AUTORITÉ DE SÛRETÉ NUCLÉAIRE

GENERIC PHASE
THE FOURTH
PERIODIC REVIEW
900 MWe REACTORS FROM EDF

Investigation report
of the Nuclear Safety Authority

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SUMMARY

1 SUMMARY

ASN adopted a position in 2016 on the guidelines for the fourth periodic review of 900 MWe reactors, setting the objectives to be achieved.

These objectives relate to:

- verifying the condition of the installations and their compliance with the rules applicable to them, in particular with regard to controlling the aging of equipment important to safety;
- improving the way in which attacks are taken into account in the safety
- demonstration; improving the prevention of accidents leading to core meltdown;
- improving the consideration of accidents likely to occur in the fuel storage pool;
- limitation of the consequences of accidents with core melt;
- reduction of the radiological consequences of accidents;
- the integration of all the modifications resulting from the lessons learned from the accident at the Fukushima Daiichi nuclear power plant.

To meet these objectives, EDF has undertaken substantial study work, at the end of which it has defined a set of measures to be implemented as part of the review of each of the reactors concerned. These provisions concern, on the one hand, the checks and verifications to be carried out in order to ensure that the conformity of the systems, structures and components participating in the safety demonstration is maintained over time, and on the other hand the safety improvements. in order, in particular, to move towards the level of safety of third generation reactors.

Compliance of installations and aging control

Actions contributing to maintaining compliance and controlling aging (monitoring, maintenance, control, treatment of deviations) must be carried out on a daily basis on the installations. Since the conformity of the installations is an essential condition for their safety, its verification constitutes a fundamental objective of the periodic reviews.

As part of the fourth periodic review, EDF has planned to implement a reactor conformity review program which in particular makes it possible to ensure the correct application of existing preventive maintenance programs. EDF has also supplemented its actions with field visits carried out by multidisciplinary teams in certain premises including systems important to safety necessary in an accident situation to reach and maintain the reactor in a safe state. The fourth periodic review was also an opportunity to re-analyze the compliance of certain equipment or systems with regard to their safety requirements. In this regard, EDF has in particular checked:

- the ability of standby generators (diesels) to provide electrical power required, in the high outdoor temperature situations considered in the safety demonstration; ASN prescribes the minimum value of the power margin of this equipment;

- the capacity of the borated water recirculation in the event of a loss of primary coolant accident. EDF has carried out significant R&D and studies to better understand the physical phenomena involved. EDF is committed to improving the reliability of the recirculation function by implementing modifications aimed at reducing the term source of debris liable to damage. to be transported by water as well as the risk of chemical effects. These modifications to the installations will ensure, with reasonable confidence, that the means provided for the recirculation of borated water in the event of an accident will be able to perform their functions. ASN prescribes their deployment schedule.

To complete the actions planned to verify that the reactors remain in conformity after around 40 years of operation, EDF has undertaken to carry out specific tests on equipment important for safety. However, ASN considers that this test program should be completed and prescribed additional tests to EDF.

Furthermore, since the third ten-yearly outages, EDF has implemented a process to control equipment aging and obsolescence, which contributes to maintaining reactor compliance. This approach no longer calls for comment in its principles. It is based on a generic analysis of aging and its consequences and on a local analysis specific to each reactor, in particular during its ten-yearly outage.

To justify the holding of the tanks up to ten years after the fourth ten-yearly outage, EDF has carried out studies of resistance to sudden fracture, taking into account the evolution of the characteristics of the materials and will carry out checks to ensure the absence of harmful defects in the steel during the ten-yearly outage of each reactor. The studies carried out make it possible to conclude that the capacity of the tanks without defect to operate for ten additional years. For tanks, for which checks carried out in the past have shown that they contain manufacturing defects [1], specific studies will be carried out before the ten-yearly outage of each of the reactors concerned. This was particularly the case for reactor n ° 1 at the Tricastin nuclear power plant.

The approach implemented by EDF to justify the behavior of the equipment in the primary and secondary circuits (regulatory reference files) is satisfactory. In particular, EDF's approach to assessing areas sensitive to fatigue or sudden failure is adapted to the challenges: these areas are subject to special monitoring by non-destructive tests.

EDF has revised its studies on the thermal aging of molded elbows in the primary circuit as part of the review and must provide additional justifications. With regard to elbows for which justification difficulties remain, EDF will have to define an appropriate treatment strategy, or even consider replacing them if necessary.

EDF reassessed the performance of the containment. ASN considers that the monitoring of the containment enclosures and their behavior is satisfactory. However, it requires certain additions, in particular on preventive maintenance programs, control of the premature aging of certain prestressing cables, and on the pathologies observed in concrete. In addition, the actions planned within the framework of this review will improve the containment at the level of the crossings of the enclosure as well as the peripheral buildings.

Finally, EDF has undertaken to give priority, in the event of a discrepancy being detected, to bringing it back into conformity rather than justifying its maintenance as it is. In particular, EDF has planned to correct, at the latest during the fourth ten-yearly outage of each reactor, any deviations having an impact on safety which will have been identified beforehand, which is satisfactory. Any deviations detected during the ten-year inspection will be corrected as soon as possible, taking into account their importance for safety.

[1] Reactors n ° 1 of the Tricastin power station, n ° 2 of the Blayais nuclear power plant, n ° 5 of the Bugey nuclear power plant, n ° B1 and n ° B2 of the Saint Laurent-des-Eaux nuclear power plant.

In conclusion, EDF's program to check the conformity of its reactors as part of their fourth periodic review, supplemented by ASN's requests, is satisfactory. The application of this program to each reactor will have to be the subject of special attention on the part of EDF. ASN has therefore planned to carry out specific inspections on each of the reactors, in particular during the ten-yearly outage.

The control program and verifications planned by EDF, supplemented by responses to ASN's requests, will make it possible to achieve the objectives set for the review.

Improved consideration of assaults

EDF reassessed, for the fourth periodic re-examination of the 900 MWe reactors, the characteristics of the natural hazards considered as well as the measures planned to deal with them.

At the end of the appraisal, the hazard levels retained for the earthquake and tornadoes are acceptable for all the sites, taking into account the commitments made by EDF. For other hazards, the methods used to assess the hazards are acceptable, given the commitments made by EDF. The levels retained for each site will be presented by EDF in the report concluding the review of each reactor.

For natural hazards, the climate watch implemented by EDF is satisfactory: it defines in particular major weather events, the occurrence of which triggers a reassessment of the hazard levels to be considered. However, the thresholds associated with these events need to be revised.

The fourth periodic review was also an opportunity to ensure that the risk levels selected comply with the recommendations published in 2014 by the WENRA association of heads of nuclear safety authorities in Western Europe. In the event of non-compliance, EDF studied the capacity of the facilities to cope with hazards significantly greater than these.

During the generic phase of the fourth review, EDF also included, in the safety demonstration, the study of the consequences of equipment failure in the event of an attack, such as a fire door, for example, what is recommended by the WENRA association. This study makes it possible to identify the most important arrangements for dealing with attacks and to define means to guarantee their correct functioning, for example by setting up an alarm when a fire door is open. This approach constitutes a significant improvement compared to previous periodic reviews and makes it possible to increase the robustness of the installations.

For the control of the risks associated with the fire, the new method adopted by EDF to justify the sectorization of the premises constitutes a significant advance. Regarding the effect of fumes, EDF has developed a new method to identify, for electronic equipment, which is the most sensitive, situations in which fumes could attack equipment important for safety, which is satisfactory. The studies carried out have also made it possible to define operating measures to limit the risk of fire outbreaks in high-stakes premises.

For the control of the risks associated with the explosion, the studies carried out by EDF constitute a significant advance, insofar as EDF studied their consequences and considered that the leaks could occur, not only at the level of singularities, but also elsewhere. EDF has identified the situations likely to lead to the loss of redundant equipment. In most cases, EDF has defined measures to be implemented to bring the installation back to a safe state. However, EDF must complete its analysis for certain premises.

To control the risks associated with high outside temperatures, EDF has undertaken to improve its safety demonstration in order to better take into account the uncertainties associated with the calculations of temperatures in the premises. ASN prescribes the assessment of the capacity of the installations to cope with situations of loss of electrical power supplies, in particular in the event of extreme temperature.

For other hazards, the methods and assumptions used by EDF to carry out its studies are satisfactory. The modifications to the installations resulting from these studies will be implemented as part of the periodic review of each reactor.

Finally, EDF has carried out studies to shed probabilistic light on the attacks associated with fires, explosions, internal floods, earthquakes and external floods. This clarification made it possible to identify additional modifications to be implemented for each of these attacks, which will improve the level of safety.

ASN underlines the important work carried out by EDF to update all the stress studies. Certain studies have led EDF to define modifications; further studies are necessary in order to assess whether new provisions need to be implemented. All of these modifications, supplemented by responses to ASN's requests, will constitute a significant improvement in the control of risks associated with hazards, which will make it possible to achieve the objectives set for this review.

Accident studies

EDF has carried out significant work on the resumption of all of its studies (sizing studies, studies in the complementary field and so-called specific supporting studies), by declining a set of new standards and by integrating the lessons of the previous instructions. In general, the modifications planned by EDF in the context of the review to limit the consequences of certain initiating events constitute improvements for the safety of the reactors.

ASN instructs EDF to ensure control of reactivity in certain situations (situations of homogeneous dilution of the primary circuit, loss of primary coolant accident given the risk of buckling of the fuel assembly grids as well as 'in the event of total loss of electrical power supplies) and, if necessary, to define additional provisions. In addition, ASN asks EDF to carry out critical flux tests to verify the applicability of the correlation used for the peripheral rods of deformed fuel assemblies.

The modifications planned by EDF will make it possible to limit the radiological consequences of the accidents studied in the safety report. This will significantly reduce the occurrence of situations with the implementation of population protection measures.

In particular, EDF has planned to carry out modifications in order to limit the quantity of radioactive liquid water discharged into the environment in the event of a tube rupture accident of a fourth category steam generator (RTGV4). This accident has the most significant radiological consequences and EDF must continue its efforts to further reduce them.

The fourth periodic review was also an opportunity to reassess the probabilistic safety studies associated with events of internal origin. This probabilistic insight made it possible to identify additional modifications to be implemented, which will improve the level of safety.

The modifications resulting from the reassessed studies will make it possible to improve the management of incident and accident situations without core meltdown and, consequently, to improve the prevention of accidents with core melt. The results of these studies and the modifications planned by EDF, supplemented by responses to ASN's requests, will make it possible to meet the objectives set for this review.

Safety of the fuel storage pool

Following the deployment of the modifications planned in the context of the fourth periodic review, EDF will have an additional cooling system for the fuel storage pool (PTR bis), a water make-up system and 'an ultimate diverse water source. These means, which belong to the "hard core[2]», Are likely to greatly reduce the risk of the fuel being exposed and will, in most of the situations considered, make it possible to reach a final state after an accident without boiling the pool. They are major improvements to the review.

In addition, EDF has undertaken to include in the safety demonstration the accident situations considered for the sizing of the fuel storage pool for the Flamanville EPR reactor, with the exception of a limited number of situations. The resulting safety improvements will be a step forward for safety.

In addition, ASN instructs EDF to verify that, in the event of an accident, a safe state which is characterized by a lack of of boiling fuel storage pool. EDF will have to make provisions to improve the prevention of situations for which such a state cannot be reached with the means selected in the safety demonstration, as well as post-accident management measures enabling such a state to be reached in the long term.

EDF has undertaken to analyze the accident scenarios affecting both the reactor and the fuel storage pool, which is satisfactory. Likewise, EDF has undertaken to complete the list of situations studied that may lead to a loss of water inventory or to an absence of sufficient cooling of the assemblies in the storage pool, in order to identify possible measures. to implement.

EDF has also reassessed the risks associated with fires, explosions and internal flooding occurring in the fuel building. These studies have led to the definition of material modifications to prevent the risk of loss by common mode of the means for injecting water into the swimming pool or for cooling. ASN also asks EDF to define operating provisions to prevent these risks.

EDF also studied the consequences of the fall of a general aviation aircraft on the fuel building. This situation does not lead to the uncovering of the assemblies in the fuel storage pool.

Finally, the fourth periodic review was an opportunity to shed a probabilistic light on events of internal origin, attacks associated with fires, explosions, internal floods, earthquakes and external floods. This clarification made it possible to identify additional modifications to be implemented, which will improve the level of safety.

The modifications resulting from all the studies provided or to come will complete the safety demonstration and will constitute major improvements in the safety of the fuel storage pools. The results of these studies and the modifications planned by EDF, supplemented by responses to ASN's requests, will make it possible to meet the objectives set for this review.

[2] The “hard core” was defined after additional safety assessments carried out following the accident at the Fukushima Daiichi nuclear power plant. This is a set of material and organizational measures aimed, in the event of extreme aggression of external origin, at preventing an accident with fuel melting or limiting its progression, limiting massive radioactive releases and enabling the operator to carry out the missions incumbent on him in the management of an emergency situation.

