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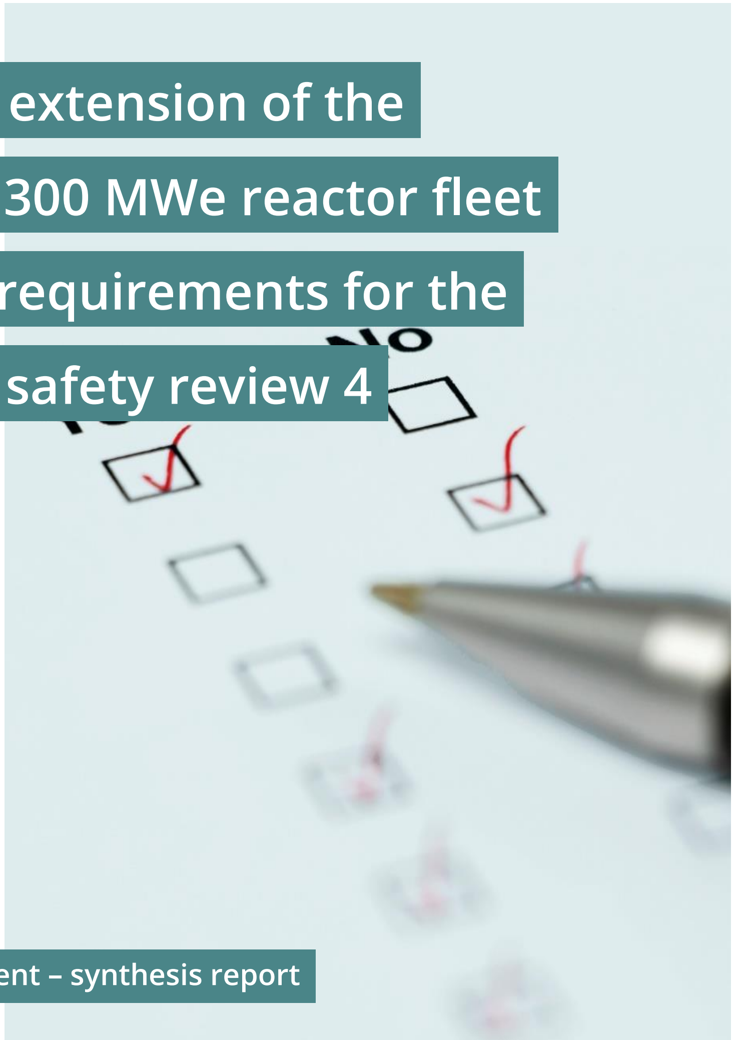
Lifetime extension of the French 1300 MWe reactor fleet

Generic requirements for the periodic safety review 4



Expert statement – synthesis report

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LIFETIME EXTENSION OF THE FRENCH 1300 MWE REACTOR FLEET GENERIC REQUIREMENTS FOR THE PERIODIC SAFETY REVIEW 4

Expert statement – synthesis report

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Innovation and Technology

REPORT
REP-0915

VIENNA 2024

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Layout Doris Weismayr (Umweltbundesamt)

Title photograph © iStockphoto.com/imagestock

Contracting authority Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology, Directorate General VI – Climate Action and Energy, Directorate VI/8 – General Coordination of Nuclear Affairs

GZ: 2023-0.313.651

Publications For further information about the publications of the Umweltbundesamt please go to: https://www.umweltbundesamt.at/

Imprint

Owner and Editor: Umweltbundesamt GmbH
Spittelauer Laende 5, 1090 Vienna/Austria

This publication is only available in electronic format at https://www.umweltbundesamt.at/.

ISBN 978-3-99004-759-0

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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 some countries, like France, an unlimited operating license is issued, with the condition that periodical safety reviews (PSR) have to be conducted at least every ten years. In France, once the design life-time 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 PSR4.

An important aspect when extending the design lifetime of a NPP is termed "obsolesce of regulations, codes and standards". A NPP is designed according to the regulations at that time. But especially in the field of nuclear safety the knowledge on risks and accidents increased considerably in the last 40 years. The lessons learned from the accidents of Three Mile Island, Chernobyl and Fukushima pushed regulations as well as the state of the art towards higher safety.

In addition to the broadened scope of the PSR4 in respect to the previous PSRs, 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 by submitting this report.

A specific phase, treating each of the twenty reactors individually, will follow. For the generic phase, the French regulator ASN and the utility EDF agreed among others on the following objectives for the PSR4 (ASN 2019a):

Verification of the conformity of the installations with applicable safety requirements.

As part of the continuous improvement of safety, elevate the 1300 MWe plants towards the safety objectives set for the 3rd generation reactors, with the EPR Flamanville 3 as reference.

Implementation of all provisions of the hardened safety core which have been prescribed by ASN.

Substantial information was provided for the consultation process, and most importantly the document "Note de Réponse aux Objectifs du 4 ème Réexamen Périodique du Palier 1300 MWe" (EDF 2023a), that outlines how EDF intends to achieve those objectives.

Method: The present work provides an expert opinion to the consultation process. Selected aspects of the objectives of the PSR4 were investigated. In particular:

We looked at past safety-significant events at French NPPs. Events that were related to aging were taken into closer consideration. Looking at this subset, we were investigating if and how those events changed over time, and which actions were taken by EDF to reduce the number of such events. From this analysis, we derived recommendations for the operation beyond 40 years of the French 1300 MWe reactors.

The "Western European Nuclear Regulators Association" issued Safety Reference Levels for Existing Reactors (WENRA 2014, 2021). Those Reference Levels are binding for French reactors. We were summarizing the relevant French regulatory requirements and compared these national requirements with the most important requirements of WENRA. Investigations and measures that should be carried out as part of the PSR were compared to the corresponding WENRA requirements. In addition, design basis hazards of the 1300 MWe reactors and the protective measures already taken and planned were analyzed. From this analysis within the scope of the first PSR objective a further set of recommendations was derived.

Finally we were systematically comparing the safety concept of the 1300 MWe reactors after the planned retrofitting in the frame of the PSR4 with the EPR safety concept. This was done for safety systems installed for design basis accidents as well as for equipment relevant for safety, needed in the management of design extension conditions (with and without core melt). It was then analyzed how far the 1300 MWe safety concept and the EPR-Flamanville safety concept differ from each other. The analysis led to a final set of recommendations within the scope of the second PSR objective.

Results – first PSR objective: **Earthquake:** In the frame of the first PSR objective, verification of the conformity of the installations with applicable safety requirements, our analysis showed that regarding earthquake, the regulatory requirements for the assessment of natural hazards are not fully in line with WENRA Reference Levels and guidance. For earthquakes, 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.

With respect to external hazards, ASN stipulates that definitions of design basis events and design extension conditions 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 a Probabilistic Seismic Hazard Assessment (PSHA). However, ASN specifications for the PSR4 do not make sufficiently clear if a PSHA shall lead to the definition of new design basis parameters and, subsequently, updated requirements for plant protection.

Previous PSHA approaches for defining DBEs in line with WENRA were 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, and it is unclear if the deterministically derived DBEs for all sites can be defended against PSHA-derived DBEs with occurrence probabilities of 10-4 per year. The PSR4 should consequently be used to implement up-to-date PSHA for all 1300 MWe sites, update the seismic design basis accordingly, and implement measures to ensure conservative protection against the updated DBEs. The same applies to the design of the HSC which is required to sustain a 20,000-years earthquake.

Flooding: In response to the Blayais flooding, in 2013, the ASN published the new Guide No. 13 (ASN 2013g), 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 completely in line with WENRA (2014; 2021).

Part of the PSR4 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 described in the paragraph “Earthquake” above 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 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.

Man-made hazards: The reassessment of man-made hazards as part of the PSR4 is apparently only to be carried out after the PSR4 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 should be appropriate in scope and timeframe. All inspections and any resulting retrofits should be carried out during the shutdown period.

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. 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. Russia's attack on Ukraine has led to scenarios that were previously hardly considered realistic. 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.

Results – second PSR objective:

The second objective of the PSR4 of the French 1300 MWe reactor fleet (P4 and P'4 reactors) is to move those reactors towards the state of the art. The reference hereof is the EPR reactor in Flamanville, for which fuel loading has recently begun. Especially after the Fukushima accident, significant modifications have been made to increase the resilience of the reactors against natural hazards and severe accidents.

For design basis accidents, the 1300 MWe reactor safety systems follow an n+1 safety concept, meaning that the degree of redundancy is such that one safety system may fail. In general, this is implemented by two independent trains of safety systems, each capable to fulfill the safety function (2x100% safety concept). The EPR, in contrast, has four trains of each safety system with 4x100% redundancy, a (n+3) safety concept. Even if three trains fail out of various reasons, the last train can fulfil the full safety function. At the EPR, an aircraft crash-resistant shell covers the reactor building, the fuel building and two buildings housing two engineered safety trains; provision for the prevention of severe accident conditions are integrated from the design stage.

When comparing different aspects that affect safety of the 1300 MWe and the EPR reactors, the following points stand out:

- The EPR has a system for the stabilization of the core melt (corium) to prevent failure of the containment in case of severe accidents. Retrofitting of a so-called core catcher is not possible due to space limitations below the nuclear reactor core of the old reactors. EDF claims that the provisions implemented in the 1300 MWe reactor series are in principle similar, but they rely on cooling the corium from above by flooding. Research & development efforts aiming to show that this is possible (LICHT 2023) are still ongoing and have not shown convincing results yet.
- The total number of independent emergency electricity generating sources present at the reactor is about the same for the EPR as for the 1300 MWe reactors after retrofitting measures. However, for the 1300 MWe reactors only two systems fulfil the more rigorous requirements for safety systems (n+1) while this holds true for four systems of the EPR (n+3).
- NPPs are designed to have redundant and diverse safety systems to ensure that essential safety functions are performed. The safety systems of the 1300 MWe reactors consists of two trains. If one of those trains fails, the other train can fulfil the necessary safety functions (single failure criterion). The EPR safety systems consist of four trains. Backfitting the 1300 MWe reactors does not seem to address the redundancy and diversity of level 3 safety systems that handle design basis accidents.
- The Nuclear rapid intervention force (FARN) is located at different NPPs all over France and is supposed to be on-site in case of emergency within 24 hours and their mobile systems should be operational within 36h. FARN provides support in case of design extension conditions on safety level 4, which is put in operation to prevent and mitigate severe accidents. Those systems relevant for safety must not be credited to compensate for existing deficits at safety level 3.

- The hardened safety core increases the resilience of the 1300 MWe reactor fleet against external hazards such as earthquakes and flooding. The design of the EPR against earthquakes and flooding is based on much more stringent requirements.

Based on the information available it can be stated that it is not possible to increase the safety level of the 1300 MWe reactor fleet to state-of-the-art. It should be emphasized, though, that improvements have been made by retrofitting compared to the original design.

Results – third PSR objective:

Hardened Safety Core: The third safety objective of PSR4, implement all the provisions of the Hardened Safety Core, was looked at. It was concluded that implementation of the "Hardened Safety Core" at the 1300 MWe sites has not been completed by now and will probably not be fully implemented before the start of the PSR4. In addition, there are doubts as to whether the HSC design against flooding events considers adequately the effects of climate change.

Risk Report supporting Safety Report

One of the objectives of the PSR4 is moving the safety level of the 1300 MWe plants towards the current state of the art. However, this objective does not set hard targets: there is no requirement to reach the safety level of state of the art NPPs (like the EPR), there is not even a regulation prescribing how far the safety levels of the 1300 MWe plants should be elevated.

Analysis allows the conclusion that especially at the level of the safety systems related to design basis accidents, regarding redundancy and diversity, there is remaining significant gap. This means that not all NPPs in France will operate according to the highest standards of nuclear safety – there will be a difference between life-time extended NPPs, which are allowed to operate according to lower requirements, and the new reactors, with a construction license issued after 2014 (Nuclear Safety Directive 2014/87/Euratom), which will be designed, build and operated according to higher standards. As a consequence, the 1300 MWe will entail a higher risk for severe accidents and large releases than state of the art generation III NPPs.

For full transparency, ASN and EDF should provide information on those remaining risks in the frame of the consultation process to enable decision makers and the public to make an informed decision whether life-time extension should be favored. Such a risk report would supplement the safety analysis and should comprise two main elements – firstly, a comprehensive comparison of the 1300 MWe design and the EPR design. Secondly, based on the gaps, a risk analysis would point out accident sequences that are eliminated by the EPR safety concept, but still possible in the 1300 MWe reactors.

An informed decision requires not only information on conformity of the 1300 MWe reactors with current regulations, but also information on the risks that will still accompany people in France and abroad during the extended operational life of the 1300 MWe fleet.

