refers to the effectiveness of the measures taken at the site after Fukushima (DUS, filling of the ASG by the SEG, FARN) to deal with external flooding situations. However, the inspections revealed that, due to maintenance deficiencies and handling difficulties, there is no guarantee that the necessary equipment will be ready for use in the event of external flooding.

After the 3rd PSR, reactor 2 of the Flamanville nuclear power plant was shut down for two years until the end of 2020. In view of the operator's difficulties with maintenance, the ASN placed the plant under increased surveillance in September 2019. In a statement published in December 2019, IRSN described the situation as “very worrying”, particularly in view of the significant deviations found in various safety-relevant systems during the last ASN inspections. Even though the deficiencies found there were rectified, the lack of safety-oriented behavior was evident during an ASN inspection of the implemented post-Fukushima measures.

6 REFERENCES

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7 LIST OF FIGURES AND TABLES

8 GLOSSARY

AGW .... Ocean Waves

ALARP................................. As far as reasonably practicable

ASG..................................... Steam Generator Emergency Feedwater System

ASN..................................... French Nuclear Safety Authority

Bq .... Becquerel

CCF .... Common cause failure

CDF..................................... Core Damage Frequency

CGB .... Large watershed flooding

CGCS .... Combustible gas control system

CHRS .... Containment heat removal system

CLA .... Local wind waves

CMM................................... Maximum thousand year flood

CMS .... Flood safety margin level

CMSS .... Core Melt Stabilisation System

CPB .... Small watershed flooding

Cs-137 .... Caesium-137

DAC .... Design Acceptance Confirmation

DBE..................................... Design Basis Earthquake

DBF..................................... Design basis flood

DCH .... Direct Containment Heating

DDOCE .... Deterioration or malfunctioning of structures, circuits or equipment

DEC..................................... Design Extension Conditions

DUS .... Ultimate Backup Diesel Generators

ECMWF............................... European Centre for Medium Range Weather Forecasting

EIA .... Environmental Impact Assessment

ENSREG .... European Nuclear Safety Regulators Group

EPR .... European Pressurised Reactors

ES .... Environmental Statement

EU .... European Union

FARN .... Rapid Response Nuclear Taskforce

FL3 .... Flamanville Unit 3

FMEA .... Failure Modes and Effects Analysis

FRA .... Flood Risk Assessment

G .... Ground acceleration expressed as a fraction of the acceleration of gravity of 9.81 m/s²

GDF .... Geological disposal facility

GRS .... Gesellschaft für Anlagen- und Reaktorsicherheit, Deutschland

GW .... Giga Watt hour

HCS .... Hardened Safety Core (noyau dur)

HFT .... Hot functional testing

HLW .... High level waste

HPME .... High Pressure Melt Ejection

HRA .... Human Reliability Analysis

HSC .... Hardened Safety Core

HVAC .... Heating, Ventilation and Air Conditioning

I&C .... Instrumentation & Control

IAEA .... International Atomic Energy Agency

IDAC .... Interim Design Acceptance Confirmation

INT .... Mechanically induced wave

IRSN .... Institut de Radioprotection et de Sûreté Nucléaire

IWRST .... In-containment refuelling water storage tank

LOCA .... Loss of Coolant Accident

LOOP .... Loss of offsite power

LTE .... Life time Extension

MW .... MegaWatt

MWe .... MegaWatt electric

MWh.................................. Mega Watt hour

NAcP.................................. National Action Plan

ND .... Noyau Dur

NDA.................................... Nuclear Decommissioning Authority

NFLA.................................. Nuclear Free Local Authorities

NMA .... Sea level

NPP.................................... Nuclear Power Plant

NTI .... Nuclear Threat Initiative

PAR.................................... Passive autocatalytic recombiners

PBq.................................... Peta Becquerel, E15 Bq

PCSR.................................. Pre-Construction Safety Report

PDS.................................... Primary Depressurisation System

PFI...................................... high intensity rainfall

PGA.................................... Peak Ground Motion

PLU .... Local rainfall

PRA.................................... Probabilistic risk assessment

PRB.................................... low-lying close protection

PRH.................................... high close protection

PSA .... Probabilistic Safety Assessment

PSHA .... Probabilistic Seismic Hazard Assessment

PSR .... Periodic Safety Review

RCS .... Reactor Cooling System

RFS..................................... Basic safety rules

RFS..................................... Reference Flooding Situation

RNP .... High groundwater level

ROR .... Failure of a water-retaining structure

RPV.................................... Reactor Pressure Vessel

RRC.................................... Risk Reduction Category

SBO.................................... Station Black Out

SEG.................................... Ultimate Heat Sink

SEI .... Seiche

SEO .... Sewerage

SGTR .... Steam generator tube ruptures

SMA .... Seismic Margin Assessment

SND .... Séisme Noyau Dur

SRI .... Scenario

SSC .... Structure, Systems, Components

UDG .... Ultimate Diesel Generators

UHS .... Ultimate Heat Sink

VAG .... Ocean waves

VP .... Volumetric Protection

WENRA .... Western European Nuclear Regulators´ Association umweltbundesamt

Umweltbundesamt GmbH
Spittelauer Laende 5
1090 Vienna/Austria

Tel.: +43-1-313 04

office@umweltbundesamt.at
www.umweltbundesamt.at

EMAS
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