Limiting the consequences of accidents with core meltdown

The improvement objectives adopted for the field of accidents with core meltdown concern the reinforcement of the means of limiting its consequences. The latter aim in particular to limit the radiological consequences during a serious accident, by making the risk of a major early release extremely unlikely and by avoiding lasting effects in the environment.

To meet this objective, EDF has defined improvements in order to:

- to evacuate the residual heat, without it being necessary to open the ventilation and filtration device of the containment enclosure of the reactor building. This absence of venting makes it possible to limit discharges outside the containment enclosure;
- to limit the risk of corium piercing the concrete of the base of the reactor building.

EDF made a commitment at the end of the instruction to set up systems for detecting and reinjecting the effluent present in the fuel building into the reactor building. EDF also plans to implement means to deal with an eventual loss of the so-called “ultimate” device for removing residual power from the containment, in a post-accident situation.

In order to further reduce the risk of discharges, ASN prescribes that EDF must have the means to inject an additional volume of borated water into the reactor building in the short term.

In order to reduce the releases of iodine in the gaseous phase from the contaminated water present in the containment of the reactor building during a serious accident as well as in the fuel building in the event of recirculation of this water, EDF is committed to putting specific measures in place.

ASN asks EDF to implement measures to limit the leaks of contaminated water outside the reactor building and the fuel building in the event of an accident leading to core meltdown, and to have the necessary resources allowing to reduce the contamination of the water present in the reactor building after an accident which led to the core meltdown. For each site, EDF must also, in order to limit the extent and duration of the contamination in the event of a contaminated water leak outside the buildings, study the means of limiting the dissemination outside the site of radioactive substances, by soil and groundwater.

The fourth periodic review was also an opportunity to reassess the probabilistic safety studies making it possible to assess the risk of releases into the environment in the event of an accident leading to core meltdown. This probabilistic insight made it possible to identify additional modifications to be implemented, which will improve the level of safety.

ASN underlines the very important work carried out by EDF on limiting the consequences of accidents with core meltdown and the very ambitious nature of the associated modification program. This program will allow major advances in terms of safety and meet the objectives set for this review.

The "hard core"

EDF plans to deploy, during the fourth periodic review of 900 MWe reactors, the “hard core” defined after additional safety assessments carried out following the accident at the Fukushima Daiichi nuclear power plant. In particular, EDF provides robust resources for extreme situations in order to:

- prevent an accident with fuel melting or limit its progression: in particular, it involves diversifying and strengthening a channel in the water supply system for the steam generators, setting up a means for supplying water the supply tank for this system, to inject water into the storage pool and to have new means to cool the storage pool;
- to ensure the maintenance of the sub-criticality of the core in extreme situations: this involves having a means of injecting borated water at high pressure;
- to limit large-scale radioactive discharges: this concerns in particular the means implemented in the event of a core meltdown (new device, called "ultimate", for removing residual power from the containment, means prevention of perforation of the raft ...).

The electrical supply to this equipment is provided by the ultimate emergency diesels (DUS) already present on all the 900 MWe reactors and by an instrumentation and control system resistant to extreme situations.

These measures will make it possible to limit the risk of core meltdown in the event of extreme situations, limit the consequences of a serious accident and reduce the risk of the fuel assemblies stored in the swimming pool uncovering. They will constitute major advances for safety.

Organizational and human factors

Given the scope of the changes planned in the context of the review, EDF has put in place specific organizational measures to improve the design and implementation activities of the changes, the preparation of operational documentation and the capitalization of lessons learned from the feedback.

EDF has also undertaken to analyze the organization put in place at its nuclear power plants and the possible improvements to strengthen its capacity to cope with the diversity of actual operating situations. In particular, it will study the activities contributing to the control of compliance.

EDF has also verified that the particular environmental conditions likely to be generated in an accident situation are acceptable in the premises in which actions must be carried out. It has undertaken to complete its demonstration concerning the ability to travel to these premises and to carry out, within the deadlines, the actions required in an accident situation.

These analyzes will improve the consideration of organizational and human factors and meet the objectives of the review.

The disadvantages presented by the normal operation of the installations

The inconvenients [3] presented by the normal operation of the installations are specific to each site. The generic phase of the review made it possible to define the actions that will be implemented for each of the reactors to review the control of the drawbacks. EDF has thus defined the scope of the checks to be carried out and the studies to be carried out, for example on the chemical and radiological state of the environment.

[3] These are the potential impacts of water withdrawals, effluent discharges as well as nuisances constituted by noise and vibrations, flying dust, odors, the dispersion of pathogenic microorganisms and waste.

ASN prescribes additional information on the checks to be carried out, in particular on equipment and structures allowing effluent treatment and waste conditioning. It also calls for the consolidation of impact studies in the form currently provided for by the environment code and the identification of improvements allowing the reduction of environmental impacts.

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The measures planned by EDF, supplemented by the responses to the prescriptions formulated by ASN, will make it possible to achieve the objectives of the review and bring the level of safety of the 900 MWe reactors closer to that of the third generation reactors.

These provisions, as well as those which will be defined within the framework of studies specific to each site, must be applied to each reactor with a view to continuing its operation. ASN asks EDF to carry out most of the safety improvements before submitting the review conclusion report, and in practice during the ten-yearly outage of each reactor. The other improvements must be made no later than five years after the submission of this report. This period is extended to six years for the seven reactors, the ten-year inspection of which is prior to 2022.

This phasing is linked to the scope of the work on each reactor, which will also be carried out simultaneously on several 900 MWe reactors. It takes into account the capacity of the industrial fabric to achieve them with the expected level of quality, as well as the necessary associated training for operators to take ownership of these changes.

ASN asks EDF to report annually on the progress of the actions to be carried out, the lessons it has drawn from the implementation on the sites of the provisions resulting from the periodic review, as well as its industrial capacity and that of the stakeholders. to carry out the modifications of the installations on time. It also asks, in the event of a risk of non-compliance with deadlines, to specify the additional measures implemented to remedy the shortcomings observed. ASN requests that these elements be made public.

At the end of the generic review phase, ASN considers that these safety improvements open the prospect of continued operation of the 900 MWe reactors for the ten years following their fourth periodic review.

2 INTRODUCTION

2.1 PURPOSE OF THE REPORT

Electricité de France (EDF) in 2013 initiated the fourth periodic review of its thirty-four 900 MWe nuclear reactors, namely those of the nuclear power plants of Blayais, Bugey, Chinon, Cruas, Dampierre-en-Burly, Gravelines, Saint- Laurent-des-Eaux and Tricastin. In accordance with Article L. 593-18 of the Environment Code, the periodic review must make it possible to verify the compliance of an installation with the rules applicable to it and to update the assessment of the risks and drawbacks it present for the interests mentioned in Article L. 593-1 of the same code, namely public safety, health and cleanliness and the protection of nature and the environment, taking into account in particular the state installation, experience acquired during operation,

Pursuant to Article L. 593-19 of the Environment Code, EDF must submit to ASN and the Minister responsible for nuclear safety a report presenting the conclusions of the periodic review of each of the 900 MWe reactors. This report includes in particular the measures that EDF intends to take to remedy the anomalies observed or to improve the protection of interests.

As with the previous periodic reviews, in order to take advantage of the standardized nature of its reactors, EDF plans to carry out this periodic review in two stages: **a generic phase, which covers subjects common to all 900 MWe reactors, then a specific phase**[4] **at each reactor.**

This report constitutes ASN's analysis of the generic phase of the fourth periodic review of 900 MWe reactors and presents its conclusions on the achievement of the objectives set for this phase. This report accompanies an ASN decision, applicable to 900 MWe reactors in operation.

The two reactors at the Fessenheim nuclear power plant were definitively shut down in 2020 and will be the subject of a dedicated periodic review, which is not covered by this report.

In accordance with Article L. 593-19 of the Environment Code, ASN will adopt a position on the continued operation of each reactor after analysis of its review conclusion report specific to this reactor. If necessary, ASN may have to adopt new prescriptions specifically governing the continued operation of each reactor.

2.2 REGULATORY FRAMEWORK

In France, the operating time of a reactor is not defined. *a priori.* In its capacity as operator of basic nuclear installations (BNI), EDF must, in accordance with the provisions of Article L. 593-18 of the Environment Code, carry out a periodic review of each of its reactors.

Periodic reviews are governed by Articles L. 593-18, L. 593-19 and R. 593-62 of the Environment Code.

[4] For 900 MWe reactors, the “specific” phase of periodic reviews will take place between 2020 and 2031 (dates corresponding to the submission of the conclusion report by the operator).

Article L. 593-18 of the Environment Code introduces the two main objectives of the periodic review:

- **checking the condition of the installation and its conformity:** this step aims to check the situation of the installation with regard to the rules applicable to it. It is based on a set of checks and tests, complementary to those carried out throughout the operation of the installation. These verifications may also concern reviews of initial design studies, verification of the proper performance of maintenance operations, field checks of equipment or even ten-year tests such as the test carried out on the containment. Any deviations detected during these investigations are then brought back into conformity as soon as possible and, in any event, within a timeframe suited to the challenges they present for the protection of people and the environment;
- **safety reassessment:** this step aims to improve the level of safety by taking into account the experience acquired during operation, the development of knowledge, the requirements applicable to the most recent installations as well as international best practices. Periodic reviews are thus an opportunity for upgrades or improvements in areas where safety requirements have evolved. At the end of the reassessment studies thus carried out, the licensee identifies the modifications to its facilities that it intends to deploy to enhance their safety.

As such, periodic reviews constitute one of the essential processes put in place to re-examine nuclear safety, by requiring the operator not only to check the level of safety of his installation but also to improve it.

The scope of the review concerns radiological and non-radiological risks, as well as the disadvantages that the installation presents in normal operation (discharge of chemical or radioactive effluents, noise, other nuisances, etc.).

Pursuant to Article L. 593-19 of the Environment Code, following the periodic review, the licensee submits a report to ASN and to the Minister responsible for nuclear safety presenting:

- the conclusions of the review carried out;
- the measures it intends to take to remedy the anomalies observed and to improve safety.

This act sets the date from which the ten years are counted to define the deadline for submitting the report concluding the following review.

For the fourth periodic reviews that occur after the thirty-fifth year of operation of the reactors, Article L. 593-19 of the Environment Code provides for a public inquiry into the measures proposed by the operator during this review.

At the end of its examination, ASN communicates to the Minister responsible for nuclear safety its analysis of the continued operation of the reactor and, in application of Article L. 593-19 of the Environment Code, may also impose new requirements to govern the continuation of operation until the next periodic review.

In addition, the order of 7 February 2012 [1] and certain ASN regulatory decisions set specific requirements on certain themes of periodic reviews.

2.3 PROCESS FOR PERIODIC REVIEW OF EDF REACTORS

The fifty-six operating nuclear reactors operated by EDF are divided into major types associated with their power: 900 MWe, 1300 MWe and 1450 MWe. In order to take advantage of the standardized nature of reactors of the same type, EDF has decided to carry out periodic reviews of its reactors in two stages:

- a so-called “generic” review phase, which covers subjects common to all reactors of the same type. This generic approach makes it possible to pool certain studies and the design of any modifications to the facilities. During this phase, EDF proposes objectives to be achieved during the review through a review orientation file, then EDF then carries out the necessary studies in order to define the measures to be taken, in particular in terms of modification of the installations. , to achieve the objectives set;

- a so-called “specific” review phase, which covers each reactor. This phase makes it possible to integrate the particular characteristics of the installation and its environment, such as, for example, the state of the installation and certain natural risks.

2.4 GENERIC PHASE OF THE FOURTH PERIODIC REVIEW OF 900 MWE REACTORS

In 2009, EDF informed ASN of its intention to significantly extend the operating life of its reactors beyond 40 years. In this context, it sent ASN a file presenting its guidelines for this continued operation. Following IRSN's assessment of this file at the request of ASN and the consultation of the standing group of experts for nuclear reactors (GPR) at its meeting on January 18 and 19, 2012, ASN adopted a position in June 2013 in the letter in reference [2] on EDF's guidelines and the additions to be made during the operational roll-out on the occasion of periodic reviews of the different types of reactors.

In addition, the fourth periodic review of the 900 MWe reactors takes place after the additional safety assessments (ECS) prescribed by decision in reference [3] following the accident at the Fukushima Daiichi nuclear power plant on March 11, 2011. The additional safety assessments of the fifty-eight reactors then operated by EDF were submitted on September 13, 2011. They were analyzed by ASN with the support of IRSN. ASN issued an opinion [81] on these assessments on January 3, 2012. This analysis led ASN to issue additional requirements for all of the nineteen nuclear power plants which were imposed on EDF by the decisions in the references. [5].