RÉSUMÉ

Vingt réacteurs nucléaires installés en France d'une puissance de 1300 MWe approchent aujourd'hui leurs quarante ans d'exploitation, soit la fin de leur durée de vie de conception. Leur exploitant EDF a l'intention de prolonger la durée de vie de ces centrales.

En France, comme dans d'autres pays, une licence d'exploitation sans limite de durée est accordée, à condition que des réexamens périodiques de sûreté soient effectués au moins tous les dix ans. Lorsque la durée de vie de conception est atteinte et que le fournisseur d'électricité prévoit de prolonger l'exploitation d'une centrale nucléaire au-delà, une réévaluation complète de l'état de la centrale devient nécessaire dans le cadre du 4e RPS.

Un autre aspect important pour la prolongation de la durée de vie d'une centrale nucléaire est ce qu'on appelle « l'obsolescence des réglementations, des codes et des standards ». Une centrale nucléaire est conçue conformément aux réglementations en vigueur d'une époque. Or, le domaine de la sûreté nucléaire en particulier a connu un développement considérable des connaissances sur les risques et les accidents depuis une quarantaine d'années. Les leçons tirées des accidents de Three Mile Island, Tchernobyl et Fukushima ont fait progresser les réglementations et l'état de la technique vers toujours plus de sécurité.

Outre l'élargissement du champ d'application du 4e RPS par rapport aux RPS précédents, le Haut comité pour la transparence et l'information sur la sécurité nucléaire (HCTISN) organise une consultation publique permettant de donner des avis sur la phase générique du 4e RPS, qui couvre des sujets pertinents pour tous les réacteurs de 1300 MWe.

En cas d'accident majeur sur une centrale nucléaire française, on ne peut exclure des conséquences significatives pour l'Autriche. L'Autriche participe donc à cette consultation en soumettant le présent rapport.

La phase générique sera suivie d'une phase spécifique, qui traitera individuellement chacun des vingt réacteurs. Pour la phase générique, l'autorité de régulation française ASN et le fournisseur d'électricité EDF ont convenu, en autres, des trois objectifs suivants pour le 4e RPS (ASN 2019a) :

Vérification de la conformité des installations avec les exigences de sécurité applicables.

Dans le cadre de l'amélioration continue de la sûreté, rapprocher autant que possible la sûreté des centrales de 1300 MW des objectifs de sûreté fixés pour les réacteurs de 3e génération, avec l'EPR de Flamanville 3 comme référence.

Mise en œuvre de toutes les dispositions du noyau dur de sécurité prescrites par l'ASN.

Des informations substantielles ont été fournies pour le processus de consultation, notamment le document « Note de Réponse aux Objectifs du 4eme Réexamen Périodique du Palier 1300 MWe » (EDF 2023a), qui décrit comment EDF a l'intention d'atteindre ces objectifs.

Méthode: Le présent document apporte un avis d'expert au processus de consultation. Certains aspects des objectifs du 4e RPS ont été étudiés. En particulier:

Nous avons examiné les événements antérieurs significatifs pour la sûreté dans les centrales nucléaires françaises. Une attention particulière a été portée aux événements liés au vieillissement. En examinant ces événements, nous avons cherché à savoir s'ils évoluaient dans le temps et de quelle manière, et quelles actions avaient été entreprises par EDF pour réduire le nombre de ces événements. De cette analyse, nous avons tiré des recommandations pour l'exploitation au-delà de 40 ans des réacteurs français de 1300 MWe.

L'Association des autorités de sûreté nucléaire des pays d'Europe de l'Ouest, la « WENRA », a publié des « Niveaux de référence » pour les réacteurs existants (2014, 2021). Ces Niveaux de référence sont contraignants pour les réacteurs français. Nous avons résumé les exigences réglementaires françaises pertinentes et comparé ces exigences nationales avec les exigences clés de la WENRA. Les investigations et les mesures qui devraient être effectuées dans le cadre des RPS ont été comparées aux exigences correspondantes de la WENRA. En outre, les aléas de référence retenus pour les réacteurs de 1300 MW et les mesures de protection déjà prises et planifiées ont été analysés. Cette analyse, qui s'inscrit dans le champ d'application du premier objectif des RPS, a permis de formuler une nouvelle série de recommandations.

Enfin, nous avons systématiquement comparé les objectifs et la démarche de sûreté appliqués aux réacteurs de 1300 MW, après les travaux de modernisation prévus dans le cadre du 4e RPS, avec les objectifs et la démarche de sûreté appliqués l'EPR. Cela a été fait pour les systèmes et dispositifs de sûreté installés en lien avec les accidents de référence ainsi que pour les équipements importants pour la sûreté et nécessaires à la gestion des conditions d'accident correspondant au domaine étendu (avec et sans fusion du cœur). Il a ensuite été analysé en quoi le concept de sûreté pour 1300 MWe et le concept de sûreté de l'EPR-Flamanville diffèrent l'un de l'autre. L'analyse a débouché sur une série de recommandations pour le champ d'application du deuxième objectif du RPS.

Résultats – premier objectif du RPS : **Séismes :** Dans le cadre du premier objectif des RPS, soit la vérification de la conformité des installations avec les exigences de sûreté applicables, notre analyse a montré qu'en ce qui concerne les séismes, les exigences réglementaires pour l'évaluation des risques naturels ne sont pas entièrement conformes aux Niveaux de référence et aux préconisations de la WENRA. Pour les tremblements de terre, la France a suivi une approche déterministe pour définir les paramètres de référence, tandis que la WENRA exige des définitions d'événements de référence pour une probabilité d'occurrence de 10-4 par an. La définition du « Séisme de référence » (DBE) sur la base de méthodes déterministes ne correspond plus à l'état de la technique.

En ce qui concerne les aléas externes, l'ASN stipule que les définitions des événements de référence et des conditions d'extension de conception doivent suivre les exigences fixées par la WENRA. La principale implication de l'objectif en ce qui concerne les séismes est que les approches déterministes pour l'évaluation des risques, qui sont les standards français actuels, doivent être complétées par une évaluation probabiliste des aléas sismiques (PSHA). Cependant, les spécifications de l'ASN pour le 4e RPS ne précisent pas suffisamment si un PSHA doit conduire à la définition de nouveaux paramètres de référence et, par conséquent, à une mise à jour des exigences en matière de protection des sites.

Les approches précédentes de PSHA pour définir les DBE en accord avec WENRA ont fait l'objet de discussions approfondies entre EDF, l'IRSN et l'ASN dans le passé. Apparemment, EDF a choisi à plusieurs reprises des paramètres, des modèles et des hypothèses conduisant à des valeurs de danger trop faibles, et il n'est pas certain que les DBE calculés de manière déterministe pour tous les sites puissent se justifier par rapport aux DBE calculés par PSHA avec des probabilités d'occurrence de 10-4 par an. Le 4e RPS doit donc être l'occasion de réactualiser la PSHA pour tous les sites de 1300 MWe, d'actualiser le dimensionnement sismique en conséquence et de mettre en œuvre des mesures de protection conservatrice vis-à-vis des DBE réactualisées. Il en va de même pour la conception du noyau de sécurité renforcé (HSC), censé résister à un tremblement de terre vieux de 20 000 ans.

Inondations : Suite à l'inondation de la centrale nucléaire du Blayais, l'ASN a publié en 2013 son nouveau Guide n°13 (ASN 2013g) qui traite du risque d'inondation externe. Il a été élaboré entre 2005 et 2012 et doit désormais être considéré comme obsolète. Le guide ne tient pas compte des documents de la WENRA élaborés après l'accident de Fukushima. Les règles ne sont pas entièrement alignées à celles de la WENRA (2014 ; 2021).

Une partie du 4e RPS consiste à vérifier si l'étanchéité, qui est un élément clé de la protection volumétrique (VP), n'est pas affectée sur les différentes implantations, démontrant ainsi que les inondations provoquées par les séismes n'ont pas d'impact sur la sûreté. À cette fin, il est très important que la puissance des tremblements de terre potentiels ait été déterminée avec suffisamment de certitude. Comme nous l'avons déjà expliqué plus haut, dans la section « Séismes », ce n'est pas le cas. En outre, d'autres éléments de la VP doivent faire l'objet d'une vérification approfondie. Étant donné que la protection contre les inondations extrêmes externes repose essentiellement sur la VP et que, par ailleurs, des lacunes considérables ont été constatées à ce jour dans la mise en œuvre et l'analyse de la VP, des analyses approfondies et des contrôles de conformité devraient être effectués dans le cadre du 4e RPS.

Risques industriels : Le réexamen des risques industriels dans le cadre du 4e RPS ne devrait apparemment être effectué qu'après les contrôles du 4e RPS. Le réexamen des risques liés aux crashs accidentels d'avions reste limité. Il est recommandé de procéder à un réexamen approprié, en termes de champ d'application et de calendrier, des risques liés à l'activité humaine dans le cadre du 4e RPS. Toutes les inspections et les améliorations qui en découlent doivent être effectuées pendant la période d'arrêt prévue au titre du RPS.

La protection contre les impacts extrêmes externes, en particulier les scénarios de crash d'avion, ne correspond pas à l'état de la technique comme dans les EPR. En l'état actuel des connaissances, le crash délibéré d'un avion sur une centrale nucléaire ne peut être exclu. Ces scénarios ne sont généralement pas couverts par l'approche probabiliste utilisée pour la conception des réacteurs de 1300 MWe. Les bâtiments abritant les piscines de stockage de combustible épuisé sont un point faible des réacteurs français et l'ASN a conclu que cette lacune subsistera de toute façon vis-à-vis des centrales de nouvelle génération. L'évacuation de la chaleur résiduelle du cœur du réacteur et de la piscine de désactivation du combustible doit également être assurée en cas de crash d'un avion commercial. L'attaque de la Russie contre l'Ukraine a donné lieu à des scénarios qui, auparavant, n'étaient guère considérés comme réalistes. Le nouveau besoin de protection résultant de la situation de guerre en Ukraine en termes d'armes utilisées et de scénarios d'attaque devrait également être pris en compte dans le cadre du 4e RPS.

Résultats – deuxième objectif du RPS :

Le deuxième objectif du quatrième réexamen périodique de sûreté (RPS) du parc français de réacteurs de 1300 MW (réacteurs P4 et P'4) est de faire évoluer ces réacteurs pour les amener à un niveau de sûreté correspondant à la pointe des savoir-faire et des technologies disponibles. La référence ici est le réacteur EPR de Flamanville, dont le chargement en combustible a récemment commencé. En particulier après l'accident de Fukushima, des modifications importantes ont été apportées pour accroître la résistance des réacteurs aux risques naturels et aux accidents graves.

Pour les accidents de référence, les dispositifs de sûreté du réacteur de 1300 MW suivent un concept de sûreté n+1, ce qui signifie que le degré de redondance est tel qu'il est tolérable qu'un système de sûreté tombe en panne. En général, cela est mis en œuvre par deux trains indépendants de systèmes de sûreté, chacun capable de remplir la fonction de sécurité (concept de sûreté à 2x100 %). L'EPR, en revanche, possède quatre trains de chaque système de sûreté avec une redondance de 4x100%, un concept de sûreté (n+3). Même si trois trains tombent en panne pour diverses raisons, le dernier train peut assurer la totalité des fonctions de sauvegarde. Pour l'EPR, une coque résistante aux crashs d'avion recouvre le bâtiment du réacteur, le bâtiment combustible et deux bâtiments abritant deux trains de sauvegarde ; des dispositions pour la prévention d'accidents graves sont intégrées dès le stade de la conception.

La comparaison des différents aspects qui affectent la sûreté des réacteurs de 1300 MWe et de l'EPR fait ressortir les points suivants :

- L'EPR dispose d'un système de stabilisation de la fusion du cœur (corium) afin d'éviter une défaillance du confinement en cas d'accident grave. En raison de l'espace limité sous le cœur des anciens réacteurs, il n'est pas possible de réaménager ce que l'on appelle un « récupérateur de corium » à l'identique. EDF affirme que les dispositions mises en œuvre dans la série des réacteurs de 1300 MWe sont en principe similaires, mais elles reposent sur le refroidissement du corium par le haut, par inondation. Les efforts de recherche et de développement visant à démontrer que cela est possible (LICHT 2023) sont toujours en cours et n'ont pas encore donné de résultats convaincants.

- Le nombre total de sources indépendantes d'électricité de secours présentes dans le réacteur est à peu près le même pour l'EPR que pour les réacteurs de 1300 MWe post-renforcement. Toutefois, pour les réacteurs de 1300 MWe, seuls deux systèmes répondent aux exigences renforcées en matière de systèmes de sécurité (n+1), alors que c'est le cas pour quatre systèmes dans l'EPR (n+3).
- Les centrales nucléaires sont conçues pour disposer de systèmes de sûreté redondants et diversifiés afin de garantir l'exécution des fonctions essentielles de sûreté. Les systèmes de sûreté des réacteurs de 1300 MW comportent deux trains de sauvegarde. Si l'un de ces trains tombe en panne, l'autre train peut remplir les fonctions de sécurité nécessaires (critère de défaillance simple). Les systèmes de sûreté de l'EPR se composent de quatre trains. Le rééquipement des réacteurs de 1300 MWe ne semble pas tenir compte de la redondance et de la diversité des systèmes de sûreté de niveau 3 qui prennent en compte les accidents de référence.
- La Force d'Action Rapide du Nucléaire (FARN) est présente sur différents sites nucléaires en France et est censée être sur place en cas d'urgence dans les 24 heures, et ses systèmes mobiles doivent être opérationnels dans les 36 heures. La FARN apporte sa contribution dans le cadre des conditions complémentaires pour les situations de catégorie 4 mises en œuvre pour prévenir et atténuer les accidents graves. On ne doit pas valoriser ces systèmes importants pour la sûreté pour compenser les déficiences au niveau des situations de catégorie 3.
- Le noyau dur renforcé accroît la résistance du parc de réacteurs de 1300 MW aux aléas externes comme les séismes et les inondations. La conception antisismique et anti-inondation de l'EPR repose sur des exigences beaucoup plus strictes.

Sur la base des informations disponibles, on peut affirmer qu'il n'est pas possible d'augmenter le niveau de sûreté du parc de réacteurs de 1300 MW pour qu'il corresponde à l'état de l'art tel que représenté par l'EPR. Il convient toutefois de souligner que des améliorations significatives ont été apportées grâce aux travaux de modernisation par rapport à la conception d'origine.

Résultats – troisième objectif du RPS :

Noyau de sécurité renforcé : Le troisième objectif de sûreté du 4e RPS, à savoir la mise en œuvre de toutes les dispositions du noyau dur, a été examiné. La conclusion qui en a été tirée est que la mise en œuvre du « noyau dur » sur les sites de 1300 MWe n'est pas encore achevée à ce jour et ne sera probablement pas entièrement mise en œuvre avant le début du 4e RPS. En outre, il n'est pas certain que la conception de l'HSC pour faire face aux inondations tienne suffisamment compte des effets du changement climatique.

Le rapport de risque soutenant le rapport de sécurité

L'un des objectifs du 4e RPS est de rapprocher le niveau de sûreté des centrales de 1300 MWe de l'état actuel de la technique. Cependant, cet objectif n'est pas assorti de cibles précises : il n'existe aucune obligation d'atteindre le niveau de sûreté des centrales nucléaires les plus modernes (comme l'EPR), ni même de règlement prescrivant jusqu'où relever les niveaux de sûreté des centrales de 1300 MWe.

L'analyse permet de conclure qu'il existe encore une lacune importante, notamment au niveau des systèmes de sûreté liés aux accidents de référence, en termes de redondance et de diversité. Cela signifie que toutes les centrales nucléaires en France ne fonctionneront pas selon les standards de sûreté nucléaire les plus élevés. Des différences subsisteront entre les centrales nucléaires à durée de vie prolongée, qui sont autorisées à fonctionner selon des exigences inférieures, et les nouveaux réacteurs, dont le permis de construire a été délivré après 2014 (Directive 2014/87/Euratom sur la sûreté nucléaire), qui seront conçus, construits et exploités selon des normes plus strictes. Par conséquent, les 1300 MWe représenteront un risque plus élevé d'accidents graves et d'émissions importantes que les centrales nucléaires de génération III les plus modernes.

Dans un souci de transparence, l'ASN et EDF devraient fournir des informations sur ces risques résiduels dans le cadre du processus de consultation afin de permettre aux décideurs et au public de se prononcer en toute connaissance de cause sur l'opportunité de privilégier une extension de la durée de vie. Ce rapport sur les risques devrait compléter l'analyse de sûreté et comprendrait deux éléments principaux : premièrement, une comparaison complète de la conception de 1300 MWe et de la conception de réacteurs de type EPR. Deuxièmement, sur la base des écarts, une analyse des risques mettrait en évidence les séquences d'accidents éliminées par la conception de l'EPR, mais qui restent possibles dans les réacteurs de 1300 MWe.

Une décision éclairée nécessite non seulement des informations sur la conformité des réacteurs de 1300 MW avec la réglementation en vigueur, mais aussi des informations sur les risques qui pèseront encore sur les populations en France et à l'étranger pendant la durée d'exploitation prolongée du parc de 1300 MWe.

ZUSAMMENFASSUNG

In den nächsten Jahren werden in Frankreich die zwanzig Reaktoren der Baureihe mit einer installierten Leistung von 1300 MWe die vierzig Jahre ihrer Betriebsdauer, das Ende der geplanten Lebensdauer, erreichen. Deren Betreiber, EDF, beabsichtigt die Lebensdauer dieser Kraftwerke zu verlängern.

In einigen Ländern, darunter Frankreich, werden zeitlich unbeschränkte Betriebsgenehmigungen erteilt, wobei mindestens alle zehn Jahre eine Periodische Sicherheitsüberprüfung (PSÜ) durchzuführen ist. Sobald in Frankreich die geplante Lebensdauer erreicht wurde und der Betreiber eines Kernkraftwerks eine Verlängerung der Betriebsdauer darüber hinaus plant, ist eine umfangreiche Neubewertung des Kraftwerkszustands im Rahmen der vierten PSÜ notwendig.

Ein wichtiger Aspekt bei der Verlängerung der ursprünglichen Lebensdauer eines Kernkraftwerks wird als die “Obsoleszenz von Vorschriften, Codes und Standards” bezeichnet. Ein Kernkraftwerk wird gemäß den Vorschriften errichtet, die zur Errichtungszeit gelten. Doch insbesondere im Bereich der nuklearen Sicherheit kam es in den vergangenen vierzig Jahren zu einem beträchtlichen Anstieg an Wissen über Risiken und Unfälle. Die Erkenntnisse, die aus den Unfällen von Three Mile Island, Tschernobyl und Fukushima gewonnen wurden, führten sowohl bei den Vorschriften als auch dem Stand der Technik zu einer Erhöhung des Sicherheitsniveaus.

Zusätzlich zum erweiterten Umfang der 4. PSÜ gegenüber den vorherigen PSÜs, führt das französische High Committee for Transparency and Information on Nuclear Safety (HCTISN) ein öffentliches Konsultationsverfahren durch, bei dem Stellungnahmen zur generischen Phase der 4. PSÜ abgegeben werden können, die die Themen abdecken, welche für alle 1300 MWe-Reaktoren von Bedeutung sind.

Im Falle eines schweren Unfalls in einem französischen KKW können signifikante Auswirkungen auf Österreich nicht ausgeschlossen werden. Daher beteiligt sich Österreich an dieser Konsultation und übermittelt den vorliegenden Bericht.

Die reaktorspezifische Phase zu den einzelnen zwanzig Reaktoren wird im nächsten Schritt folgen. Für die aktuelle generische Phase haben die französische Aufsichtsbehörde ASN und der Energieversorger EDF unter anderem die folgenden Ziele für die 4. PSÜ vereinbart (ASN2019a):

1. Verifizierung der Übereinstimmung der Anlagen mit den anzuwendenden Sicherheitsanforderungen.
2. Als Teil der kontinuierlichen Sicherheitsverbesserung sollen die 1300 MWe-Reaktoren an die Sicherheitsziele für die 3. Reaktorgeneration herangeführt werden, wobei der EPR Flamanville 3 als Referenz dient.
3. Umsetzung aller Maßnahmen für das “Hardened Safety Core”, wie von der ASN vorgeschrieben.

Für das Konsultationsverfahren wurden substantielle Informationen zur Verfügung gestellt, als Wesentlichste anzuführen ist das Dokument "Note de Réponse aux Objectifs du 4 ème Réexamen Périodique du Palier 1300 MWe" (EDF 2023a), das darlegt, wie EDF beabsichtigt,s diese Ziele zu erreichen.

Methode: Der vorliegende Bericht liefert ein Expert:innengutachten im Konsultationsverfahren. Ausgewählte Aspekte der Ziele der 4. PSÜ wurden untersucht, insbesondere:

Untersucht wurden die sicherheitsrelevanten Ereignisse in französischen Kernkraftwerken in der Vergangenheit. Besondere Aufmerksamkeit wurde Ereignissen geschenkt, die einen Alterungsbezug aufweisen. Bei dieser Untergruppe wurde untersucht, ob und wie sich diese Ereignisse im Laufe der Zeit verändert haben und was von EDF unternommen wurde, um die Zahl solcher Ereignisse zu reduzieren. Aus dieser Analyse wurden Empfehlungen für den Betrieb der französischen 1300 MWe-Reaktoren über die ersten 40 Betriebsjahre hinaus abgeleitet.

Die WENRA (Western European Nuclear Regulators Association) veröffentlichte Referenzlevels für bestehende Reaktoren (2014, 2021). Diese Referenzlevels sind für die französischen Reaktoren verbindlich. Dazu wurden die relevanten französischen regulatorischen Anforderungen zusammengefasst und dann mit den wichtigsten WENRA-Anforderungen verglichen. Die Untersuchungen und Maßnahmen, die im Rahmen der PSÜ durchgeführt werden, wurden mit den entsprechenden WENRA-Anforderungen verglichen. Ebenso analysiert wurden die Auslegungsgefährdungen für die 1300 MWe-Reaktoren und die bereits durchgeführten und geplanten Schutzmaßnahmen. Aus dieser Analyse innerhalb des Umfangs des ersten PSÜ-Zieles wurde eine Reihe von Empfehlungen abgeleitet.

Schließlich wurde das Sicherheitskonzept der 1300-MWe Reaktoren nach den geplanten Nachrüstmaßnahmen im Rahmen der 4. PSÜ systematisch mit dem EPR-Sicherheitskonzept verglichen. Einerseits wurde dies für die Sicherheitssysteme untersucht, die für die Auslegungsunfälle installiert sind, wie auch für die Anlagen mit Sicherheitsrelevanz, die beim Management der erweiterten Auslegungsbedingungen DEC (mit und ohne Kernschmelze) benötigt werden. Dann wurde betrachtet, wie weit sich die Sicherheitskonzepte der 1300 MWe-Reaktoren und des EPR Flamanville voneinander unterscheiden. Diese Analyse mündete in ein abschließendes Set von Empfehlungen innerhalb des Umfangs für das zweite PSÜ-Ziel.

Resultate: Erstes Ziel der PSÜ **Erdbeben:** Im Rahmen des ersten PSR-Ziels, der Überprüfung der Konformität der Anlagen mit den geltenden Sicherheitsanforderungen, zeigte die Analyse für Erdbeben, dass die Anforderungen der Aufsicht zur Bewertung von Naturgefahren nicht vollständig den Referenzlevels und Richtlinien der WENRA entsprechen. Bei der Festlegung der Auslegungsparameter für Erdbeben verfolgt Frankreich einen deterministischen Zugang, während WENRA die Definition von Auslegungsereignissen für die Eintrittshäufigkeit von 10-4 pro Jahr fordert. Die Festlegung von Auslegungserdbeben (DBE) mit deterministischen Methoden entspricht nicht mehr dem Stand der Technik.

Für die externen Gefährdungen sieht ASN vor, dass die Festlegung der Auslegungsereignisse und erweiterten Auslegungsbedingungen gemäß den WENRA-Anforderungen erfolgt. Die wichtigste Implikation für das Ziel Erdbeben besteht darin, dass die deterministischen Ansätze für die Risikoberechnung, wie sie aktuell französischer Standard ist, durch eine Probabilistische Seismische Risikoanalyse (PSHA) zu ergänzen ist. Die Vorgaben der ASN für die 4. PSÜ stellen allerdings nicht ausreichend klar, ob eine PSHA zur Definition von neuen Auslegungsparametern und in Folge zu aktualisierten Anforderungen an den Schutz des Kraftwerks führen soll.

Frühere PSHA-Ansätze für die Festlegung von Auslegungsbeben (DBE) gemäß WENRA-Vorgaben wurden zwischen EDF, IRSN und ASN ausführlich diskutiert. EDF scheint wiederholt Parameter, Modelle und Annahmen angewendet zu haben, die zu einer Unterschätzung der Gefährdungswerte geführt haben und es ist unklar, ob die deterministisch abgeleiteten DBE für alle Standorte gegenüber den von PSHA abgeleiteten DBE mit einer Wahrscheinlichkeit von 10-4 pro Jahr verteidigt werden können. Die PSÜ4 sollte daher für die Anwendung von PSHA auf dem neuesten Stand für alle 1300 MWe-Standorte genutzt werden, wie auch für eine Aktualisierung der seismischen Auslegung und die Realisierung von Maßnahmen, um einen konservativen Schutz gegen die aktualisierten DBE sicherzustellen. Dasselbe gilt für das Design des Hardened Safety Core, das einem 20 000-jährigen Erdbeben standhalten soll.