In 2013, EDF sent ASN its orientation file for the generic phase of the fourth periodic review of 900 MWe reactors, defining the objectives of this review and establishing the work program. ASN examined this program with the support of IRSN and requested the opinion of its permanent group of experts for reactors (GPR) and its permanent group of experts for nuclear pressure equipment (GP ESPN) respectively the 1er and 2 April 2015 and 10 June 2015. At the end of this examination, ASN concluded that the outline and the objectives of EDF's work program concerning the generic studies for this periodic review were satisfactory, subject to the consideration of certain requests and observations [6].

The periodic review program aimed to:

- define the scope of control of the condition of installations and their compliance with the rules that are applicable to them;
- reassess the safety and protection of the environment on some forty topics covering all aspects of nuclear safety demonstration and, more specifically:

- radiological risk assessment; this involved reassessing the risks associated with attacks, accident control (with or without core meltdown) concerning the reactor, the fuel storage pool and certain peripheral buildings containing radioactive materials (building of auxiliary conditioning and effluent treatment building),
- assessment of the control of non-radiological risks;
- the reassessment of the control of the disadvantages presented by the normal operation.

ASN requested IRSN's expertise on the studies carried out during the generic phase as well as (see modifications identified by EDF as necessary to achieve the objectives of the periodic review appendix).

In addition, ASN also gathered the group's opinion on several occasions in 2018, 2019 and 2020. standing of experts for nuclear reactors, as well as of the standing group of experts for nuclear pressure equipment on the following themes:

- controlling aging and obsolescence ([90] and [91]); the
- mechanical resistance of the tanks ([92], [91] and [92]);
- the regulatory reference files for nuclear pressure equipment [95];
- the aging and service life of the molded elbows of the main primary circuit [94];
- accident studies for 900 MWe CPY type reactors [97];
- the capacity of the installations to resist attacks from internal and external origins
- [98]; probabilistic safety studies for 900 MWe CPY type reactors [99]; management of
- accidents with core melt [100].

Lastly, on 12 and 13 November 2020, ASN gathered the opinion of the permanent group of experts for nuclear reactors on the results of the generic phase of the review [109].

This report presents, on the basis of these opinions and its own expertise, ASN's position on achieving the objectives of the generic phase of the fourth periodic review of the 900 MWe reactors and on the conditions for their continued operation. .

2.5 SPECIFIC PHASE OF THE FOURTH PERIODIC REVIEW OF 900 MWE REACTORS

The fourth periodic reviews of the 900 MWe reactors will run until 2031.

Type	Site	Reactor	Fourth periodic review deadline (deadline for submission of review conclusion report)
CP0	Bugey	2	04/27/2021
		3	04/30/2024
		4	12/21/2021
		5	06/15/2022
CPY	Blayais	1	12/28/2022
		2	07/30/2024
		3	02/24/2026
		4	04/01/2026
	Dampierre-en-Burly	1	02/06/2022
		2	06/11/2022
		3	06/27/2024
		4	04/07/2025
	Gravelines	1	09/14/2022
		2	03/21/2024
		3	04/30/2023
		4	12/19/2024
		5	11/02/2027
		6	06/14/2030
	Tricastin	1	02/22/2020
		2	11/18/2021
		3	03/05/2023
		4	06/18/2025
	Chinon B	1	04/24/2024
		2	03/21/2027
		3	06/25/2030
		4	03/15/2031
	Cruas	1	03/11/2026
		2	07/29/2029
		3	06/02/2025
		4	01/11/2027
	Saint Laurent-waters	1	12/17/2025
		2	02/13/2024

Table 1: Schedule for the fourth periodic review of the 900 MWe reactors

Before submitting the report on the conclusion of the re-examination of each reactor, EDF carries out a ten-yearly outage during a long shutdown of this reactor. During this shutdown, EDF is carrying out work[5] of magnitude linked to compliance control and safety reassessment. In particular, EDF carries out the ten-year tests of the containment enclosure and the main primary circuit during this shutdown.

[5] In this context, ASN may have to authorize certain modifications to the installation after they have been examined in order to ensure that they are not likely to degrade safety.

To take into account the constraints linked to the control of the volume of work on the installations, to industrial capacities, as well as to the capacity of the teams in the field to integrate the various changes to the installations, EDF informed ASN in February 2017 of its industrial strategy, which consists of deploying the modifications associated with the fourth periodic review of 900 MWe reactors in several phases (see paragraph 5.1).

The periodic review of the reactor is materialized by the submission of the review conclusion report, which is partly based on the conclusions of the generic phase. ASN considers that before this submission, EDF must verify that the state of knowledge, on which the generic part of the review is based, remains relevant with regard to changes in knowledge and experience feedback. Otherwise, EDF must present in this report the measures it will have taken or will plan to integrate these changes.

2.6 DESCRIPTION OF THE 900 MWE REACTORS

2.6.1 General information on 900 MWe reactors

The French nuclear reactors in operation, all using pressurized water technology, were designed and built by Framatome. Following the final shutdown of the two reactors at the Fessenheim nuclear power plant in 2020, EDF operates thirty-two 900 MWe reactors.

There are two types of 900 MWe reactors, CP0 type reactors and CPY type reactors. The CPY type reactors are an optimization of the CP0 type reactors, without questioning their main technical options. This optimization results in an evolution of the design of the buildings, the presence of an intermediate cooling circuit between that allowing the sprinkling in the enclosure in the event of accident and that containing the water of the cold source, as well as '' a control mode adapted to load monitoring. Table 1 specifies the CP0 and CPY type nuclear power plants.

2.6.2 Specific features of 900 MWe reactors

2.6.2.1 Main characteristics of 900 MWe reactors

The primary circuit of the 900 MWe reactors is made up of three cooling loops each comprising a primary motor-pump unit (GMPP) and a steam generator (GV). The steam produced in the secondary circuit of the steam generators, in the saturated state, is directed to the main turbine where it expands before reaching the condenser.

2.6.2.2 Fuel management

To benefit from the series effect provided by its reactors, EDF has implemented standardized fuel management systems. Fuel management is a method of using fuel, specific to one or more reactors of the same type. It is characterized in particular by the nature of the fuel, the enrichment of the fuel in uranium 235 and the plutonium content, the number of assemblies of the standard recharge and the cycle time. The safety demonstration is therefore also standardized.

Three different fuel management systems are implemented for the 900 MWe reactors:

- “Cyclades” management for the four reactors of the Bugey nuclear power plant, whose cycle time between two recharges is approximately 18 months;
- “Garance” management for the four reactors of the Cruas nuclear power plant as well as reactors 3 and 4 of the Blayais nuclear power plant, whose cycle time is annual;
- “MOX parity” management for the 22 other 900 MWe reactors, which have an annual cycle time.

2.6.2.3 Containment

The 900 MWe reactor containment enclosures consist of a cylindrical wall, resting on a raft and surmounted by a dome. These elements are made of prestressed reinforced concrete. The internal wall of the enclosures, called the intrados, is entirely covered with a metallic skin. The concrete structures ensure the mechanical strength of the enclosure and the metal skin ensures its tightness.

The 900 MWe reactor containments are all of comparable size. The reactor enclosures of the Bugey and Cruas nuclear power plants differ in terms of the base due to the nature of the soil and the seismic conditions taken into account during their design. The slabs of the reactors at the Cruas nuclear power plant were built on earthquake-resistant supports. For all the other 900 MWe reactors, the foundations of the containment chambers are similar.

2.6.2.4 History of modifications made to 900 MWe reactors during previous periodic reviews

The concept of “periodic safety review” was introduced by Decree No. 90-78 of January 19, 1990. During their first ten-yearly outage, most 900 MWe reactors were therefore not subject to an inspection. re-examination in the current sense. The modifications carried out at that time concerned upgrading to all 900 MWe reactors, as well as taking account of experience feedback, lessons learned from significant events and corrections of anomalies. The modifications were carried out according to the principle of continuous improvement, without always being associated with the ten-year shutdown, this shutdown being more devoted to checks and tests. Thus, in this context, several hundred modifications have been carried out in order to comply with the so-called “end-of-bearing state (EFP)”, defined during the commissioning of the Chinon B3 and B4 reactors. It is possible to cite:

- improvement of several systems or circuits important for safety: in particular the installation of the emergency turbo-generator unit, the installation and improvement of pilot-operated pressurizer valves, the installation of the sand filter for the containment , improvements to the emergency power supply circuit for steam generators;
- simplifying the management of incidents or accidents by improving the safety injection and water sprinkling circuits in the enclosure, setting up an isolation system for the discharge of the volumetric and chemical control in the event of loss of the intermediate cooling circuit, modifications to the sumps of the safety injection and water sprinkling systems in the containment, the setting up of force-feeding of the injection of high pressure safety by low pressure injection and simultaneous injection into hot branches and cold branches of the primary circuit, the addition of numerous automatic mechanisms (detection of an incident without automatic shutdown, automatic isolation on the steam system, 'emergency stop, etc.) and alarms,the establishment of an effluent reinjection system in the reactor building in the event of an incident, the development of procedures in the event of total loss of electrical sources and, more generally, the constitution of a coherent set of accident procedures transcribed in the general operating rules;
- the reinforcement of protection against attacks, in particular in terms of protection of ventilated buildings against very cold situations, earthquake resistance of the pipes of the emergency power supply circuits of steam generators and equipment resistance not classified as earthquake, improving fire protection by generalizing sectorization, installing additional detection and sprinkling systems;
- improving radiation protection conditions, in particular by adding radiation detectors and associated automation, and installing remote controls on valves in the safety injection circuit.

The requirements associated with the review introduced in the 1990s led to additional material modifications, carried out following a process which was not always linked to a ten-year shutdown, but carried out as close as possible to the implementation decision. Thus, the equipment classification process has resulted in a large number of equipment replacements by qualified equipment. Likewise, a systematic review resulted in the development of many additional periodic trials.

In addition, many material changes were implemented without being attached to a specific review. This is particularly the case for the replacement of steam generators by new models, changes in regulations allowing remote control and load monitoring, improvements on the fuels then the introduction of other compositions for the fuel, or even, provisions against “boiler effects” on the primary circuit.

The main objectives of the modifications made to the 900 MWe reactors during the second periodic review were:

- improving the safety of the reactor with regard to accident management by setting up an automatic shutdown device for the primary pump units during certain accidents associated with breaches in the primary circuit, d 'overfilling of the safety injection accumulators and of a new filtration system in the sumps of the safety injection and water sprinkling systems in the containment;
- modification or replacement of equipment in order to guarantee qualification for accident conditions;
- improving the management of severe accidents by installing containment pressure measurement sensors and installing passive autocatalytic hydrogen recombiners;
- protection against earthquakes by improving the anchoring of equipment and against flooding and fire by implementing dedicated action plans.
- the renovation of the instrumentation and control system associated with the neutron measurement chains (RPN system) of the nuclear power plants of Bugey and Fessenheim in order to improve their performance and anticipate the obsolescence of electronic cards;
- the generalization of accident procedures based on the state approach (APE).

The main objectives of the modifications made to the 900 MWe reactors as part of the third periodic review were:

- reinforcement of works, structures and equipment to ensure their resistance to earthquakes;
- the creation of an automatic protection system to limit the risk of the occurrence of a cold overpressure in the primary circuit;
- the modification of the operating conditions of the emergency water supply system of the steam generators, in order to reduce the risk, in the event of a tube rupture of a steam generator, that the primary fluid resulting from this breach will be discharged into the environment in liquid form;
- strengthening of fire prevention and fire-fighting measures, as well as prevention against the risk of explosion, in particular of hydrogen, inside installations;
- improving the reliability of emergency diesel generator sets which, in the event of an external voltage failure, provide electrical power to the equipment necessary to maintain the reactor in a safe state;
- improving the reliability of certain radioactivity measurement chains;

- the reinforcement of the systems for fixing the equipment access cover (large diameter passage in the reactor containment which, during reactor shutdowns, allows the necessary equipment and materials to penetrate), to guarantee its resistance and its tightness, in the event of a serious accident;
- improving the tightness of certain crossings of the enclosure to ensure satisfactory containment in a post-accident situation;
- making the opening of the pressurizer valves more reliable, in the event of a serious accident, to depressurize the primary circuit and prevent the reactor core from melting under pressure;
- the reinforcement of the provisions, material and organizational, making it possible to prevent the emptying of the fuel storage pool in order to avoid the uncovering of the fuel assembly;
- the installation, in the reactor containment, of sensors to detect hydrogen and the breakthrough of the vessel by the corium, in order to have, in the event of a serious accident, information on the progress of the situation;
- the replacement of certain valves in order to make the recirculation function of the water present at the bottom of the reactor building at the bottom of the reactor building during an accident involving loss of primary coolant, taking into account the reassessment of the volume, of the and the size of the debris that can be carried in the recirculating water;
- the reinforcement of certain provisions making it possible to improve the resistance of structures and equipment to climatic attacks, such as strong winds or frazil.

3 ASSOCIATION OF THE PUBLIC DURING THE GENERIC PHASE OF THE REVIEW PERIODIC

During the generic phase of the review, several actions were taken to involve the public.

The objectives of these actions were to inform the public, to facilitate understanding of the safety issues, to explain the ASN requirements associated with the review and to collect the expectations, questions, questions and positions of various contributors.

This chapter presents a summary of the actions taken to involve the public and understand their expectations regarding continued operation beyond the fourth periodic review. It also explains how the observations made by the public were incorporated into the examination and preparation of the ASN position.

3.1 ACTIONS TAKEN

Actions taken during the orientation phase of the review

From April 2014, a series of meetings was set up by IRSN and the National Association of Local Information Committees and Commissions (ANCCLI). The first step was to create a framework for discussion on the safety issues of the fourth periodic review. These meetings were then mainly dedicated to the topic of controlling the aging of equipment (vessel, containment, etc.): they enabled information to be shared on the safety issues associated with the review. They also facilitated the public's access to expertise and helped to support the development of skills on these subjects.

ASN organized a consultation on its draft position on the guidelines for the fourth periodic review of 900 MWe reactors on its website from January 26 to February 16, 2016 and organized a discussion meeting with stakeholders on the subject. This consultation collected 255 contributions. These contributions were taken into account by ASN in its position paper. In particular, they led ASN to integrate additional requests, for example concerning internal flooding, as well as routine maintenance.

Actions taken during the generic phase of the review

From June 2016, technical meetings took place with members of local information committees (CLI), ANCCLI, associations and with non-institutional experts.

In October 2016, ASN, IRSN, ANCCLI and the local Commission for information on major energy equipment in Tricastin (CLIGEET) organized in particular a seminar entitled "Continuation of operation of 900 MWe reactors beyond 40 years old: what security issues and what participation? ". The purpose of this seminar, which brought together around 150 people, was both to present ASN's position on the orientations of the fourth periodic review of these reactors and to collect questions from the public on the subjects addressed in the context of of this review, as well as to discuss the involvement of the CLIs in the periodic review process. This seminar showed the need to build a system of participation throughout the instruction.

From 2016 to 2019, a new cycle of thematic meetings, organized by IRSN, ANCCLI and ASN, focused on issues related to:

- compliance of installations and treatment of
- deviations; controlling aging;
- the risks associated with attacks of internal and external origin (in particular meteorological and climatic hazards);
- accidents with core meltdown.

These meetings allowed the participants to better understand the technical subjects and the technical instruction work. They also allowed them to develop their skills on sometimes complex technical subjects. They also enabled ASN to hear representatives of civil society well in advance of its position on the conditions for the continued operation of the 900 MWe reactors after their fourth periodic review, with the objective of include these questions in your instructions.

National consultation organized in 2018 and 2019

Following a recommendation from the High Committee for the Transparency of Information on Nuclear Safety (HCTISN), a national consultation was conducted, from September 2018 to March 2019, on the issues of the fourth periodic review of 900 reactors. MWe.

This consultation was supported by the note responding to the objectives of the review [104] drafted by EDF for the generic phase of the review. This note was presented and discussed with various stakeholders (local residents, informed audiences, students, etc.). Under the aegis of the HCTISN, the actors of this consultation (EDF, ANCCLI, IRSN, ASN) were thus able to gather, upstream of the periodic review of each of the reactors concerned, the feedback of these audiences on EDF's proposals and their security and information expectations.

During this consultation, which took place in particular around the eight nuclear sites concerned, and which brought together more than a thousand people, ASN sought to promote understanding of the issues. On this occasion, she published an issue of *ASN notebooks* entitled "Nuclear power plants beyond 40 years: the challenges of the 4e periodic review of 900 MWe nuclear reactors "[105]. It also contributed to the participatory platform designed for consultation, in particular by answering the questions that were posted there.

This consultation was also an opportunity for ASN to gather the public's expectations and concerns with regard to nuclear safety, with a view to its position on the conditions for the continued operation of the 900 MWe reactors after their fourth periodic review.

Public consultation on the draft ASN decision at the end of the generic phase of the review

ASN consulted the public on the draft decision setting EDF requirements in light of the conclusions of the generic phase of the fourth periodic review of its 900 MWe reactors.

This consultation was held from December 3, 2020 to January 22, 2021 on the ASN website. In order to

facilitate understanding of the issues by the public, ASN attached to the consultation:

- thematic information sheets presenting the conclusions of its investigation; the
- draft of this investigation report;
- the opinion [109] of the standing group of experts for nuclear reactors on the results of the generic phase of the fourth periodic review of 900 MWe reactors.

During this consultation, ASN presented its draft decision to several stakeholders, during a discussion meeting held by videoconference on December 17, 2020.

During the consultation, ASN collected 1,235 comments on its website. ANCCLI, Greenpeace and the Austrian Ministry of the Environment provided a detailed contribution.

ASN also gathered EDF's observations on the draft decision, in application of article R. 593-38 of the environment code.

3.2 TAKING INTO ACCOUNT THE OBSERVATIONS COLLECTED DURING THE NATIONAL CONSULTATION CONDUCTED IN 2018 AND 2019 IN ASN'S POSITION

The national consultation carried out in 2018 and 2019 under the aegis of the HCTISN made it possible to identify subjects of concern to the public.

The report [25] of the guarantors, appointed by the HCTISN to ensure the smooth running of the consultation, lists the questions raised and the observations collected. Certain questions concerned in particular the governance of nuclear safety, the costs of nuclear safety and the human resources it requires. Questions from the public also focused on energy policy, in particular on the advisability of carrying out the investment necessary for the continued operation of nuclear power plants.

Other questions related to more technical subjects, in particular the conformity of installations, control of aging, reassessment of safety, organizational and human factors as well as control of environmental impacts.

ASN noted the strong attention paid to controlling the conformity of installations and their aging (obsolescence of components, non-replaceable equipment, quality of materials).

ASN notes that even " *whether the safety reassessment measures have been regularly deemed relevant by the public* », Many questions were asked on this topic. In particular, ASN has heard how important it is for the public to strengthen analysis of the risks associated with climate change (flood, heatwave, drought), but also of other attacks (explosion, fire, domino effects in highly industrialized environments).

ASN also noted many questions relating to organizational and human factors, in particular aspects relating to skills, training and subcontracting.

The expectations and concerns of the public have been taken into account by ASN at several levels:

- to guide the work on the various themes of the review and to define the objectives to be achieved;
- by ensuring that the matters raised were properly examined during the investigation, as soon as they came under the reconsideration process;
- by ensuring that the products of the review meet the expectations expressed, whether this concerns their effective consideration for the continued operation of the reactors or the response to the questions raised.

ASN asked IRSN to include in its expert appraisals the questions raised by the public which reflected a particular expectation. By way of example, ASN thus asked IRSN to shed light on the approximation of the level of safety of 900 MWe reactors to that of third generation reactors as part of its expertise relating to studies. safety probabilists.

The following paragraphs specify, for each topic, how these questions and observations were taken into account when drawing up ASN's position on the conditions for continued operation of the 900 MWe reactors after their fourth periodic review.

Control of compliance of installations and their aging

The public wondered about the lifespan of a nuclear power plant.

In France, as in most European countries, the operating life of basic nuclear installations is not limited. *a priori.* In return, Article L. 593-18 of the Environment Code requires operators to thoroughly examine, every ten years, the compliance of their installations with the applicable standards, to remedy any discrepancies detected, to carry out a in-depth examination of the effects of aging on equipment and to improve the safety of their facilities. All basic nuclear installations on French territory are subject to this regulatory obligation.

The public questioned the compliance of the facilities. This topic is dealt with in paragraphs 4.1 and 4.3 of this report. On this subject, the main questions focused on:

- the defects observed in the walls of the tanks of certain reactors:
  Some tanks are affected by defects, the dimensions of which are known. The absence of significant change is checked at each ten-yearly outage. The acceptability of these proven defects is justified by specific studies. These specific studies do not give rise to any comments from ASN (see paragraph 4.3.1.3.1);
- the carbon segregations present in certain parts of the steam generators:
  Carbon segregation, which corresponds to a local increase in carbon content, can affect the characteristics of steel. EDF has carried out a specific study program on this point. Pending the conclusions of this program, ASN has imposed restrictions on the operation of reactors to restore margins in the face of this risk;
- the availability of spare parts:
  The availability of spare parts is strongly conditioned by changes in the industrial fabric of suppliers, the stopping of the production of certain components or the disappearance of their manufacturer, which can lead to supply difficulties. The objective of managing the obsolescence of equipment implemented by EDF is based on the constitution of sufficient stocks of identical equipment or the establishment of a long-term supply of new adapted or qualified equipment. This point is the subject of a request from ASN, in particular with regard to taking into account the qualification requirements for spare equipment (see paragraph 4.2).

More generally, the compliance verification strategy was revised as part of the fourth periodic review. ASN considers that the inspection program *in situ* planned by EDF, supplemented by design reviews and specific tests, is satisfactory. ASN has, however, issued specific requests on this topic, which is a fundamental issue in the review.

The approach adopted by EDF for controlling aging consists, as indicated in paragraph 4.2 of this report:

- for replaceable equipment, to assess their aging, carry out maintenance operations to limit their degradation, and, if necessary, replace them;
- for irreplaceable equipment such as the vessel and the containment, to verify their ability to perform their functions, in normal or accidental operation, for the ten years following the review of the reactor. These analyzes lead EDF in particular to adapt the operation and maintenance of this equipment.

The overall approach to controlling the effects of aging does not, in its principles, call for any comment on the part of ASN. Its application must be rigorous to ensure control of reactor aging with a view to their operation beyond their fourth periodic review. ASN will be attentive to the measures put in place by EDF and their effects over time, in particular during the inspections which will be carried out on these subjects.

In addition, ASN asked EDF [11] that the final shutdown of the reactors at the Fessenheim nuclear power plant be used to carry out certain tests or expert reports on the components taken in order to verify the behavior or the absence of phenomena. unplanned degradation or aging, in particular for systems, structures and components that are difficult to access.

Safety reassessment

The report of the guarantors underlines that the safety reassessment measures were regularly deemed relevant by the public, " *in particular the diesel emergency, the means of cooling the fuel, the corium recuperator, the modernization of the control command, the intervention of the FARN, the reassessment of the containment control* ".

Numerous questions focused on the relevance of the objective of striving for the level of safety of the Flamanville EPR reactor when its construction is experiencing difficulties and on the suitability of this benchmark given current knowledge. The objectives selected for the fourth periodic review are in fact aimed at tending towards the general safety objectives of the EPR reactor, in particular by:

- limiting the radiological consequences of accidents without core meltdown in order to significantly reduce the occurrence of situations with the implementation of population protection measures;
- reducing the risk of an accident with core melt and limiting its consequences, in particular by reducing the situations requiring the opening of the containment venting and filtration device as well as by reducing the risk of the bottom of this enclosure pierced by the corium;
- improving the consideration of attacks of internal or external origin. Reactors will be able to cope with attacks of more severe intensity than those previously used and will be more robust in the face of the failure of active equipment in the event of an attack;
- improving the safety of spent fuel storage in the storage pool. These subjects have been incorporated into the instruction and are dealt with in paragraphs 5.2, 5.3, 5.4, 5.5 and 5.6.

Concerning the safety of the fuel storage pool, ASN underlines the work carried out by EDF in terms of safety studies which have led to the definition of additional provisions which will make it possible to significantly improve the safety of the fuel storage. fuel and meet the objectives set for the fourth periodic review of 900 MWe reactors.

About the assaults , the public wondered about the need to strengthen the analysis of the risk of hydrogen explosion, the risk of fire and climate change (risks of flooding, rising water levels, heat waves, etc.) and on the consideration of domino effects in a highly industrialized environment. These elements are presented in paragraph 5.2.7. Numerous studies were carried out as part of the fourth periodic review, which led to the definition of new provisions. The implementation of these provisions, supplemented by the modifications resulting from ASN's requests, will make it possible to significantly improve the safety of the installations and achieve the objectives which had been set for this review.

In order to take into account the "domino effects" in a highly industrialized environment, EDF considered, in the context of the additional safety assessments carried out after the accident at the Fukushima nuclear power plant, the risks that would arise from industrial activities located nearby. nuclear power plants, in accordance with ASN requirements. EDF in particular considered the effects of a general fire at the entire Flanders Petroleum Platform (APF) on the Gravelines nuclear power plant.

The public also questioned the lessons of the accident at the Fukushima Daiichi nuclear power plant. This subject was incorporated into the instruction and is the subject of paragraph 5.8. The modifications implemented during the fourth periodic review of the 900 MWe reactors take into account the lessons learned from this accident: they must make it possible to deal with situations of loss of the electrical sources or of the cold source for a long period, possibly cumulating at major natural events (earthquake, flood, tornado, etc.).