Überflutung: Als Reaktion auf die Überflutung von Blayais veröffentlichte die ASN 2013 den neuen Leitfaden Nr. 13 (ASN 2013g), der die Risiken einer externen Überflutung behandelt. Er wurde zwischen 2005-2012 entwickelt und ist heute als veraltet zu betrachten. Dieser Leitfaden berücksichtigt die relevanten WENRA-Dokumente nicht ausreichend, die zu diesem Thema nach dem Fukushima-Unfall ausgearbeitet wurden und erfüllte daher die WENRA-Vorgaben (2014; 2021) nur unzureichend.

Ein Teil der 4. PSÜ für die 1300 MWe-Reaktoren besteht in der Überprüfung, ob die Wassersperren, als Schlüsselelemente des Volumetrischen Schutzes, nicht von unterschiedlichen Ablagerungen beeinträchtigt werden, um nachzuweisen, dass die Erdbeben-induzierte Überflutung keine Auswirkungen auf die Sicherheit hat. Zu diesem Zwecke ist es wichtig, dass die Stärke der potentiell eintretenden Erdbeben mit ausreichender Sicherheit bestimmt werden. Wie bereits im Absatz zu Erdbeben erwähnt, ist dies nicht der Fall. Darüber hinaus müssen auch weitere Elemente des Volumetrischen Schutzes umfassend überprüft werden. Da der Schutz gegen extreme externe Überflutung im Wesentlichen auf dem Volumetrischen Schutz basiert und bei der Implementierung und Analyse eben jenes Schutzes deutliche Defizite zu verzeichnen sind, sollten umfassende Analysen und Konformitätsprüfungen als Teil der 4. PSÜ durchzuführen.

Menschengemachte Gefahren: Die Neubewertung der menschengemachten Gefahren soll offensichtlich erst nach den Inspektionen der 4. PSÜ durchgeführt werden. Die Risiken im Zusammenhang mit einem unabsichtlichen Flugzeugabsturz sind nur in einem eingeschränkten Ausmaß neu zu prüfen. Es wird empfohlen, die Neubewertung von menschengemachten Gefährdungen als Teil der 4. PSÜ in Umfang und Zeitplan adäquat durchzuführen. Alle Inspektionen und sämtliche resultierenden Nachrüstungen sollten während der Abschaltperiode durchgeführt werden.

Der Schutz gegen extreme äußere Einwirkungen, insbesondere gegen einen Flugzeugabsturz, entspricht nicht dem Stand der Technik, wie er im EPR umgesetzt ist. Basierend auf dem aktuellen Kenntnisstand kann ein beabsichtigter Absturz eines Flugzeugs auf ein KKW nicht ausgeschlossen werden. Solche Szenarien werden allgemein nicht durch probabilistischen Ansatz abgedeckt, der für das Design der 1300 MWe-Reaktoren verwendet wurde. Die Gebäude für die Abklingbecken der abgebrannten Brennstäbe sind bei den französischen Reaktoren als Schwachstellen zu betrachten und die ASN hat festgehalten, dass ein Defizit im Vergleich zu den Reaktoren der nächsten Generation bestehen bleiben wird. Die Restwärmabfuhr aus dem Reaktorkern und dem Abklingbecken muss auch im Falle eines Absturzes eines Verkehrsflugzeugs gesichert bleiben. Der russische Angriff auf die Ukraine hat zu Szenarien geführt, die bisher als kaum realistisch betrachtet werden konnten. Der aus der Kriegssituation in der Ukraine nun neu entstandene Schutzbedarf betreffend verwendeter Waffen und Angriffsszenarien sollte im Rahmen der 4. PSÜ berücksichtigt werden.

Resultate: Zweites Ziel der PSÜ

Das zweite Ziel der 4. PSÜ für die französischen 1300 MWe-Reaktoren (P4 und P'4 Reaktoren) ist das Bestreben, diese Reaktoren auf den Stand der Technik zu bringen. Als Referenz dient hier der EPR in Flamanville, bei dem die Brennstoffbeladung vor kurzem begonnen hat. Insbesondere nach dem Unfall in Fukushima wurden signifikante Modifikationen durchgeführt, um die Widerstandsfähigkeit der Reaktoren gegen natürliche Gefährdungen und schwere Unfälle zu erhöhen.

Für Auslegungsstörfälle folgen die Schutzsysteme der 1300 MWe-Reaktoren einem n+1 Sicherheitskonzept, d.h. die Redundanz ist so bestimmt, dass ein Sicherheitssystem ausfallen kann. Im Allgemeinen wird dies durch zwei unabhängige Stränge an Sicherheitssystemen erreicht, wobei jeder einzelne die Sicherheitsfunktion erfüllt (2x100% Sicherheitskonzept). Beim EPR hingegen bringen vier Stränge jedes Sicherheitssystem eine 4x100% Redundanz, d.h. es handelt sich um ein (n+3) Sicherheitskonzept. Selbst beim Versagen von drei Strängen aus verschiedenen Gründen, steht der letzte Strang zur Erfüllung der Sicherheitsfunktion zur Verfügung. Beim EPR sind der Reaktor, das Brennstoffgebäude und zwei Gebäude mit technischen Sicherheitssträngen mit einer Hülle abgedeckt, die gegen einen Flugzeugabsturz gesichert ist. Vorkehrungen zur Verhinderung von schweren Unfallbedingungen sind von der Designphase an integriert worden.

Der Vergleich der sicherheitsrelevanten Aspekte des 1300-MWe mit dem EPR-Reaktor zeigt folgende wesentlichen Punkte:

- Der EPR verfügt über ein System zur Stabilisierung der Kernschmelze (Corium), welches ein Containmentversagen im Falle von schweren Unfällen verhindert. Aufgrund von Platzbeschränkungen in den alten Reaktoren ist ein nachträglicher Einbau eines sogenannten Core Catchers nicht möglich. EDF behauptet zwar, dass die Vorkehrungen in den 1300 MWe-Reaktoren im Prinzip ähnlich wären, doch diese kühlen das Corium durch Flutung von oben. Forschung und Entwicklung zum Nachweis, dass dies möglich sei (LICHT 2023), sind noch nicht abgeschlossen und haben bisher keine überzeugenden Ergebnisse erbracht.

- Die Gesamtanzahl an unabhängigen Notstromquellen für den Reaktor entspricht bei den nachgerüsteten 1300 MWe-Reaktoren etwa denen im EPR, doch beim 1300-MWe Reaktor erfüllen nur zwei Systeme die strengeren Anforderungen für Sicherheitssysteme (n+1), während dies beim EPR für vier Systeme gilt (n+3).
- Kernkraftwerke sind so ausgelegt, dass die redundanten und diversen Sicherheitssysteme die wesentlichen Sicherheitsfunktionen leisten können. Die Sicherheitssysteme der 1300 MWe-Reaktoren bestehen aus zwei Strängen. Wenn einer dieser Stränge ausfällt, dann soll der andere Strang die benötigte Sicherheitsfunktion erfüllen (Einzelfehlerkriterium). Die Sicherheitssysteme des EPR verfügen über vier Stränge. Die Nachrüstung der 1300 MW-Reaktoren scheint die Redundanz und Diversität der Level 3 Sicherheitssysteme für die Auslegungsstörfälle nicht ausreichend zu behandeln.
- Die Nukleare Eingreiftruppe (FARN) ist bei verschiedenen KKW in ganz Frankreich angesiedelt und soll in Notsituationen innerhalb von 24 Stunden am Standort sein, die mobilen Systeme sollten innerhalb von 36 Stunden einsatzbereit sein. FARN bietet Unterstützung bei erweiterten Designbedingungen (DEC) auf Sicherheitslevel 4, das zur Verhinderung und Minderung von schweren Unfällen dient. Diese sicherheitsrelevanten Systeme dürfen jedoch nicht zur Kompensation von bestehenden Mängeln auf Sicherheitslevel 3 herangezogen werden.
- Das Hardened Safety Core erhöht die Widerstandsfähigkeit der 1300 MW-Reaktoren gegen externe Gefährdungen wie Erdbeben und Überflutungen. Das EPR-Design gegen Erdbeben und Überflutungen basiert auf wesentlich strengeren Anforderungen.

Aus der zur Verfügung stehenden Information kann man schließen, dass es nicht möglich ist, das Sicherheitsniveau der 1300 MWe-Reaktoren auf den Stand der Technik anzuheben. Es sollte allerdings betont werden, dass bei der Nachrüstung des ursprünglichen Designs Verbesserungen erzielt wurden.

Resultate: Drittes Ziel der PSÜ

Hardened Safety Core: Das dritte Sicherheitsziel der 4. PSÜ, nämlich die Umsetzung aller Maßnahmen des Hardened Safety Core, wurde untersucht und festgestellt, dass diese Maßnahmen an den 1300-MWe Reaktorstandorten noch nicht abgeschlossen wurden und vor Beginn der 4. PSÜ wohl nicht vollständig abgeschlossen sein werden. Darüber hinaus bestehen Zweifel, ob die Auslegung des Hardened Safety Core gegen Überflutungsereignisse die Effekte des Klimawandels ausreichend berücksichtigt hat.

Risikobericht zur Unterstützung des Sicherheitsberichts

Eines der Ziele für die PSÜ liegt darin, das Sicherheitsniveau der 1300 MWe Reaktoren auf den Stand der Technik zu bringen, wobei eine klar messbaren Zielsetzung fehlt: Es gibt keine Anforderung, die festlegen würde, dass die 1300 MW-Reaktoren das Sicherheitsniveau auf dem Stand der Technik (wie etwa der EPR) zu erreichen hätten. Es liegt nicht einmal eine Regelung vor, die festlegen würde, wie weit das Sicherheitsniveau der 1300 MWe-Reaktoren angehoben werden soll.

Die Analyse erlaubt die Schlussfolgerung, dass, insbesondere auf der Ebene der Sicherheitssysteme mit Bezug zu Auslegungsstörfällen, bei Redundanz und Diversität eine deutliche Lücke weiterbestehen wird. Das bedeutet, dass in Frankreich nicht alle Kernkraftwerke gemäß den höchsten Standards der nuklearen Sicherheit betrieben werden. Es wird einen Unterschied geben zwischen KKW mit verlängerter Betriebsdauer, die nach niedrigeren Anforderungen betrieben werden dürfen, und den neuen Reaktoren mit einer nach 2014 erteilten Baugenehmigung (Richtlinie 2014/87/Euratom über nukleare Sicherheit), die nach höheren Standards geplant, gebaut und betrieben werden müssen. Daher werden die 1300 MWe-Reaktoren ein höheres Risiko für schwere Unfälle und große Freisetzungen mit sich bringen als Kraftwerke der Generation III, die dem Stand der Technik entsprechen.

Im Sinne einer vollen Transparenz sollten ASN und EDF über diese weiterhin bestehenden Risiken im Rahmen des Konsultationsverfahrens informieren, damit Entscheidungsträger und Öffentlichkeit eine informierte Entscheidung darüber treffen können, ob der Lebensdauerverlängerung der Vorzug zu geben ist. Solch ein Risikobericht würde die Sicherheitsanalyse ergänzen und sollte zwei wesentliche Elemente beinhalten – erstens einen umfassenden Vergleich des Designs der 1300 MWe-Reaktoren und des EPR. Zweitens könnte, basierend auf den Lücken, eine Risikoanalyse diejenigen Unfallabläufe aufzeigen, die durch das EPR-Sicherheitskonzept ausgeschlossen sein sollen, aber bei den 1300 MWe-Reaktoren noch möglich sind.

Eine informierte Entscheidung benötigt nicht nur Informationen über die Erfüllung der aktuellen Regelungen durch die 1300 MWe-Reaktoren, sondern auch Informationen über die Risiken, die die Lebensdauerverlängerung der 1300 MWe-Flotte für die Menschen in Frankreich und im Ausland bedeutet.

1 INTRODUCTION

In France, 56 nuclear power plants (NPPs) are in operation, including 20 1300 MWe reactors that will soon reach or have already reached 40 years of operation. A periodic safety review (PSR) must be carried out every ten years to ensure continued operation.