Some questions related to risk assessment methods based on probabilistic approaches and their limits with regard to the accident at the Fukushima Daiichi nuclear power plant. In France, the safety demonstration is based on a deterministic approach, i.e. an approach which postulates the occurrence of an event independently of their probability (for example, a rupture of piping) while also retaining a failure of equipment and pessimistic assumptions. This deterministic approach is supplemented by probabilistic lighting, taking into account in particular the reliability of the equipment, in order to determine additional provisions making it possible to reduce the risks of the installation. In this regard, the elements presented in paragraph 5.7 show the contributions of probabilistic lighting.

Organizational and human factors

The public also wondered about the contribution of organizational and human factors, in particular on the transmission of skills, monitoring of maintenance, continuous training of EDF staff, service providers and subcontractors. This topic is dealt with in paragraph 7.3.1. For ASN, organizational and human factors refer to a set of factors of a very diverse nature, including skills and their acquisition and transmission methods. These factors have an influence on the way in which the work activities, for example the operating activities of a nuclear installation or more specifically the maintenance activities, are carried out by the various actors (EDF employees, service providers or sub-contractors). treating).

Finally, some participants wondered about the risks induced by over-regulation. This question is linked to the question of the link between regulated safety and managed safety dealt with by one of the working groups of the Steering Committee on Organizational Social and Human Factors (COFSOH) set up by ASN. This working group published a report on the subject [108].

EDF proposed a deployment of the modifications spread over several phases, with the aim of standardizing the deployment of these modifications on the various reactors in order to limit the risks. This two-phase deployment aims on the one hand to have sufficient industrial capacity to implement the modifications, and on the other hand to facilitate the appropriation by the management teams of these modifications in terms of the operation of the installations. . This deployment in several phases complies with the regulatory provisions and takes into account the capacity of the industrial fabric to carry out the modifications with the expected level of quality, as well as the necessary associated training of the operators to take ownership of these evolutions. In principle, it does not call for any comment from ASN.

Control of environmental impacts

Many public comments have focused on the environmental impacts and health effects of normal operation of nuclear power plants. This subject was incorporated into the ASN instruction and is the subject of section 6.

The public wondered about the discharge of hot effluents into rivers or the sea by nuclear power plants. These thermal discharges lead to a rise in temperature between the upstream and downstream side of the discharge which can range, depending on the reactors, from a few tenths of a degree to several degrees. In the case of nuclear power plants using a watercourse, ASN has defined, for each site, the conditions for discharging the water used for cooling. In order to preserve the environment, in particular the ecosystem, the heating of the watercourse due to the operation of the nuclear power plant and the temperature of the water downstream are controlled by limit values. If the limit values are exceeded, the operator must reduce the power of the reactor or shut it down.

With regard to waste management, which has also been the subject of numerous questions from the public, ASN asks EDF to update the impact study for each of the sites in order to integrate the practices and most recent knowledge. This impact study should integrate the elements currently presented in the study on waste provided for by the decision [22]. It will thus have to justify, on the basis of the best available techniques, the measures adopted for the management of the waste produced or to be produced, in particular to prevent and reduce the production and the harmfulness of the waste at source, and to ensure the traceability of the waste.

3.3 TAKING INTO ACCOUNT THE OBSERVATIONS COLLECTED DURING THE CONSULTATION CONDUCTED BY ASN ON THE DRAFT DECISION IN DECEMBER 2020 AND JANUARY 2021

A significant part of the observations collected focused on issues that are not related to the periodic review. Many contributions have in particular underlined the issue of the final shutdown of nuclear reactors in France. ASN may at any time suspend the operation of a reactor in the event of a serious and imminent danger. This is part of its mission of permanent control of nuclear installations. However, the final shutdown of a nuclear reactor for energy policy reasons is decided by the government and not by ASN.

Some observations have re-questioned objectives defined in the orientation phase of the fourth periodic review. For example, comments have called for a “bunkerization” of fuel storage pools.

Many observations pointed to a lack of understanding that all the modifications to the installations resulting from the periodic review will not be implemented during the ten-yearly outages. These observations concerned both the subdivision of modifications planned by EDF and the deadlines set by ASN in its prescriptions.

Comments expressed a request for additional information. They demanded clarification of the level of safety achieved at the end of the fourth periodic reviews, in particular with regard to the level of safety set for EPR-type reactors, or even a clarification of the subjects that will be dealt with in the context of the review phase. specific to each reactor.

Comments have shown that part of the public does not agree with certain ASN conclusions, in particular with regard to controlling the aging of the cells or the effectiveness of the spreading and cooling function of the tank. corium.

Finally, the comments generally expressed a strong position in favor or against the continued operation of the 900 MWe reactors beyond their fourth periodic review. Part of the public expressed mistrust of EDF (ability and willingness to implement all the measures) and, to a lesser extent, of ASN (ability to do so). comply with its prescriptions). Another party underlined the quality of the work carried out within the framework of the generic phase of the review and expressed its confidence in the actors involved.

The main topics covered in the public comments are:

- *general topics*
    - The meaning and objective of the consultation, as well as the way in which the results will be taken into account.
    - The duration of the consultation, generally considered too short.
    - The lack of consultation with border countries, the application of the Espoo Convention and the Aarhus Convention, the lack of availability of an English version of the documentation attached to the consultation and the lack of of public debate.
    - The links between the fourth periodic review of the 900 MWe reactors, the multi-year energy program (PPE), future decommissioning operations and waste management.
    - The criteria for determining which plants to shut down first, in particular proximity to built-up areas or high-risk areas.
    - The fact that several reactors carried out their ten-yearly outage before the ASN took a position on the generic phase of the review.
    - Lack of confidence in the nuclear industry and in EDF. Some comments suggested that independent expertises be carried out on certain technical themes.
    - The constraints induced by the review on the operator: the cost of the work to be carried out as part of the fourth periodic review and the increasing complexity of the systems and procedures resulting from this work, which could in certain cases be unfavorable to safety.
    - The economic cost of a major accident at a nuclear power plant and the evacuation policy in this situation.
- *matters relating to the objectives of the review or the implementation of the provisions resulting from the review*
    - Achievement of the objectives set during the guidelines of the fourth periodic review of 900 MWe reactors and the level of safety achieved with regard to that set for EPR type reactors.
    - The subdivision of the modifications resulting from the review, the deadlines for ASN prescriptions and the time limit for taking account of experience feedback in general and that of the accident at the Fukushima nuclear power plant in particular.
    - EDF's capacity (human and financial resources, etc.) and willingness to implement the provisions resulting from the fourth periodic review simultaneously on several reactors.
    - ASN's ability to ensure that its prescriptions are complied with and the possibilities of changing their deadlines in the future, in particular in the event of shutdown of certain reactors as part of the multi-year energy program.
- *technical subjects*
    - Control of the conformity of the installations and the discrepancies that persist over time and reviews.
    - Control of aging, in particular of the vessel, containment and cables, consumption of margins as well as the possibility of carrying out tests or sampling of equipment at the Fessenheim nuclear power plant.
    - The risks associated with fuel storage pools and in particular their resistance to extreme external attacks and malicious acts, in particular the fall of a plane.
    - Organizational and human factors, the control of which is essential for safety: the management of subcontracting, the quality of the workers, training, know-how and the maintenance and transfer of skills.

- The attacks, in particular the sufficiency of the hazard levels selected with regard to experience feedback and climate change and, more specifically, the earthquake resistance of the installations and the taking into account of experience feedback from the Teil earthquake of November 11, 2019 for the Cruas and Tricastin nuclear power plants. Taking into account
- the risks associated with a pandemic.
- Taking into account the risks associated with extreme cold.
- Taking into account the risks associated with industrial activities close to nuclear power plants.
- Accidents with core melt and the efficiency of the corium stabilization and cooling system.
- Protection of the environment and, in particular, releases from nuclear power plants and radioactivity dissemination events that have occurred in the past.

- *comments on specific points in the draft decision*
  - Annex 2 in which certain limitation periods appear was difficult to read. The The decision deadlines were not the same for all reactors.
  - could have been aimed at the assessment of the consultation conducted by the HCTISN and 2019.
  - in 2018 Article 3 of the draft decision on the annual assessment requested from EDF left hear that prescription deadlines could be revised later.
  - The annual assessment should have been public and presented to the local commissions of information.
  - The elimination period deviations "as soon as possible" (requirement [CONF-A]) was The not clear enough.
  - wording of II of the requirement [AG-C] on strengthening the sufficiently clear. containment venting and filtration device was not

- *observations made by EDF*
  - EDF has proposed changes to certain precise formulations of the draft decision, some of remove the requirement for a phase opening test and modify the deadlines for the prescriptions.

These observations have led ASN to change the draft decision on the following points:

- ASN revised certain limitation periods. In particular, ASN has prescribed the submission of certain studies on a fixed date for an entire site or for all the 900 MWe reactors rather than on different dates depending on the reactors. This has led to the corresponding deadlines being brought forward for certain reactors. ASN also postponed some of the deadlines due to specific industrial and operating constraints when the postponement was acceptable from a safety point of view;

- ASN has improved the readability of the deadlines appearing in the tables in appendix 2 of the decision, by distinguishing between the modifications that must be implemented before the submission of the review conclusion report (i.e., in practice, during the ten-yearly inspection);
- ASN added a visa to the results of the consultation conducted by the HCTISN in 2018 and 2019, in order to show that its conclusions were taken into account by ASN;
- ASN added a recital in order to clarify its position on the deployment schedule for the modifications resulting from the review. This schedule must take into account the importance for safety of the modifications and the capacity of the industrial fabric to carry them out with the expected level of quality, as well as the necessary associated training of operators to take ownership of these changes. Most of the safety improvements will be carried out during the ten-yearly outage;

- ASN reviewed article 3 of the draft decision relating to the annual review requested from EDF. ASN asked EDF in particular to anticipate any difficulties in meeting the prescribed deadlines, to define additional measures to remedy the shortcomings observed and to make this report public;
- ASN clarified its expectations with regard to the deviations detected during the ten-yearly outage and which could not be resolved during the latter by asking to include them in the file that EDF must submit to it before restarting the reactor;
- ASN has reformulated section II of prescription [AG-C] relating to the reinforcement of the containment venting and filtration system to make it clear that this is a request.

The comments of the public were also taken into account by ASN in other frameworks.

In order to meet the need for information, ASN published at the same time as its decision, a dedicated number of ASN notebooks. In this guide, ASN has provided answers to certain recurring questions formulated by the public. They focused in particular on:

- the safety level of the 900 MWe reactors at the end of their fourth periodic review;
- the means available to ASN to ensure compliance with its prescriptions;
- the link between the fourth ten-yearly outage which has already taken place for certain reactors and ASN's position on the generic phase of the review;
- taking into account climate change and extreme aggressions;
- the role of ASN in the decision to permanently shut down a reactor.

In addition, the answers to some questions raised by the public can be found in this report. The remainder of this section explains the main responses.

The application of the Espoo convention

The audience questioned the lack of official consultation with neighboring countries and, in particular, the application of the Espoo Convention on Environmental Impact Assessments in Transboundary Contexts.

The operating life of nuclear reactors is a matter of energy policy, which is defined and implemented by the government. The multiannual energy program (PPE) currently in force provides for the shutdown of the two reactors at the Fessenheim plant in 2020, then the shutdown of 12 nuclear reactors by 2035, for the majority of them at the time of of their 5th ten-yearly inspection, thus retaining the principle of their continued operation. This PPE was the subject of a strategic environmental assessment, including a public debate at national level and consultation of neighboring countries.

Whatever the energy policy orientations, a reactor can only continue to operate if it meets safety requirements. The objective of the review is to verify in depth compliance with these requirements and to update them. The generic phase of the fourth periodic review of 900 MWe reactors thus leads to an ASN decision strengthening the requirements applicable to EDF reactors, which does not constitute an authorization which would fall under the Espoo agreement.

Controlling compliance and aging

This theme is dealt with in part 4 of this report. On this subject, the main questions focused on:

- the performance of tanks in general and those in particular in which faults have been detected in the past. ASN dedicates a paragraph of its investigation report (§ 4.3.1) to the risk of sudden vessel rupture. Some tanks are affected by defects, the dimensions of which are known. The absence of significant change is checked at each ten-yearly outage. The acceptability of these defects is justified by specific studies. These specific studies do not give rise to any comments from ASN (§ 4.3.1.3.1);

- taking advantage of the final shutdown of the Fessenheim nuclear power plant. The investigation report indicates (§ 4.2.3.3) that ASN has requested that the final shutdown of the reactors at the Fessenheim nuclear power plant be used to carry out certain tests or assessments of the components taken in order to verify the behavior or the absence of unforeseen degradation or aging phenomena, in particular for systems, structures and components that are difficult to access;
- replacement of steam generators. The status of the replacement of the steam generators is discussed in paragraph § 4.2.3.4: "EDF is completing the program to replace the steam generators in its 900 MWe reactors. The steam generators of five 900 MWe reactors have yet to be replaced and will be replaced at the latest during their fourth ten-yearly outage ".