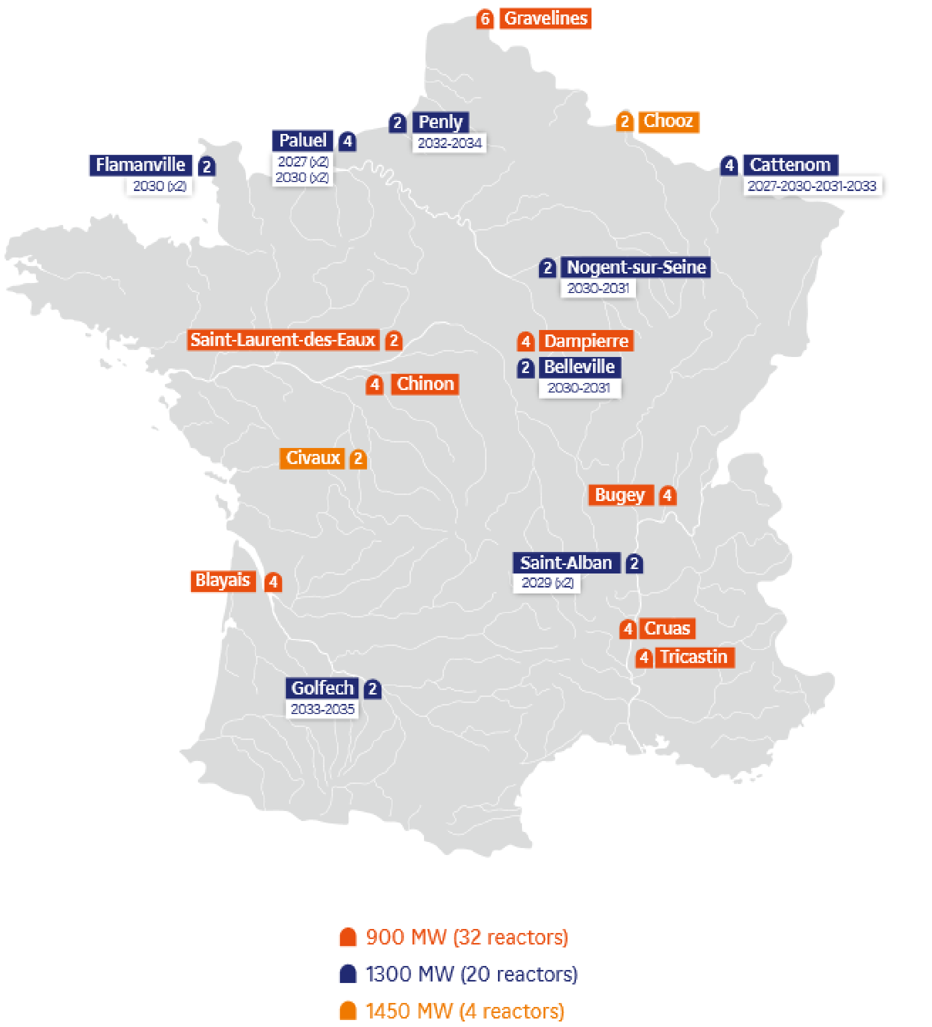
The French High Committee for Transparency and Information on Nuclear Safety (HCTISN) is organizing a consultation on the generic phase of the PSR4 of the 1300 MWe reactors. In case of a severe accident in a French NPP, significant impacts on Austria cannot be excluded. Therefore Austria is participating in this consultation.

The following table lists the French 1300 MWe reactors and shows the start of operation and the planned dates of the reactor-specific PSR4.

Table 1: List of 1300 MWe reactors in France in operation (Source: ASN 2024a)

1300 MWe site	Unit no.	Start of operation	PSR
Cattenom	1	1986-10-24	2027
Paluel	1	1984-05-13	2027
Paluel	2	1984-08-11	2027
Saint-Alban	1	1985-08-04	2029
Saint-Alban	2	1986-06-07	2029
Cattenom	2	1987-08-07	2030
Paluel	3	1985-08-07	2030
Paluel	4	1986-03-29	2030
Belleville-sur-Loire	2	1988-08-25	2030
Flamanville	1	1985-09-29	2030
Flamanville	2	1986-06-12	2030
Nogent-sur-Seine	1	1987-09-12	2030
Nogent-sur-Seine	2	1988-10-04	2030
Cattenom	3	1990-02-16	2031
Belleville-sur-Loire	1	1987-09-09	2031
Penly	1	1990-04-01	2031
Cattenom	4	1991-05-04	2033
Golfech	1	1990-04-24	2033
Penly	2	1992-01-10	2034
Golfech	2	1993-05-21	2035

Figure 1: Nuclear power plants in France. Dates of sending 1300 MWe reactors PSR4 conclusion reports.



Source: EDF (2023b, p. 5)

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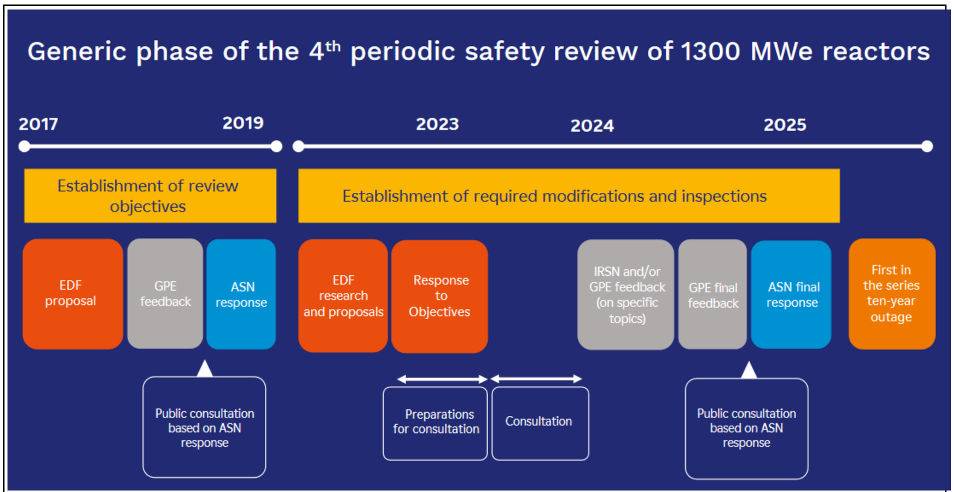
The operating license for French nuclear power plants is unlimited, but a PSR must be carried out every ten years to ensure continued operation. The fourth PSR that is now being carried out is of particular importance, as the original design of the reactors is only designed for a service life of 40 years.

Contents and objectives of the PSR4 are defined on the basis of a dossier by EDF (2017) which was sanctioned and amended by ASN (2019a). In 2023, EDF filed its "Note de réponse aux objectifs" (NRO) (EDF 2023a) presenting its responses to the objectives, together with a summary of the methods used and the main results known to date for each topic covered, on a generic level for all of the concerned reactors (apart from a few topics only applying to specific sites or units).[1]

The PSR4 is planned to be carried out in two phases (ASN 2019a): first, a generic PSR phase covering subjects common to all 1300 MWe reactors; and second, a specific PSR phase, which will focus on each reactor individually (2027-2035).

The following figure gives an overview of the procedure.

Figure 2: Overview of the different steps in the generic phase of the PSR4. GPE = ASN's Advisory Board of Experts



Source: EDF (2023b, p. 4)

The French High Committee for Transparency and Information on Nuclear Safety (HCTISN) is organizing a consultation on the generic phase of the PSR4 of the 1300 MWe reactors. The consultation was announced to be open for the public from 18 January until 30 June 2024, but recently it has been extended until after the planned elections in France, most probably to early autumn 2024[2].

Furthermore, Austria intends to participate in the second public consultation based on the ASN response that is foreseen in 2025.

In its summary of the NRO, EDF declares: "For the 4th periodic safety review of its 1300 MWe reactor fleet, EDF's general policy is to aim for the nuclear safety objectives that have been set for the 3rd generation reactors which include

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[1] Note: The summary of the NRO is published in French (EDF 2023c) and an official English translation (EDF 2023b). A translation error seems to have occurred. While the first Paragraph of the Annex of the document reads in the French version "La figure cidessous schématise une installation nucléaire du palier 1300 MWe avec les principales modifications, intégrées **en amont ou au cours** du 4e réexamen périodique, qui permettent de répondre aux objectifs du RP4 1300", the English version reads "The diagram shown below depicts a 1300-MWe nuclear plant with the main modifications **having been implemented before the 4th periodic safety review**, in order to meet the objectives of 4PR 1300". However, the modifications shown are not likely to be implemented before the 4th PSR.

[2] http://www.hctisn.fr/la-concertation-publique-sur-les-reacteurs-de-1-a362.html?lang=fr, seen 20-06-2024

EDF's standard-beared, the Flamanville-3 EPR." (EDF 2023b) This general objective is further translated into four main safety-related topics:

1. Accidents without core-melt
2. Hazards
3. Spent fuel pool
4. Core-melt accidents

These main topics are discussed in seven sections in EDF's « Note de Réponse aux Objectifs du 4ème Réexamen Périodique du Palier 1300 MWe » (EDF 2023a) :

1. Section 1 : Accidents without core-melt
2. Section 2 : Hazards
3. Section 3 : Spent fuel pool
4. Section 4 : Core-melt accidents
5. Section 5 : Conventional risks
6. Section 6 : Transversal studies
7. Section 7 : Contribution of the Hardened Safety Core to the Objectives of the Re-examination

The recommendations in the report at hand have been allocated to these seven sections to better fit them to EDF's workplan.

Austria already took part in the consultation on the PSR4 for the 900 MWe reactor fleet. (UMWELTBUNDESAMT 2019a, 2021a, 2021b)

For the consultation at hand, the Federal Environment Agency coordinated the preparation of this expert opinion on behalf of the Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology. The aim of Austria's participation is to review the proposed changes to the reactors to determine whether they can minimize or, if possible, prevent likely significant adverse consequences of severe accidents in Austria.

For a substantial expert opinion on the French procedure, four task reports were produced on four topics:

- Experiences with the PSR procedure in France in general and for the 900 MWe reactors
- Operational experiences of the 1300 MWe reactor fleet
- Hazard assessment
- A comparative assessment of whether the 1300 MWe reactors can reach the safety level of the EPR.

In these task reports, recommendations to the French side were developed, on which this synthesis report builds upon. General recommendations are also formulated.

As mentioned, for the generic phase, the French regulator ASN and the utility EDF agreed on the following three objectives for the P4SR (ASN 2019a):

- Verification of the conformity of the installations with applicable safety requirements.
- As part of the continuous improvement of safety, elevate the 1300 MWe plants towards the safety objectives set for the 3rd generation reactors, with the EPR Flamanville 3 as reference.
- Implementation of all provisions of the hardened safety core which have been prescribed by ASN.

Method: The present work provides an expert opinion to the consultation process. Selected aspects of the objectives of the PSR4 were investigated. In particular:

We looked at past safety-significant events at French NPPs. Events that were related to aging were taken into closer consideration. Looking at this subset, we were investigating if and how those events changed over time, and which actions were taken by EDF to reduce the number of such events. From this analysis, we derived recommendations for the operation beyond 40 years of the French 1300 MWe reactors.

The "Western European Nuclear Regulators Association" issued Reference Levels for existing reactors WENRA (2014, 2021). Those Reference Levels are binding for French reactors. We were summarizing the relevant French regulatory requirements and compared these national requirements with the most important requirements of WENRA. Investigations and measures that should be carried out as part of the PSR were compared to the corresponding WENRA requirements. In addition, design basis hazards of the 1300 MWe reactors and the protective measures already taken and planned were analyzed. From this analysis within the scope of the first PSR objective a further set of recommendations were derived.

Finally we were systematically comparing the safety concept of the 1300 MWe reactors after the planned retrofitting in the frame of the PSR4 with the EPR safety concept. This was done for safety systems installed for design basis accidents as well as for equipment relevant for safety, needed in the management of design extension conditions (with and without core melt). It was then analyzed how far the 1300 MWe safety concept and the EPR-Flamanville safety concept differ from each other. The analysis led to a final set of recommendations within the scope of the second PSR objective.

2 GENERAL RECOMMENDATIONS

2.1 Governance of the decision-making process

Motivation/ Observation: Extending the operation of reactors beyond their PSR4 is part of an overall strategy for managing the nuclear fleet, which must take into account the technical, industrial and financial challenges and guarantee that safety is maintained at the required level in all circumstances. This issue is being tackled under conditions of pressure, due to the lack of anticipation of any alternative to extension.

Recommendation: The governance of the decision-making process following the PSR4 should ensure that the absence of an alternative does not lead to an extension by fait accompli.

The decision-making process on the possible terms and conditions for extending operation must make it possible to guarantee safety independently of any consideration of EDF's industrial and financial capacity.

2.2 Safety system’s level P4/P’4 and EPR

Relates to EDF NRO (2023a) chapter I.2.1.2.1.1.

Motivation/ Observation: The guidelines for PSR4 of 1300 MWe reactors are based on general objectives which come close to, but do not fully meet, the objectives set for the safety requirements of the EPR reactor. However, this increase is not to be reflected in their existing licences, which remain unchanged. Moreover, the enhanced level of safety is mostly aimed for through ways of new means (such as the core catcher) that are of a very different nature, in terms of defence in depth, from those used in new designs, therefore not bridging differences in the initial design.

Recommendation: The proposed change in safety requirements for 1300 MWe reactors through the PSR4 is substantial and should therefore be reflected in the regulatory provisions laid down in their authorisation decrees (Design Acceptance Confirmation DAC).

As the means introduced to achieve general objectives as close as possible to those of the EPR rely, by design and nature, on a very different defence in depth strategy, this difference should be explained and its implications elucidated.

In practice, the implementation of the general requirements results in numerous deviations (in design, rules, studies and compliance criteria). All these deviations and their implications should be explained.

2.3 Evaluation of safety margins

Relates to EDF NRO (2023a) chapter I.2.1.2.1.1

Motivation/ Observation: The margins available to a reactor with regard to safety requirements, taking into account a degree of uncertainty, form an important component of its safety level. Phenomena such as ageing and wear, which can only be partially offset by maintenance and replacement, materially consume these margins. Changes in design rules, and any increase in requirements that is not accompanied by a reinforcement designed to restore safety margins, actually reduces the existing safety margins. The state of the safety margins and their evolution must be constantly clarified and made explicit, including defining in advance, where relevant, the thresholds beyond which the reactor must be shut down.

Recommendation: The main safety margins from which reactors benefit in relation to the requirements applicable should be systematically identified, quantified where possible, and their use in the context of the PSR4 should be explained.

The safety margins that 1300 MWe reactors aim to achieve after extension in relation to the previously defined safety requirements should be compared with the margins that a newly built EPR-type reactor achieves in relation to comparable requirements.

When the safety margins relating to important parameters are reduced by identifiable or foreseeable phenomena, temporary or definitive shutdown criteria should be set in relation to a predefined threshold.

2.4 Experience feedback

Motivation/ Observation: Recent experience feedback alerts us: questions relating to the quality of the work carried out, the accumulation of non-conformities relating to the resistance of major components to damage, and the potential existence of non-conformities relating to non-inspectable components all combine to raise serious questions about the degree of compliance of the installations, and to prompt the strengthening of the examination procedures provided for in this area.

Recommendation: The extent and variety of the causes of non-compliance call for open and traceable processes to be put in place to monitor all the actions taken to examine compliance.

In view of the shortcomings revealed by the random examination approach, a (much more) exhaustive, controlled verification of all the items important to safety that are accessible to physical inspection should be considered as part of the PSR4.

The risk of non-compliance should be covered more comprehensively in the studies, by examining the consequences of the accumulation of non-compliances observed on the one hand, and by developing a method with regard to the risk of non-compliance on important elements not accessible to physical verification on the other.

Temporary or definitive shutdown criteria should be defined in advance in order to manage the detection of significant non-conformities, in a way that is proportionate to their consequences.

2.5 Implementation of Post-Fukushima action plan

Motivation/ Observation: In view of the difficulties encountered in recent years by EDF in meeting deadlines for studies and work, and even in complying with regulations, as well as those encountered by the ASN in ensuring that the operator complies with these various commitments, there is a high risk that the implementation of the safety improvements planned as part of the PSR4 will drift over time. A 4 to 5 years delay has already been granted by ASN for some of the works planned in the PSR4 of 900 MWe reactors, including the completion of the last post-Fukushima reinforcements. This risk is reinforced by concerns about EDF's technical and financial capacity to cope with this work, in a context when ASN said in 2022 that the industry needs a "Marshall Plan" to meet its objectives.

Recommendation: In view of the continuous slippage in the deadlines for carrying out studies and work, it is necessary to provide the review with a more precise and stricter framework of timetable obligations.

To ensure that all stakeholders and the public are properly informed, this framework should be accompanied by the introduction of a public scoreboard of the commitments made by the operator, which should, wherever possible, be the subject of instructions, and by monitoring of their implementation.

In order to avoid fait accompli situations where deadlines are not met, stricter technical criteria for information from the operator and justification of deadlines should be defined.

Temporary or permanent shutdown criteria could then be developed to deal with situations where there is an unjustified slippage in relation to these criteria for assessing the technical difficulties of meeting deadlines.

2.6 Prestress losses in 1300 MWe containments

Motivation/ Observation: Studies[3] indicate that the tension of steel wires of prestressed concrete containments might drop below acceptable limits after 40 years of operation in 1300 MWe reactors.

Recommendation: To operate the 1300 MWe reactors beyond 40 years it is recommended to require an assessment of existing containment prestress levels.

[3] E.g. Prestress losses in NPP containments - The EDF experience, Conference: Joint WANO/OECD-NEA workshop on pre-stress loss in NPP containments, Poitiers (France), 25-26 Aug 1997

3 OPERATIONAL EXPERIENCE OF THE 1300 MWE REACTORS

3.1 Introduction

The collection and analysis of the weak points and events identified in operational practice gives a picture of the condition of the 1300 MWe NPPs, which may be of significance with regard to the planned general need for retrofitting.

The number of safety-significant level 1 events on the international scale for nuclear and radiological events (INES) has been rising steadily for several years. It has risen by more than 30% since 2017.

In 2020 ASN noted an increase in the number of incidents majority of NPPs, in the number of significant events where analysis of the causes revealed inadequate documentation used by the operating team or incorrect use of this documentation.

ASN's 2021 annual report states, among other things: "In general, all operators of nuclear installations still need to make progress in terms of fire risk control, organization and crisis management, as well as in monitoring the compliance of their installations with regard to ageing, deterioration and corrosion of installations, which tend to increase."

3.2 Recommendations

3.2.1 Implement Hardened Safety Core and safety upgrades before start of lifetime extension (LTE)

Relates to EDF NRO (2023a) chapter I.2.7 "Contribution of the Hardened Safety Core to the Objectives of the Re-examination"

Motivation/ Observation:

Due to the deficits of the design of the 1300 MWe in regard to the degree of redundancy, the diversity, spatial separation and required manual intervention by personnel, internal and external hazards can lead to beyond-design-basis events.

The retrofit measures planned for the 1300 MWe essentially focus on eliminating weak points identified during operation, recognising problems of obsolescence and ageing in structures, systems and components (SSC), tracking them and eliminating them where possible. In the event of extreme impacts that significantly exceed the design, the cooling of important components should be ensured by the Hardened Safety Core (HSC). ASN has already called for the construction of a "Hardened Safety Core" for NPPs in France in 2013. (ASN 2013a)

IRSN (2023c) points out that it will not be possible to realise all of the RP4 changes during the shutdown periods for the ten-year inspections of the reactors. It is currently reported that the 900 MWe plants are also experiencing considerable problems with the timing of the retrofit programmes. It is therefore questionable whether the planned retrofit programmes can be implemented in the planned frame in order to ensure plant safety.

Recommendation: ASN should take measures to ensure that the necessary upgrades to improve the safety of the 1300 MWe reactors are carried out before the start of LTE. In particular, the "Hardened Safety Core" should be fully realised.

3.2.2 Reduce number of reportable incidents related to "safety culture"

Motivation/ Observation: In chapter 1.2.1 of ASN (2020) the "safety culture" is discussed: "Safety culture reflects the way in which the organisation and individuals fulfil their roles and responsibilities with regard to safety. It is one of the essential foundations to maintaining and improving safety. It commits organisations and individuals to pay special and appropriate attention to safety. It must be expressed at individual level through a rigorous and prudent approach and a questioning attitude that allows both sharing and initiative. It is reflected in day-to-day decisions and actions related to activities."

A considerable number of reportable incidents are related to the "safety culture". (ASN 2019b)

Recommendation ASN should ensure that EDF acts in compliance with the "culture for safety" in order to reduce the number of such incidents in French NPPs.

3.2.3 Perform root cause analysis for feed-in system damage events before LTE

Motivation/ Observation: The causes of the safety-relevant damage in the safety feed-in system of French NPPs have not yet been conclusively clarified[4].

Scenarios are conceivable in which mechanical loads act simultaneously on all affected lines of the safety feed-in system, e.g. in the event of a severe earthquake. If, in such a case, several of these lines were to be torn down at the same time, core damage or even a meltdown could only be prevented if further emergency measures for reactor cooling could be successfully implemented.

Recommendation: The root cause of safety-related damage in the safety feed-in system of French NPPs would have to be conclusively clarified before an LTE could be initiated.

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4 https://www.grs.de/en/news/safety-relevant-damage-safety-injection-systems-french-nuclear-power-plants#SnippetTab, seen 20-06-2024

3.2.4 Avoid corrosive environment for steam generator u-tubes

Relates to EDF NRO (2023a) chapter I.2.1 "Accidents without core melt" and especially affaire no TCDI0147

Motivation/ Observation: Damage to the steam generator u-tubes caused by corrosion during operation must be prevented. With this in mind, preventive measures should be taken to avoid operating modes that could lead to corrosion of the steam generator u-tubes. The EPR safety systems are designed against simultaneous failure of two steam generator u-tubes, while the P4/P'4 reactors can cope with just a single failed u-tube. (ASN 2014, EUR 16244 1996)

Recommendation: The operation mode of 1300 MWe reactors should ensure that failure of more than one steam generator u-tube can be excluded.

4 HAZARD ASSESSMENTS

4.1 Introduction: Regulatory requirements

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[5] 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).

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[5] 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)

4.2 Recommendations

4.2.1 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 implemented into the French national regulatory framework and expect that Issue TU of the 2021 SRLs (External Hazards) will be implemented in due course[6]. 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.

4.2.2 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.

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[6] 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.

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 showed that a single weather pattern can trigger both localized heavy precipitation with flash floods and regional precipitation with river flooding.[7] (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.

4.2.3 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.

[7] 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.

4.3 Introduction: External hazards in the PSR4 1300

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.

4.4 Recommendations

4.4.1 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.

4.4.2 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)[8] 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.

4.4.3 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.

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

4.4.4 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.

4.4.5 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.

4.4.6 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.

4.5 Introduction – Design basis, design extension conditions and protection measures of the 1300 MWe reactors

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.

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[9]:

- The use of a minimum magnitude as high as M=5 and Cumulative Average Velocity (CAV) filtering10 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[11] are well developed and were already applied to French nuclear sites (Clément et al. 2004b; Chartier et al. 2017; Jomard et al. 2017)[12].

Figure 3 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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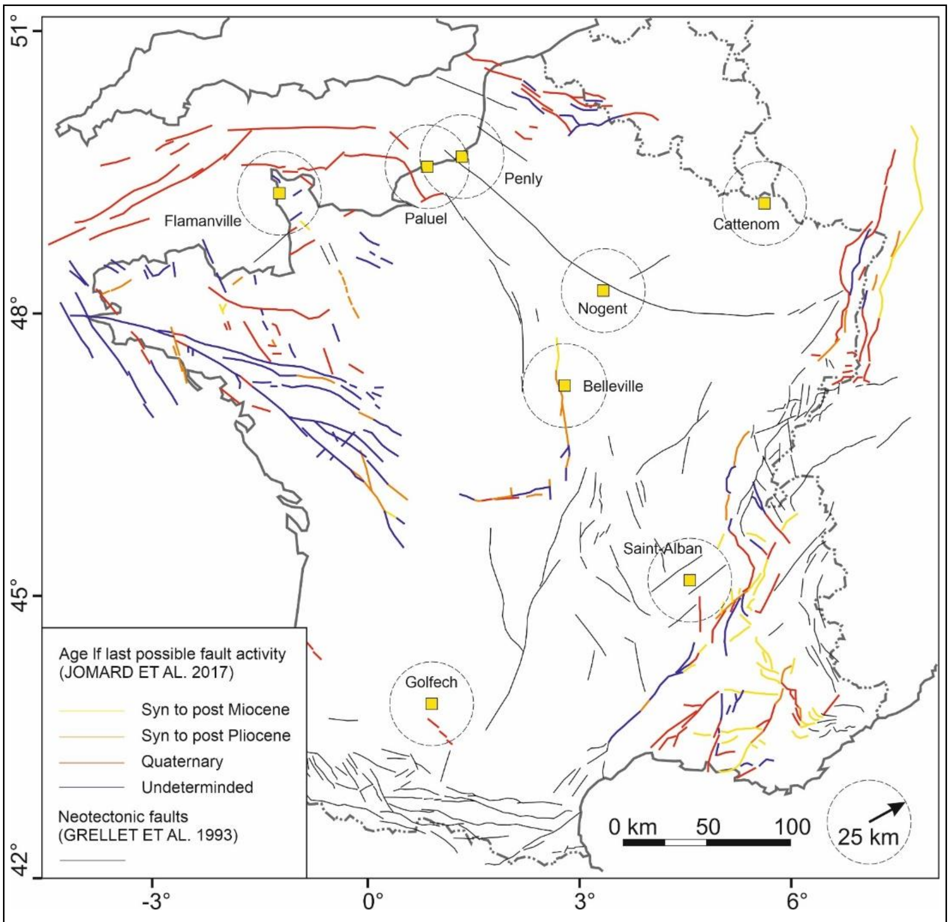
9 It must, however, be noted that comprehensive information on the PSHA database and methodology used for assessing the French nuclear sites could not be obtained for this report.