Safety reassessment

Numerous questions focused on the relevance of the objective of striving for the level of safety of the Flamanville EPR reactor when its construction is experiencing difficulties and on the suitability of this benchmark given current knowledge. These subjects were incorporated into the training and are dealt with in paragraphs 5.2, 5.3, 5.4, 5.5 and 5.6 of the training report.

The safety objectives of new generation reactors, such as the Flamanville EPR reactor, were taken as a reference for the continued operation of 900 MWe reactors beyond 40 years.

At the end of the review, differences will remain between the safety level of the EPR reactor and that of the 900MWe reactors. There are in fact significant design differences, such as the more favorable layout of the various EPR reactor buildings, the protection of the fuel storage pool building or the number of safety systems making it possible to deal with an accident.

However, the fourth periodic review will bring the safety level of the 900 MWe reactors closer to that of the third generation reactors. EDF in particular plans to reinforce the power and cooling power sources and the protection of the reactors against extreme aggressions. The review will reduce the radiological consequences of accidents. It will also lead EDF to deploy safety improvements directly inspired by new generation reactors: this is the case, for example, of the corium stabilization and cooling function inside the containment.

Regarding the attacks, the public wondered about the need to strengthen the analysis of the risk of hydrogen explosion, the risk of fire and climate change (risks of flooding, rising water levels, heat waves ...) And on the taking into account of the risks linked to industrial activities close to nuclear power plants. These elements are presented in paragraph 5.2.7 of the investigation report.

The recommendations of the WENRA association have in particular been considered for the reassessment of protection against the effects of internal and external attacks (intensity of attacks to be used for the sizing of installations, consideration of an aggravating factor in the studies). The effects of global warming are taken into account in stress studies, and a “heat wave” stressful situation is defined and taken into account.

EDF considered, in the context of the additional safety assessments carried out after the accident at the Fukushima nuclear power plant, the risks that would arise from industrial activities located near the nuclear power plants, in accordance with ASN requirements. EDF in particular considered the effects of a general fire at the entire Flanders Petroleum Platform (APF) on the Gravelines nuclear power plant.

For the risks associated with external flooding, ASN indicates in this report (§5.2.6) that the assessments are based on ASN guide no. 13 which incorporates the hydrodynamic effects associated with a dam failure.

For the plane crash (§ 5.2.7), EDF updated the accidentology parameters (annual probability of an aircraft falling in a given category, regional air traffic density factors) as part of the review. Site-specific air traffic parameters will be updated and assessed as part of the review conclusion reports.

There were also many questions about the safety of the fuel storage pool. In this report, ASN underlines the work carried out by EDF in terms of safety studies, which has led to the definition of additional provisions which will make it possible to significantly improve the safety of fuel storage and meet the objectives. selected for the fourth periodic review of the 900 MWe reactors (§ 5.4).

Organizational and human factors

The public also wondered about the contribution of organizational and human factors, in particular on the transmission of skills, monitoring of maintenance, continuous training of EDF staff, service providers and subcontractors. This topic is dealt with in paragraph 7.3.1. These factors have an influence on the way in which the work activities, for example the operating activities of a nuclear installation or more specifically the maintenance activities, are carried out by the various actors (EDF employees, service providers or sub-contractors). treating). ASN considers that EDF should analyze risk management in operating activities in a broader and more structured manner.

Finally, some comments focused on the risks induced by an excess of regulatory framework. ASN considers that the growing complexity of the rules to be observed and the actions to be carried out in operation is indeed a point of vigilance. This question is also linked to that of the link between regulated safety and managed safety dealt with by one of the working groups of the Steering Committee on Organizational and Human Social Factors (COFSOH) set up by ASN. This working group published a report on the subject.

Control of environmental impacts

Public comments focused on the environmental impacts and health effects of normal operation of nuclear power plants. This subject was incorporated into the ASN instruction and is the subject of section 6.

The public wondered about the discharge of hot effluents into rivers or the sea by nuclear power plants. These thermal discharges lead to a rise in temperature between the upstream and downstream side of the discharge which can range, depending on the reactors, from a few tenths of a degree to several degrees. In the case of nuclear power plants using a watercourse, ASN has defined, for each site, the conditions for discharging the water used for cooling. In order to preserve the environment, in particular the ecosystem, the heating of the watercourse due to the operation of the nuclear power plant and the temperature of the water downstream are controlled by limit values. If the limit values are exceeded, the operator must reduce the power of the reactor or shut it down.

With regard to waste management, which has also been the subject of numerous questions from the public, ASN asks EDF to update the impact study for each of the sites in order to integrate the practices and most recent knowledge. This impact study should integrate the elements currently presented in the study relating to waste. It will thus have to justify, on the basis of the best available techniques, the measures adopted for the management of the waste produced or to be produced, in particular to prevent and reduce at source the production and the harmfulness of the waste and to ensure its traceability.

3.4 PUBLIC ASSOCIATION AFTER THE GENERIC PHASE OF THE FOURTH REVIEW

The arrangements defined by EDF for the fourth periodic review of each of the 900 MWe reactors will give rise to a public inquiry, on each site concerned, as and when they are reviewed.

ASN will also submit for public consultation the draft prescriptions that it deems necessary for the continued operation of each of the reactors as part of the specific phase of their review.

4 ASN POSITION ON THE COMPLIANCE OF THE INSTALLATIONS AND CONTROL OF AGING AND OBSOLESCENCE

In accordance with Article L. 593-18 of the Environment Code, the periodic review of a basic nuclear installation must make it possible to assess its situation with regard to the rules applicable to it.

The verification and maintenance over time of the conformity of the installations revolve mainly around:

- a verification of the compliance of equipment and structures with their defined requirements[6] and carrying out the necessary compliance actions;
- control of aging and obsolescence.

The periodic review constitutes a privileged framework for re-examining the means of demonstrating the sufficiency and effectiveness of the measures implemented to maintain this compliance.

EDF's approach to verifying and maintaining the compliance of installations over time during periodic reviews is based on four provisions: the unit compliance review (ECOT), the additional investigation program (PIC), the provisions for controlling aging and obsolescence and the specific tests to be carried out during ten-yearly outages. These measures are carried out in addition to routine maintenance, operational monitoring and the treatment of deviations detected during operation.

In addition, EDF has carried out significant work to verify the conformity of certain equipment or systems, such as systems participating in containment (paragraph 4.3.2), emergency diesel generator sets (paragraph 4.3.4) and systems used for recirculating the water present at the bottom of the reactor building sumps, necessary in certain accident situations (paragraph 4.3.3).

4.1 VERIFICATION OF CONFORMITY

4.1.1 Specific objectives of the review

Verifying the conformity of 900 MWe reactors is part of a specific framework since, in 2009, EDF expressed the wish to significantly extend the operating life of its reactors beyond forty years. In this context, ASN asked EDF in 2013 [2] to significantly strengthen the scope of the conformity examination of each reactor and its operation and to propose verifications, in particular on the basis of " *on-site inspections, which must cover all the requirements defined for the elements important for the protection of interests* "(EIP) mentioned in article L. 593-1 of the environment code.

As experience feedback from reactor operation revealed inadequacies in the processes implemented to ensure and maintain over time the compliance of the installations with the requirements defined during design and operation, ASN requested to EDF in 2016, by the letter in reference [6], to review its compliance verification strategy for the fourth periodic review

[6] Defined requirement: requirement assigned to an element important for protection, so that it fulfills, with the expected characteristics, the function provided for in the safety demonstration.

by going beyond the compliance reviews carried out during previous periodic reviews. To this end, ASN has formulated requests based on five axes:

- extension of the scope and controls of compliance verification; defining and
- carrying out design reviews [7] systems important to safety;
- the definition and performance of additional tests to those carried out during the ten-yearly outages;
- the strengthening of the organization put in place to deal with the deviations at the latest during the fourth ten-yearly inspections, in particular those identified upstream of these;
- the correction of anomalies identified in the studies. This point is dealt with in paragraph 5.3.

4.1.2 Summary of inspections and tests planned by EDF

4.1.2.1 Unit conformity examination (ECOT)

On the occasion of the periodic review of each reactor, EDF carries out a design and construction verification, called a "unit compliance review", aimed at specifically monitoring the reactor compliance with its applicable safety benchmarks before the re-examination in order to detect any latent deviations and, if necessary, to correct them. This examination is carried out in addition to the current maintenance and monitoring arrangements as well as the treatment of deviations.

EDF's approach to establishing its ECOT program for the fourth periodic review of 900 MWe reactors turns out to be very close to that implemented during previous reviews. After integrating ASN's requests [7] and the additions defined during the examination of the orientations of the fourth periodic review, EDF has chosen the following themes for this ECOT:

- processing of deviation sheets;
- qualification of equipment for accident conditions;
- the specific features of the design and production of backup equipment for each site;
- the black steel pipes, under insulation, of the demineralized water distribution system (SED) and the crossings between the exterior and interior of buildings;
- the civil engineering of retentions and ultimate sumps with regard to non-radiological risks, the conformity of the buildings of the conditioning auxiliaries (BAC), the galleries and the concrete pipes with sheet metal core of the rescued raw water system (SEC);
- the main components making it possible to control liquid and gaseous radioactive discharges in normal operation;
- containment and ventilation;
- protection against earthquakes (supports and
- anchors); fire protection;
- protection against internal explosion;
- protection against flooding of internal or external
- origin; lightning protection;
- local crisis equipment and resources.

4.1.2.2 Extended in situ verification

In response to the requests made by ASN in 2016 and in addition to the ECOT program implemented for the fourth periodic review, EDF presented an approach that it describes

[7] The purpose of the design reviews is, in addition to checking the condition of the equipment, to verify the adequacy of the system design studies with the requirements set by the safety demonstration.

of "innovative". This approach is based on a transverse vision (multi-business) and visual checks carried out *in situ* of targeted materials to ensure their compliance.

EDF has chosen, to deploy its approach, systems important to safety that directly contribute to the reactor fallback and to its maintenance in a safe state, namely the steam generator emergency power system (ASG), the emergency raw water (SEC) and emergency generators (LHP / Q). EDF plans to carry out on-site visits to the pump rooms of the ASG and SEC systems and of the engines of the LHP / Q emergency generator sets.

Following ASN's examination of the responses to its requests formulated in 2016 [6] as well as the ECOT program, EDF undertook to carry out, during the fourth ten-yearly outages of the 900 MWe reactors, additional checks to those initially planned as part of its “innovative” approach, in particular checks of piping, sensors located in the reactor building, supports, and the sealing of the roof hoppers of the emergency generator set buildings , bolted assemblies and electrical equipment.

4.1.2.3 System design reviews

In response to the requests made by ASN in 2016 [6], and in addition to verifying the condition of the equipment, EDF identified the systems important to safety, the design studies of which have not been reviewed since. the commissioning of facilities whose operating experience feedback is unfavorable or whose failure would significantly increase the risk of core meltdown in an accident situation.

The design reviews retained by EDF for the 900 MWe reactors concern the intermediate refrigeration systems (RRI), stationary refrigeration (RRA), emergency power supply for steam generators (ASG), treatment and cooling of swimming pool water (PTR), spraying and recirculation of the spray water in the enclosure (EAS) and safety injection (RIS), the electrical sources and the support ventilation as well as the cold source for the Bugey nuclear power plant.

For each system, EDF has:

- identified, in the safety reference system, the applicable requirements, such as, for example, the water flow to be guaranteed for a pump or earthquake resistance;
- verified the adequacy and consistency of the requirements with the operational monitoring requirements (for example, the criteria retained in the periodic tests specified in the general operating rules);
- specified the framework for dealing with inconsistencies that would be identified at the end of these verifications, if necessary using targeted on-site inspections.

4.1.2.4 Program of additional specific tests

Additional specific tests contribute to verifying that the reactor complies with the applicable safety requirements. They are carried out after the integration of the major changes associated with the fourth periodic review.

ASN asked EDF in 2016 [6] “ *to define, by the end of 2017, additional tests aimed at verifying [...] the overall functional behavior of PIEs with regard to their defined requirements and with regard to the main safety functions. Among these tests, some will relate in particular to PIEs for which the current process of current periodic and / or ten-year tests would prove to be insufficient, in terms of scope or frequency.* ". In response, EDF proposed a methodology to identify the specific tests to be performed during the fourth periodic review. This methodology is based on an analysis whose principles are similar to those applied in previous periodic reviews.

EDF's analysis consisted of examining:

- the representativeness of the functional tests carried out during the first start-up with regard to the state of the reactors after the fourth ten-yearly outage;
- the completeness and consistency of the requalification tests, carried out after each modification of the installation, in particular to take into account the cumulative number of modifications;
- the lessons learned from significant safety events that occurred during the implementation of the modifications incorporated during the third ten-yearly outages;
- the sufficiency of the checks carried out on changes in operating strategies dedicated to the management of accident scenarios in the dimensioning domain and in the complementary domain[8].