10 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.

11 E.g., Gutenberg-Richter or characteristic earthquake fault models

12 Both, databases and methodology were developed in a continued effort by IRSN.

Figure 3: Active fault map of metropolitan France and locations of 1300 MWe reactor sites.



Redrawn from: JOMARD et al., 2017; RITZ et al. 2021

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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[13].
- It is unclear whether the deterministically derived DBEs for Saint-Alban and Flamanville can be defended against PSHA-derived DBEs with an average recurrence intervals of 10,000 years. The same applies to the design of the HSC which is required to sustain a 20,000-years earthquake.
- 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

[13] 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 Equatinos.

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[14] (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 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

[14] SND = design basis earthquake for the HSC

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 Recommendations

4.6.1 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.

4.6.2 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[15] 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).

4.6.3 Protection against earthquake

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

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

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[15] *"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)

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.

4.6.4 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.

4.6.5 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 out-dated 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.

4.6.6 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.

4.6.7 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.

4.6.8 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.

4.6.9 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.

4.6.10 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.

4.6.11 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 RETROFIT TO STATE-OF-THE-ART

5.1 Introduction

A safety object of the PSR4 of the French 1300 MWe reactor fleet (P4 and P'4 reactors) is to move those reactors towards the state of the art. The reference hereof is the EPR reactor in Flamanville (Flamanville-3), for which fuel loading has recently begun. Especially after the Fukushima accident, significant modifications have been made to increase the resilience of the reactors against natural hazards and sever accidents.

The P4 and P'4 reactors are pressurized water reactors that follow an n+1 safety concept, meaning that if one safety system fails, the other can still fulfil the safety objective. The EPR, in contrast, has four trains of each safety system (n+3). Even if three trains fail out of various reasons, the last train can fulfil the full safety functionality. An aircraft crash –resistant shell covers the reactor building, the fuel building and two buildings housing two engineered safety trains. Provision for the prevention of severe accident conditions are integrated from the design stage.

When comparing different aspects that affect safety of the P4/P'4 and the EPR re-actors, the following points stand out:

- The EPR has a system for the stabilization of the core melt (corium) to prevent failure of the containment in case of severe accidents. Retrofitting of a so-called core catcher is not possible due to space limitations below the nuclear reactor core. EDF claims that the provisions implemented in the 1300 MWe reactor series are in principle similar, but they rely on cooling the corium from above by flooding. R&D efforts aiming to show that this is possible (LICHT 2023) are still on-going and have not shown convincing results yet.
- The total number of independent emergency electricity generating sources present at the reactor is about the same for the 1300 MWe reactors as for the EPR after retrofitting measures. However, for the 1300 MWe reactors only two systems fulfil the more rigorous requirements for safety systems (n+1) while this holds true for 4 systems of the EPR (n+3).
- NPPs are designed to have redundant and diverse safety systems to ensure that essential safety functions are performed. The safety system of the 1300 MWe reactors consists of two trains. If one of those trains fails, the other train can fulfil the necessary safety functions (single failure criterion). The EPR safety systems consist of four trains. Backfitting the 1300 MWe reactors does not seem to address the redundancy and diversity of level 3 safety systems that handle design basis accidents.
- The Nuclear rapid intervention force (FARN) is located at different NPPs all over France and is supposed to be on-site in case of emergency within 24 hours and operational within 36 hours. FARN equipment, as mobile equipment in general, must not be credited in the safety assessment for design basis accidents and therefore is not part of the safety systems for design

basis accidents on safety level 3. This makes it immediately clear that the FARN is acting on safety level 4, which is put in operation during design extension conditions to prevent and mitigate severe accidents. Those systems relevant for safety should not be used to compensate for existing deficits at level 3. Further, FARN would also support in case of need at EPR sites and is thus not a measure decreasing the difference in safety levels between the 1300 MWe reactor fleet and the EPR.

- For the safety analysis of a NPP, not only natural but also events that are induced by human activities are considered. This includes the crash of an aircraft. The probabilistic analysis of the French 1300 MWe reactor fleet has been updated recently to also include large commercial aircraft. For the EPR, a deterministic approach was used and explicitly the case of an intended attack of an aircraft on a NPP was considered.
- The hardened safety core increases the resilience of the 1300 MWe reactor fleet against external hazards such as earthquakes and flooding. The design of the EPR against earthquakes and flooding is based on much more stringent requirements.

Based on the information available it can be stated that it is not possible to increase the safety level of the 1300 MWe reactor fleet to state-of-the-art. It should be emphasized, though, that significant improvements have been made by retrofitting compared to the original design.

5.2 Recommendations

5.2.1 Planned provisions to terminate accidents with core melt at P4/P'4 reactors

Relates to EDF NRO (2023a) chapter I.2.4.2.2 "Measures implemented to deal with situations involving the risk of core melt"

Motivation/ Observation: The EPR has a system for the stabilization of the core melt (corium) to prevent failure of the containment in case of severe accidents. Retrofitting of an EPR type core catcher to the P4/P'4 reactors is not possible due to space limitations below the reactor pressure vessel. EDF is planning to retrofit other measures to stop accident progression in case of core melt accidents instead and claims that those provisions are similarly effective. However, they rely on a number of assumptions, including that the corium would spread on a large area and that the corium, once spread on the containment floor, could be effectively cooled by flooding with water from above. The OECD/NEA Project "Reduction of Severe Accident Uncertainties" ROSAU plays a crucial role in the demonstration of the effectiveness of the corium retention system for the 1300 MWe reactor fleet, but those R&D efforts (LICHT 2023) are still on-going and have not shown convincing results yet.

Recommendation: It is recommended to require full experimental proof and the demonstration of applicability before approving LTE.

5.2.2 Qualification of emergency diesel generators

Relates to EDF NRO (2023a) chapter I.2.7.3.1 "Ultimate backup Diesel generators",

Motivation/ Observation: There are two emergency diesel generators (EDG) per 1300 MWe reactor associated with level 3 safety systems (level of defence 3, design basis systems) and three sources of electricity associated with level 4 safety systems (DEC systems). TAC is shared among several reactor blocks and cannot supply the safety injection system (SIS). Additional AC power could be provided and be operational by FARN after a maximum of 36 hours. The EPR concept against loss of power consists of four emergency diesel generators (for design basis events) of which two are in buildings which are protected against external hazards. In addition, there are two additional so-called ultimate backup diesel generators for safety level 4, DEC, available.

Recommendation: For the 1300 MWe reactors only two EDGs fulfil the more rigorous requirements for level 3 safety systems, there is only a single redundancy, while this holds true for four EDGs of the EPR. While the EPR emergency diesel generators follow a n+3 redundancy concept, the P4/P'4 reactors follow a n+1 approach. It is recommended to try to elevate the safety level of the 1300 MWe fleet to the EPR also at the level of design basis safety systems, or, in case this is not possible, clearly state the deltas and evaluate the resulting additional risk.

5.2.3 Design basis accidents – redundancy of safety systems

Motivation/ Observation: There is a considerable gap regarding design basis safety systems redundancy between the 1300 MWe fleet and the EPR. The general safety philosophy for the 1300 MWe reactors design basis consists of two trains (2x100% safety concept). If one of those trains fails, the other train can fulfil the necessary safety functions (single failure criterion). The EPR safety systems, which are the target for retrofitting of the 1300 MWe fleet, consist of four trains (4x100% safety concept). The planned backfitting measures of the 1300 MWe reactors do not to address the redundancy and diversity of level 3 safety systems that handle design basis accidents.

Recommendation: It is recommended to retrofit additional safety systems and qualify them as design basis safety systems to elevate the P4/P'4 design closer to the EPR.

5.2.4 Consideration of FARN in the safety evaluation of P4/P'4 reactors

Relates to EDF NRO (2023a) chapter I.2.7.4. "FARN"

Motivation/ Observation: The Nuclear rapid intervention force (FARN) is located at different NPPs all over France and is supposed provide support on-site in case of emergency within 24 hours. This makes it immediately clear that the FARN is operating on safety level 4 which is put in operation during design extension conditions to prevent and mitigate severe accidents. Those systems relevant for safety should not be used to compensate for existing deficiencies at safety level 3. Further, FARN would also support in case of need at EPR sites and is thus not a measure decreasing the difference in safety levels between the 1300 MWe reactor fleet and the EPR.

Recommendation: Non-permanent measures such as the implementation of FARN are covered in IAEA Safety Standard SSG-88. One aspect is that mobile equipment should not be relevant in the short-term phase of design basis and design extension conditions. It is therefore recommended to not credit FARN equipment when comparing the safety level of 1300MWe reactors with state of the art (EPR).

5.2.5 State of the art consideration of aircraft crash

Relates to EDF NRO (2023a) chapter I.2.2.2.1.1.16 "air risk management"

Motivation/ Observation: For the safety analysis of NPPs not only natural but also events that are induced by human activities are considered. This includes the crash of an aircraft. The probabilistic safety analysis of the French 1300 MWe reactor fleet has been updated recently to also include large commercial aircraft. For the EPR, a deterministic approach was used and explicitly the case of an intended attack of an aircraft on a NPP was considered.

Recommendation: It is recommended to elevate the P4/P'4 level of protection against aircraft crash to the EPR level, which would include the same assumption on load cases and require the same method of analysis. In case this is considered to be not feasible, it is recommended to point out this gap in the safety level to the EPR and evaluate the resulting risks in a risk report.

5.2.6 Design basis protection and giving credit for HSC/FARN

Relates to EDF NRO (2023a) chapter I.2.7 "Contribution of the Hardened Safety Core to the Objectives of the Re-examination"

Motivation/ Observation: The hardened safety core increases the resilience of the 1300 MWe reactor fleet against external hazards such as earthquakes and flooding. The design of the EPR against earthquakes and flooding is based on much more stringent requirements.

Recommendation: It is recommended to address deficits in dealing with the design-based earthquake for the 1300 MWe reactor fleet by retrofitting and to also seismically harden the LLS and the TAC. It is recommended to enhance the safety level of the P4/P’4 fleet beyond providing HSC systems and FARN.

5.2.7 Spent fuel pool cooling/emergency cooling systems

Relates to EDF NRO (2023a) chapter I.2.3 “Spent Fuel Pool"

Motivation/ Observation: The spent fuel pool of the EPR is part of the hardened fuel building. It can be cooled by three different separate trains. The spent fuel pool of the 1300 MWe reactor fleet has been reinforced and improved as part of the Hardened Safety Core. An additional ultimate cooling water supply and installations for the use of mobile equipment increase the reliability of cooling, while all three trains are intermeshed. In addition, the spent fuel pool is located inside the containment in the EPR, while housed in a separate building at the 1300 MWe reactors which level of protection against hazards like aircraft crash is significantly below the level of the EPR containment.

Recommendation: It is recommended to retrofit spent fuel pool cooling systems/emergency cooling systems to match the degree of redundancy and diversity of the EPR spent fuel pool cooling systems and strengthen the structures which are housing the spent fuel pool to the level of the EPR containment.

6 REFERENCES

ASN (2012a): ASN 2012: Complementary Safety Assessments Follow-up of the French Nuclear Power Plants Stresstests, National Action Plan of the French Nuclear Safety Authority, December 2012.

ASN (2013a): ASN 2013a: Lettre ASN CODEP-DCN-2013-013464 du 28 juin 2013 relative au programme générique proposé par EDF pour la poursuite de fonctionnement des réacteurs en exploitation au-delà de leur quatrième réexamen de sûreté

ASN (2013g): Protection of Basic Nuclear Installations Against External Flooding - GUIDE N° 13; Version of 08/01/2013

ASN (2014): TECHNICAL GUIDELINES FOR THE DESIGN AND CONSTRUCTION OF THE NEXT GENERATION OF NUCLEAR POWER PLANTS WITH PRESSURIZED WATER REACTORS. Published on 28/02/2014.

ASN (2016): CODEP-DCN-2016-016677. Réacteurs électronucléaires – EDF Agressions externes extrêmes à prendre en compte pour la mise en place du «noyau dur». Montrouge, le 19 juillet 2016

ASN (2018): CODEP-DCN-2018-002381. Centrales nucléaires de Saint-Alban, Tricastin et Fessenheim. Séisme extrême à prendre en compte pour la mise en place du «noyau dur». 8 février 2018.