It has been supplemented specifically for the fourth periodic review by:

- the examination of the overall functional tests of the new systems installed beforehand and during the fourth ten-yearly outage which are not included in the periodic test programs;
- analysis of a list of tests proposed in 2018 by IRSN.

Following these analyzes, EDF identified four tests to be carried out for the fourth periodic review, three of which correspond to modification requalification tests and one test concerns the operation of the generator sets at high outside temperature.

4.1.2.5 Reduction of deviations

EDF took into account ASN's request asking it " *to strengthen [its] organization in order to be able to correct, at the latest during the fourth ten-yearly outage of each 900 MWe reactor, the deviations having an impact on safety which will have been previously identified "and for" the deviations detected during the during the said ten-yearly inspection [to correct them] as soon as possible, taking into account their importance for safety* ".

In the event that the treatment of certain deviations cannot be carried out at the end of the fourth ten-yearly outage, EDF plans to justify the acceptability of the postponement of their elimination and to present the processing deadline. EDF also reaffirmed its desire to give priority to bringing them back into conformity as soon as possible.

4.1.3 ASN's position on achieving the objectives of the review

4.1.3.1 Unit conformity examination (ECOT)

The ECOT, as planned by EDF for the fourth periodic review, essentially consists of drawing up an inventory of the application of the existing basic preventive maintenance programs, or even implementing them for the first time, without proceeding, for most of them, on site visits to check the conformity of the equipment.

The persistence of numerous compliance gaps on topics verified during previous ECOTs leads to questioning the process put in place by EDF. ASN notes that the detailed ECOT programs associated with the fourth periodic review of the 900 MWe reactors planned by EDF are a continuation of the previous years and include very few checks in the field. These programs were however supplemented by controls *in situ (* see paragraph below).

[8] "Complementary domain": accident studies in the "complementary domain" include accident situations not taken into account when sizing the installations. The list of these studies is revised on the basis of a new version of the reference probabilistic safety studies (reactor and fuel storage pool).

ASN also notes that certain themes of the ECOT which had led to the identification of numerous recurring deviations (such as, for example, in the anchorages, the supports, the "earthquake event" [9] have not always led to changes in current operating arrangements in a sufficiently responsive manner. ASN asked EDF [8] that the lessons learned from the inspections carried out within the framework of the ECOTs be incorporated more reactively into the current operating provisions in order to guarantee the compliance of the installations.

In general, ASN considers that the checks carried out within the framework of the ECOT must be supplemented by other procedures, which are the subject of the following paragraphs.

4.1.3.2 Extended in situ verification

Controls *in situ* additional amounts defined by EDF constitute a definite advance over the ECOTs carried out during previous periodic reviews.

However, even if the choice of systems (ASG, SEC, LHP / Q) is relevant, the scope of the controls, as currently defined, is limited to certain equipment and components of these systems. ASN considers that the conformity check on a portion of the system is insufficient. Indeed, some unverified parts of this system may themselves be non-compliant and call into question the compliance of the system. Therefore, the verification of compliance should be extended. At the end of the investigation, EDF undertook to complete its control program, which is satisfactory.

In addition, ASN also asks EDF [8] to specify, before carrying out the site visits, the requirements that EDF plans to check during these visits. In general, ASN considers that additional information is still necessary in order to verify and ensure control of the conformity of the 900 MWe reactors, in particular concerning the proper consideration of operating experience feedback.

The application of EDF's approach was the subject of ASN inspections as part of the fourth ten-yearly outage of reactor n ° 1 of the Tricastin nuclear power plant and of reactor n ° 2 of the nuclear power plant. du Bugey ([9] and [10]). The lessons learned from these inspections as well as the conclusions resulting from the investigation were the subject of additional requests from ASN [8].

Finally, ASN will assess the results of the compliance control actions implemented by EDF during the review of each reactor and their lessons. ASN will ensure the relevance of the adaptations that EDF will deploy as it carries out its checks.

4.1.3.3 System design reviews

ASN notes the substantial verification work carried out by EDF, which was thus able to deal with the inconsistencies between the safety standards, the general operating rules and the classification of certain equipment. These reviews also made it possible to detect two compliance deviations, which are currently being processed by EDF.

However, this approach has essentially led to formal reviews and does not fully meet ASN's expectations; in particular, they do not deal with aspects related to sizing, manufacture, maintenance, operation, feedback and reliability.

In addition, ASN considers that EDF should extend the design reviews to other systems, which support the operation of systems important to safety, such as the regulated compressed air distribution system (SAR).

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9 The “earthquake event” approach consists of identifying the structures or equipment which were not dimensioned at the design stage to withstand seismic stresses and which are liable to damage or attack, through their failure in the event of an earthquake, equipment or buildings necessary for safety in the event of an earthquake.

Finally, even taking into account the other compliance verification actions implemented as part of the fourth periodic review, the design reviews are based on too few field visits, in particular with regard to the consideration of any site specificities.

These points were the subject of requests from ASN [49] so that EDF could complete its reviews.

4.1.3.4 Program of additional specific tests

ASN noted that EDF had initially selected only four tests and considered that EDF's proposal in terms of specific tests (number and type) was insufficient.

During the appraisal, EDF undertook to study the interest and feasibility of several additional tests:

- an engine operating test after opening of an electrical phase on the transmission network on a reactor at the Fessenheim nuclear power plant;
- an operational test of the steam generator emergency power supply turbopump (ASG) at the Bugey nuclear power plant while the level of the food tank is low;
- specific tests at the end of the summer 2020 temperature measurement campaign carried out in the premises of a CPY type reactor housing equipment presenting major safety issues and low temperature margins during periods of high heat;
- tests to confirm the qualification of scientific calculation tools dedicated to thermohydraulics (MANTA and CATHARE).

In addition, during the examination, EDF identified specific tests allowing the qualification of scientific calculation tools dedicated to neutronics to be confirmed.

EDF also carried out an exhaustive analysis of the periodic test programs: it did not identify any safety requirements that would not already be verified by a periodic test or equivalent control.

However, ASN considers that these proposals do not make it possible to meet its request, in particular with regard to tests on equipment for which the current process of periodic tests or ten-yearly tests would prove to be insufficient, in terms of perimeter or frequency.

At the end of the investigation, EDF undertook to carry out additional tests, such as, for example, operating tests in the presence of smoke on electronic components taken from electrical panels, closing tests under full flow of valves. tires for which this closure is necessary in incidental or accidental operation, a test on the effectiveness of the spraying in the premises and measurements of hydrogen release in the laboratory on batteries taken from the reactors. However, ASN considers it necessary to supplement the EDF program by:

- tests to verify the operation of the steam generator emergency power system (ASG);
- tests making it possible to verify the capacity of the emergency generators (LHH / LHJ systems for the Bugey nuclear power plant and LHP / LHQ for the CPY type reactors) to operate in a prolonged manner for at least 48 hours;
- tests making it possible to verify the effectiveness of the measures implemented after a loss of track A of the ventilation system of the premises housing the electrical equipment (DVL) making it possible to ensure the operation of the electrical equipment;
- tests to verify the hydraulic characteristics of the pumps of the water sprinkler system in the containment (EAS) under conditions as close as possible to their operation in an accident situation.

These points are the subject of the ASN [CONF-B] prescription [48].

The precise methods of carrying out these tests are the subject of requests from ASN [49].

4.1.3.5 Reduction of deviations

ASN reiterates that the elimination of the deviations already identified is an important element in considering operation for an additional ten years. **This point is the subject of the ASN [CONF-A] prescription [48].**

In 2019 and 2020, ASN carried out several inspections before and during the fourth ten-yearly outage of reactor n ° 1 of the Tricastin nuclear power plant and of reactor n ° 2 of the Bugey nuclear power plant to check EDF's capacity to reduce the gaps present on these reactors. ASN considers that the organization put in place, and its development following the first inspections, makes it possible to meet the objective set by ASN on the whole, even if the process of detection, management and The analysis of the impact of cumulative deviations can still be improved ([12] and [13]).

4.2 CONTROL OF AGING AND OBSOLESCENCE

4.2.1 Specific objectives of the review

Controlling the aging and obsolescence of structures, systems and components (SSC) contributes to maintaining reactor conformity over time. The fourth periodic review of the 900 MWe reactors marks a special milestone in this regard. In fact, as certain materials and equipment are required to operate beyond their initial design assumptions, EDF must demonstrate their capacity to perform their functions with regard to the protection of interests at least for the ten years following the submission of the review conclusion report [50]. This is particularly the case for irreplaceable components such as the vessel and the containment enclosure.

In this context, ASN made, in its letter in reference [6], requests to be taken into account in the context of the review relating in particular to:

- identification and anticipation of the needs for exceptional maintenance
- operations; checks on buried or difficult to access piping;
- identification of electrical distribution components at high risk of technological obsolescence.

The detailed analysis of the aging control of certain equipment or structures (for example the vessel or the containment) is dealt with in paragraph 4.3.

4.2.2 Summary of inspections and tests planned by EDF

The approach to controlling the aging of installations implemented by EDF is based on three operational processes:

- the process of controlling the aging of structures, systems and components;
- the in-service inspection and maintenance process;
- the process of monitoring and dealing with obsolescence of equipment and spare parts.

These processes are supplemented by the complementary investigation program (PIC) and by a progressive qualification process.

The remainder of this paragraph will therefore present:

- the general approach to controlling aging adopted;
- suitability for operation and monitoring of equipment and structures;
- progressive qualification;
- exceptional maintenance;
- control of obsolescence;
- the complementary investigation program (PIC).

4.2.2.1 Approach to controlling aging

EDF's approach to controlling aging and obsolescence is based both on a generic analysis of aging and its consequences on structures, systems and components carried out by EDF central services, and on a specific local analysis to each reactor during its ten-yearly outage. It is based on the standardization of reactors, through the establishment of aging analysis sheets (AVF) and generic suitability files for continued operation (“component DAPE”) established for each component. or structure potentially sensitive to aging, the failure of which may have an impact on safety and whose aging control cannot be demonstrated by current operating provisions. The local analysis carried out for the

Fourth ten-yearly outage of the reactor results in the preparation of a suitability file for continued operation (“reactor DAPE”) and a local aging control program (PLMV).

The aging control approach also includes an annual periodic review of generic AVFs and a five-year review of “component DAPE”.

EDF is renewing its approach to controlling aging applied since the third periodic reviews of the 900 and 1300 MWe reactors, while strengthening its equipment renovation and replacement projects, with a view to continuing their operation until their fifth. periodic review.

4.2.2.2 Fitness for operation and monitoring of structures, systems and components

EDF has established and updated the generic AVFs and the twelve “component DAPE” for 900 MWe reactors. In their latest version, in accordance with the request expressed by ASN [6], all of these documents contain criteria of suitability for continued operation.

4.2.2.3 Progressive qualification

With a view to the continued operation of the reactors beyond their fourth periodic review, EDF has defined a strategy to extend the period of validity of the initial qualification to accident conditions (earthquake included) of electrical and mechanical equipment. It consists in verifying that equipment qualified for an initial period and operated during this period remains capable of performing its functions for an additional period under all of its operating conditions. If this verification is not acquired, the equipment is replaced.

4.2.2.4 Exceptional maintenance

EDF's maintenance strategy aims to define the actions to be carried out with a view to controlling the aging or obsolescence of systems, structures and components. These actions can relate to preventive maintenance, exceptional maintenance, or research and development.

Exceptional maintenance operations consist of significant replacements, renovations or repairs that require significant operational or financial resources, as well as an organization and dedicated resources, both at national and local level, to decide, program, manage and carry out these operations within deadlines compatible with safety issues and reactor standardization. Since EDF announced its intention to continue operating the reactors beyond their fourth periodic review, ASN has expressed its expectations on several occasions ([2], [6]).

EDF presented the arrangements planned for the fourth ten-yearly outages and clarified the link between exceptional maintenance and the aging control process. EDF has also identified possible improvements to better anticipate certain maintenance actions, particularly relating to the treatment of local issues.

4.2.2.5 Controlling obsolescence

Preventing equipment obsolescence, particularly qualified equipment, depends on the availability of spare parts: it requires the constitution of sufficient stocks of identical components or equipment or the establishment of a long-term supply of new components. or adapted or qualified equipment. The availability of spare parts is strongly conditioned by changes in the industrial fabric of suppliers, the stopping of the production of certain components and the continued activity of their manufacturer. The risk of reactor component obsolescence depends on EDF's ability to anticipate these changes while complying with nuclear safety requirements. In addition, prior to their assembly,

Considering the time scales associated with the design of new parts, strong anticipation is required. Following an internal review carried out in 2016 of the obsolescence management process, EDF defined an action plan to simplify and improve its organization to make it more proactive. This has resulted in particular in the restructuring of obsolescence treatment and the implementation of a monitoring system.

4.2.2.6 Additional investigation program

The objective of the complementary investigation program (PIC) is to check parts of the installation which do not already benefit from a preventive maintenance program. It thus aims to verify, by sampling on certain reactors during their ten-yearly outage, that certain areas not covered by a maintenance program are not sensitive to degradation mechanisms.