ASN (2019a): Orientations de la phase générique du quatrième réexamen périodique des réacteurs de 1300 MWe d'EDF (RP4-1300). Letter from ASN to EDF from 11 Dec 2019. Réf.: CODEP-DCN-2019-009228.

ASN (2019b): RAPPORT DE L'ASN sur l'état de la sûreté nucléaire et de la radioprotection en France en 2019.

ASN (2020): LES APPRÉCIATIONS DE L'ASN PAR EXPLOITANT, Les centrales nucléaires en fonctionnement, Rapport de l'ASN sur l'état de la sûreté nucléaire et de la radioprotection en France en 2020.

ASN (2020a) Flamanville, Paluel, Belleville, Nogent and Penly nuclear power plants: ASN rates a significant safety event affecting the emergency diesel generator sets at level 2 on the INES scale, Information notice 13/02/2020; https://www.french-nuclear-safety.fr/asn-informs/news-releases/significant-safety-event-affecting-the-emergency-diesel-generator-sets-at-level-2-on-the-ines-scale

ASN (2022b): Contrôle des installations nucléaires de base (INB); Lettre de suite de l'inspection du 26 octobre 2022 sur le thème des améliorations de sûreté post-Fukushima; N° dossier : Inspection n° INSSN-LYO-2022-0524; Référence courrier : CODEP-LYO-2022-060936; Lyon, le 13 décembre 2022

ASN (2022c): Contrôle des installations nucléaires de base, CNPE de Flamanville, INB 108 et 109; Inspection n° INSSN-CAE-2022-0150 du 13 juillet 2022 sur le thème des améliorations de sûreté Post-Fukushima; N° dossier : Inspection n° INSSN-CAE-2022-0150 À Caen, le 9 aout 2022

ASN (2024a): RÉACTEURS NUCLÉAIRES DE 1300 MWE. Fonctionnement au-delà de 40 ans : les enjeux du 4e réexamen périodique. Les cahiers de l'ASN #4, Janvier 2024.

BAIZE, S., CUSHING, E. M. ET AL. (2002): Inventaire des indices de rupture affectant le Quaternaire en relation avec les grandes structures connues, en France métropolitaine et dans les régions limitrophes. Mém. Soc. géol. Fr. (1924), 175: 1-141.

BECKER et al. (2020): The impacts of climate change on nuclear risk and supply security. Working Paper; Oda Becker, Eszter Matyas, Patricia Lorenz. 26 June 2020

CHARTIER, T., SCOTTI, O., CLÉMENT, C., JOMARD, H. & BAIZE, S. (2017): Trans-posing an active fault database into a fault-based seismic hazard assessment for nuclear facilities - Part 2: Impact of fault parameter uncertainties on a site-specific PSHA exercise in the Upper Rhine Graben, eastern France. Nat. Haz-ards Earth Syst. Sci., 17: 1585-1593.

CLÉMENT C., BONILLA L.F., SCOTTI O. & BAIZE S. (2004a): Site-specific probabilistic seismic hazard study for the Tricastin nuclear power plant, France. In: Proc. XXXIX General Assembly ESC, Potsdam, Germany, pp. 186.

CLÉMENT C., SCOTTI O., BONILLA L.F., BAIZE S. & BEAUVAL C. (2004b): Zoning versus faulting models in PSHA for moderate seismicity regions: preliminary results for the Tricastin nuclear site, France. Bollettino di Geofisica Teorica ed Applicata, 45: 187-204.

DECKER, K. & BRINKMAN, H. (2017): List of external hazards to be considered in ASAMPSA_E. Technical report ASAMPSA_E / WP21 / D21.2 / 2017-41, 51 pp.

DUROUCHOUX, C., LABBE, P. & TRAVERSA, P. (2014). I-5/1 Post-Fukushima French Seismic Hazard Assessment. 9th Nuclear Plant Current Issues Symposium, Charlotte, North Carolina, USA.

EDF (2017): Dossier d'Orientation du Réexamen Périodique VD4 1300. Document issu de la GED DPI Nucléaire le 12/07/2017. https://www.asn.fr/content/download/167479/file/dossier%2520EDF%2520orientations%2520g%25C3%25A9n%25C3%25A9riques%2520RP%25204%25201%2520300%2520MWe.pdf&ved=2ahUKEwjOqumk1MGGAxXaQvEDHY2mCYYQFnoECBQQAQ&usg=AOvVaw2q7zAN6P8GAiabGBH8gUw-.

EDF (2023a): Note de Réponse aux Objectifs du 4ème Réexamen Périodique du Palier 1300 MWe. https://concertation.suretenucleaire.fr/media/default/0001/01/abcb9641947b78e6ad2c1100f554d7eaab3e5c3e.pdf.

EDF (2023b): 4th Periodic Safety Review of the 1300 MWe Reactor Fllet. Summarised version of the Fulfilment Report. https://concertation.suretenucleaire.fr/media/default/0001/01/aa96ecad52f0dfc96f66debe95f9936c7ab9a893.pdf.

EDF (2023c): 4e Réexamen Périodique des Centrales 1300 MWe. Synthèse de la note de réponse aux objectifs. https://concertation.suretenucleaire.fr/media/default/0001/01/6d2c36bb296d68e1d5e0438bc3fe0ccac7975dbb.pdf.

ENSREG (2012b): France. Peer review country report. Stress tests performed on European nuclear power plants. http://www.ensreg.eu/document/peer-review-report-eu-stress-tests-france

EUR (1996): C.J. Ablott, S. Bouabdallah and S. Simm: The key issues in transient analysis calculations which affect the radiological consequences following design-basis steam generator tube rupture accidents. European Commission, nuclear science and technology: Office for Official Publications of the European Communities.

IRSN (2012): Definition of a post-Fukushima hard core for EDF's REPs: objectives, content and associated requirements. (Définition d'un noyau dur post-Fukushima pour les REP d'EDF : objectifs, contenu et exigences associées RAPPORT IRSN N°2012-009I) Réunion des Groupes permanents d'experts pour les réacteurs nucléaires du 13 décembre 2012 IRSN Report N°2012-009; 2012.

IRSN (2022a) : Avis IRSN n°2022-00035. EDF - Réacteur de 1300 MWe - Référentiel «Accidents graves» applicable au quatrième réexamen périodique. Objectifs généraux - Fonctions nécessaires en accident grave et exigences associées aux équipements assurant ces fonctions. To Monsieur le Président de l'ASN, 18 février 2022.

IRSN (2023c) : Avis IRSN n°2023-00066. Réacteurs électronucléaires d'EDF de 1300 MWe – RP4 1300 – Instruction anticipée portant sur le noyau dur post-Fukushima. To Monsieur le Président de l'ASN, 12 mai 2023.

JOMARD, H., Cushing, E. M. et al. (2017): Transposing an active fault database into a seismic hazard fault model for nuclear facilities - Part 1: Building a data-base of potentially active faults (BDFA) for metropolitan France. Nat. Hazards Earth Syst. Sci., 17(9): 1573-1584.

LICHT, Jeremy (2023): NEA NUCLEAR SAFETY RESEARCH JOINT PROJECTS WEEK: Success Stories and Opportunities for Future Developments, Seassion 4, Joint Projects for Safety in Accidental Situations, Learnings and Perspectives, ROSAU, 9- 13 January 2023.

NEOPAL (2009): Database of neotectonic and paleoseismic evidences. Online version available at https://data.oreme.org/fact/fact_map/neopal.

PISTNER et al. (2018): Sicherheitsdefizite des AKW Cattenom. Pistner, C., Sailer, M., Mohr, S., Küppers, C. Im Auftrag der Bundesländer Rheinland-Pfalz und Saarland, Öko-Institut Darmstadt

RITZ, J.F., Baize, S. et al. (2021): New perspectives in studying active faults in metropolitan France: the "Active faults France" (FACT/ATS) research axis from the Resif-Epos consortium. Comptes Rendus Géoscience - Sciences de la Planète, 353, no S1: 381-412.

SCOTTI, O., CLEMENT, C & BAUMONT, D. (2014): Seismic hazard for design and verification of nuclear installations in France: regulatory context, debated issues and ongoing developments. Bollettino di Geofisica Teorica ed Applicata, 55/1: 135-148.

STANDING GROUP OF EXPERTS (2019): Guidance for the generic phase of the fourth periodic reviews of nuclear reactors 1300 MWe from EDF. CODEP-DCN-2019-017737, Session of May 22, 2019.

UMWELTBUNDESAMT (2019a): Becker, O.; Giersch, M.; Meister, F.; Mertins, M.; Weimann, G.: Review of the 900 MWe reactor fleet (VD4-900). Expert Statement on the Generic Phase. By Order of the Federal Ministry for Sustainability and Tourism Directorate I/6 General Coordination of Nuclear Affairs BMNT. REP-0686, Wien.

UMWELTBUNDESAMT (2021a). Becker, O.; Mertins, M.; Mraz, G.: Frankreich: Konsultation zu den Bedingungen für den Weiterbetrieb der 900 MWe-Reaktoren über 40 Jahre hinaus. Fachstellungnahme. Erstellt im Auftrag des BMK, Abt. VI/9 Allgemeine Koordination von Nuklearangelegenheiten, REP-0752, Wien.

UMWELTBUNDESAMT (2021b). Becker, O.; Decker, K.; Mertins, M.; Mraz, G.: Frankreich: Beschluss der ASN zur Festlegung der Anforderungen an die 900 MW Reaktoren. Kurzgutachten. Erstellt im Auftrag des BMK, Abt. VI/9 Allgemeine Koordination von Nuklearangelegenheiten, REP-0764, Wien.

WENRA – Western European Nuclear Regulators Association (2014): Report WENRA Safety Reference Levels for Existing Reactors – Update in Relation to Lessons Learned from TEPCO Fukushima Dai-Ichi Accident, WENRA, 24th September 2014. http://www.wenra.org/publications/.

WENRA – Western European Nuclear Regulators Association (2020a): Guidance Document Issue TU: External Hazards. Head Document http://www.wenra.org/publications/.

WENRA – Western European Nuclear Regulators Association (2020b): Guidance Document Issue TU: External Hazards. Guidance on Seismic Events. Annex to the Guidance Head Document. http://www.wenra.org/publications/.

WENRA – Western European Nuclear Regulators Association (2020c): Guidance Document Issue TU: External Hazards. Guidance on External Flooding. Annex to the Guidance Head Document. http://www.wenra.org/publications/.

WENRA – Western European Nuclear Regulators Association (2020d): Guidance Document Issue TU: External Hazards. Guidance on Extreme Weather Conditions. Annex to the Guidance Head Document. http://www.wenra.org/publications/.

WENRA – Western European Nuclear Regulators Association (2021): WENRA Safety Reference Levels for Existing Reactors, Update in relation to lessons learned from TEPCO Fukushima Dai-ichi Accident; 17th February 2021. http://www.wenra.org/publications/.

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8 GLOSSARY

ASG .... Steam Generator Emergency Feedwater System

ASN .... French Nuclear Safety Authority

BDFA .... French active fault database

CAV .... Cumulative Average Velocity

DAC .... Design Acceptance Confirmation

DBE .... Design Basis Earthquakes

DBF .... Design Basis Flood

DEC .... Design Extension Conditions

DUS .... Ultimate Backup Diesel Generators

EDF .... Electricité de France

ENSREG .... European Nuclear Safety Regulators Group

EPR .... European Pressurised Reactors

EUR .... European Utility Requirements

FARN .... Nuclear rapid intervention force

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

GPE .... Advisory Board of Experts for ANS

HCTISN .... High Committee for Transparency and Information on Nuclear Safety

HSC .... Hardened Safety Core, in French: Noyau Dur

IAEA .... International Atomic Energy Agency

INES .... International Nuclear Event Scale

IRSN .... Institute for Radiation Protection and Nuclear Safety

LLS .... Emergency electricity system

LTE .... Lifetime extension

LTO .... Long Term Operation

MWe .... MegaWatt electric

ND .... Noyau Dur, in English: Hardened Safety Core

NPP .... Nuclear Power Plant

NRO ..... Note de réponse aux objectifs”

PSA ..... Probabilistic safety analyses

PSHA ..... Probabilistic Seismic Hazard Assessment

PSR ..... Periodic Safety Review

ROSAU ..... Reduction of Severe Accident Uncertainties

SEG ..... Ultimate Heat Sink

SIS ..... Safety Injection System

SND ..... Séisme Noyau Dur, design basis earthquake for the HSC

SRL ..... Safety Reference Level

SSC ..... Structures, systems and components

TAC ..... Emergency electricity system on level 4

VD4 ..... Visites décennales, ten-year-visits, no 4

VP ..... Volumetric protection

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

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EMAS
VERIFIED ENVIRONMENTAL MANAGEMENT
AT-000484

ISBN 978-3-99004-759-0