4.2.3 ASN's position on achieving the objectives of the review

4.2.3.1 Approach to controlling aging

EDF has taken into account the requests that ASN made in its letters in references [2] and [6] with a view to continuing operation of the reactors beyond their fourth periodic review.

The overall approach to controlling the effects of aging does not call for any comments from ASN in its principles. Its application must be rigorous to ensure control of reactor aging beyond their fourth periodic review.

However, the investigation revealed that additional information concerning the organization and the processes contributing to controlling the aging of structures, systems and components of reactors were necessary both at the level of EDF central services, mainly for the treatment of the return of the reactors. 'experience, the maintenance of qualification, the control of obsolescence or exceptional maintenance operations, only at the level of the sites, particularly for the taking into account of the specificities of the site in the files of aptitude for the continuation of reactor operation (DAPE) or local aging control programs (PLMV). EDF has provided information and implemented measures which should help resolve the difficulties identified. ASN will be attentive to their effects over time, especially during the inspections that will be carried out on these subjects. These various points are the subject of several requests from ASN [45].

ASN has also made additional requests for certain DAPE (paragraphs 4.2.3.3 and 4.3.2.3.3).

4.2.3.2 Fitness for operation and monitoring of structures, systems and components

During the appraisal, EDF undertook to clarify, update and create AVFs and to add additions, which is satisfactory. EDF also took into account the requests that ASN had made in its letters in references [2] and [6].

However, some points require additional information. They are detailed below for the vessel internals, the reactor building and fuel building pools and the transfer tube, in paragraph 4.3.1 of this report for the primary and secondary circuits and in paragraph 4.3. 2 of this report for concrete structures and certain components involved in containment control.

Tank internals

The internal equipment of the vessel includes the partitions to limit the movement of the fuel assemblies in normal and accident conditions, as well as

the envelope of the heart. They are subjected to different aging mechanisms such as cyclic stresses, irradiation or wear.

Irradiation is likely to cause a stress corrosion phenomenon known as the Irradiation Assisted Stress Corrosion Phenomenon (IASCC). ASN considers that the current monitoring of the bulkheads, bulkhead screws and reactor core shell screws is sufficient to detect any damage associated with this phenomenon for CPY type reactors.

However, the screws of the core shell of the reactors of the Bugey nuclear power plant are inaccessible due to a thermal protection screen and are therefore not monitored whereas, for this type of reactor, the cracking by IASCC of the screws bulkhead is proven and has led to the replacement of a large number of these screws. The casing screws could therefore in the long term be subject to the same phenomenon of cracking by IASCC. However, if the studies of the mechanical behavior of partitions take into account a possible degradation of the casing screws, the lack of control prevents validation. *in situ* the conservative nature of the number of degraded screws taken into account. As the risk of cracking increases with the irradiation, ASN considers that EDF must assess the actual condition of these screws in order to support the hypotheses of studies of the mechanical behavior of the envelope.

This point was the subject of a request from ASN [45].

Reactor building and fuel building pools and transfer tube

The metal skin of the reactor building pool and the spent fuel storage pool as well as the transfer tube must remain airtight to ensure their function.

As part of a program initiated in 2018 following the detection of several leaks in the metallic skin of swimming pools, EDF has planned actions to detect and repair such faults, as well as to monitor and maintain the drainage network and civil engineering structures of these pools.

As part of the examination of the fourth periodic review of the 900 MWe reactors, EDF has undertaken to carry out additional control and maintenance actions on the components contributing to the sealing of the pools of the fuel storage buildings (BK) and the reactor building (BR), as well as the transfer tube, which is satisfactory.

Concerning the transfer tube, EDF provided a note on the atmospheric corrosion mechanism of austenitic stainless steels, in particular in order to rule on the need to create a dedicated AVF. EDF concluded that this FAV is not necessary, based on the lack of experience feedback from such internal wall corrosion on French reactors in operation. This conclusion is not in accordance with the methodology for identifying AVFs which foresees the creation of an AVF also in the case of a potential aging mechanism, which is the case for atmospheric corrosion. Indeed, this cannot be completely excluded for the transfer tube, in particular with regard to international experience feedback. This point was the subject of a request from ASN [45].

The checks to be carried out on the transfer tubes are the subject of requests mentioned in the paragraph relating to the additional investigation program (paragraph 4.2.3.6).

4.2.3.3 Progressive qualification

Mechanical equipment

The valve assessments carried out confirmed the absence of an aging phenomenon affecting the integrity and operability of mechanical equipment. With regard to pumps, the appraisals carried out to date do not reveal any degradation linked to aging. At the end of the examination, EDF undertook to extend the scope of its expertise to include valves of different technologies from those of valves already assessed as well as two additional pumps, more representative of the pumps in operation of the reactors of 900 MWe.

The appraisals are in progress and will be finalized in 2021. ASN considers this program to be satisfactory with regard to the number of components appraised and will examine EDF's conclusions and the need for any additional actions to ensure that qualification is maintained. taps. ASN, however, drew EDF's attention to the vigilance to be paid to the phenomena of erosion, cavitation erosion and stress corrosion observed on certain reactors in operation [45].

ASN considers that the conclusions of these additional expertises on valves and pumps must be taken into account in the update of generic AVFs and “component DAPEs” scheduled for 2021. This point was the subject of requests for ASN [45].

Electrical equipments

ASN considers that the gradual qualification strategy adopted for electrical equipment qualified under accidental thermodynamic conditions or at significant irradiation doses is satisfactory for their operation beyond the fourth periodic review of the reactors. AVFs do not reveal an aging mechanism that would not have been taken into account during the initial qualification of the equipment and the operating conditions of the equipment in terms of temperature and irradiation remain overall in accordance with the limits set in the design. . In addition, EDF has carried out numerous tests to confirm the extension of the validity period for the qualification of most electrical equipment.

Regarding the electrical distribution equipment important for safety (high voltage distribution equipment in "area A"[10], distribution equipment supplied with low voltage, measurement transformers, protection relaying, inverters, rectifiers and converters) and motor drives supplied with low voltage having a qualification called "K3"[11] (Excluding servomotors), EDF detailed its off-take programs in 2019, which are currently being examined.

With regard to electrical cables, the mechanical and physicochemical properties of the polymer materials constituting their elements (insulating envelope, stuffing material and outer sheath) change under the effect of irradiation and temperature. The evolution of these properties has been the subject of laboratory tests and on sampled cables, the results of which have shown that qualification has been maintained. EDF has undertaken to carry out targeted samples of cables on site in order to confirm the aging kinetics of the insulation of the most stressed cables. In view of the monitoring arrangements implemented, EDF does not plan to replace any massive electrical cables for continued operation beyond the fourth periodic review of the 900 MWe reactors.

ASN considers that the conclusions of these additional expertises relating to electrical equipment must be taken into account in the update of generic FAVs and “component DAPE” scheduled for 2021. This point was the subject of a request for ASN [45].

Finally, ASN considers that the definitive shutdown of the reactors at the Fessenheim nuclear power plant should be used to carry out certain tests or assessments of components taken from these reactors in order to verify the behavior or the absence of degradation phenomena or of unforeseen aging, in particular for systems, structures and components that are difficult to access. ASN considers [11] that EDF must supplement its expertise by sampling equipment, to the extent of their representativeness, from the reactors of the Fessenheim nuclear power plant.

[10] The "field A" of high voltage (or HTA), or medium voltage, concerns electrical installations in which the voltage exceeds 1,000 volts without exceeding 50,000 volts in alternating current, or exceeds 750 volts without exceeding 75,000 volts in current continued.

[11] K3 qualification: K3 qualified equipment is located outside the containment and must be able to perform its functions in the event of an earthquake or degraded environmental situations.

4.2.3.4 Exceptional maintenance

Process

The investigation showed that EDF should aim for greater integration of safety issues into its exceptional maintenance decision-making process. In order to achieve this integration, EDF has changed its organization to achieve a single decision-making entity, with which the independent safety sector is now explicitly associated. ASN positively notes EDF's organizational changes and will be attentive to their effects.

In addition, ASN considers that the initiation of exceptional maintenance actions must be conditioned by criteria consistent with the suitability criteria established in the “DAPE components”. It notes positively that EDF incorporated in the review of the FAV in 2018 a link between the aptitude criterion and the exceptional maintenance that could be triggered in the event of this criterion being exceeded. However, recent experience feedback shows that the elements specified in certain FAVs do not always correspond to the means of repair actually available. This point was the subject of a request from ASN [45].

Finally, EDF anticipates developing exceptional maintenance solutions (replacement or repair processes and tools) in response to aging issues, mainly for large components. However, recent degradations have highlighted deficiencies in EDF's industrial strategy to react reactively to the hazards that arise during reactor outages. This point, which had already been the subject of an ASN request in 2016 [6], was the subject of an additional request in 2020 [45].

Cylinder heads of diesel engines of emergency generators

EDF has planned to replace the cylinder heads of the diesel engines of the emergency generator sets between 2016 and 2025, given their risk of thermal fatigue cracking, with the commitment that each reactor will have new cylinder heads on at least one of its two groups. emergency generators by 2021. ASN considers this replacement program acceptable.

Piping of fire protection systems

Partial or complete renovations of certain fire protection circuits have been carried out in view of the deterioration observed.

In view of the leaks in service observed on these circuits at certain sites, EDF supplemented these actions with an exceptional maintenance program allowing the renovation of these pipes, which is satisfactory.

Buried piping

An exceptional maintenance program for buried piping is being rolled out by EDF on all sites. ASN is attentive to the lessons that can be drawn from it.

Steam generators

EDF is completing the program to replace the steam generators in its 900 MWe reactors. The steam generators of five 900 MWe reactors still need to be replaced and will be replaced at the latest during their fourth ten-yearly outage.

ASN underlines the importance of the steam generator replacement program and the need for sufficient anticipation of these replacements, having regard to the end-of-life criterion that EDF has defined on the basis of the rate of plugging of the tubes.

4.2.3.5 Controlling obsolescence

Controlling obsolescence relies in particular on the spare parts management process. The process put in place by EDF to ensure the availability of spare parts has undergone significant improvements since the last investigation carried out by ASN in 2012. However, ASN still observes difficulties in the supply of parts. spare parts, which can sometimes lead to poor control of maintenance activities. At the end of 2019, ASN also noted a recurrence of supply or assembly deviations on site of unqualified spare parts.

ASN will be vigilant to ensure that the process implemented by EDF is implemented rigorously.

4.2.3.6 Additional investigation program

Process

EDF plans to carry out checks as part of the complementary investigation program (PIC) during outages for the fourth ten-yearly outage scheduled between 2019 and 2022. At the end of the investigation, in order to compensate for the time, sometimes long, of treatment of deviations detected within the framework of the ICPs, EDF undertook, in the event of discovery of an unexpected deterioration, to:

- extend the survey initially proposed by updating the note defining the PIC within six months;
- update the maintenance repository within two years from the establishment of the overall summary of the ICP, scheduled for mid-2023.

ASN considers this approach satisfactory in principle.

The investigation showed that the choice of reactors as well as areas subject to controls required additional justifications to take into account site specificities such as, for example, operating features, equipment replacements, particular isometries and the particularities likely to influence the state of the circuits. As a result, EDF has updated the note dedicated to the breakdown by family and by material of the additional investigations for the fourth periodic review in order to integrate and explain the choices that guided the experts in their selection of the different reactors (specificity of the reactor, equipment configurations, appropriate distribution of controls if no specificity).

However, with regard to the checks of the transfer tube between the pools of the reactor building and the fuel building of the 900 MWe reactors, EDF only plans to carry out internal television examinations over the entire length of the tube on only six reactors. This televisual examination is intended to verify the absence of disorder. However, its performance does not allow *a priori* failure to detect stress corrosion cracking type degradation. ASN asked EDF to find a control method capable of detecting stress corrosion cracking on the internal wall of the transfer tube [45]. In addition, ASN asked EDF to carry out an internal check of the transfer tube over its entire length for all the 900 MWe reactors, during their fourth ten-yearly outage [45].

ASN also drew EDF's attention to the fact that the maintenance reference system will have to be revised within a period of less than two years if the safety issues associated with the deviations that would be discovered during the implementation of the PIC so require. .

Finally, ASN waits for the deviations detected during the PIC to be processed within the same timeframe as the other deviations detected [45] (see paragraph 4.1.3.5).

4.3 SPECIFIC REVIEWS OF THE CONFORMITY OF CERTAIN FUNCTIONS AND THE AGING OF CERTAIN EQUIPMENT

4.3.1 Primary and secondary main circuits - Nuclear pressure equipment

4.3.1.1 Specific objectives of the review

EDF sent ASN in 2014 its work program to justify the integrity of the main primary system (CPP) and the main secondary circuits (CSP) of 900 MWe reactors beyond their fourth periodic review.

The objective of this work program was to update all the elements that contribute to the justification of this integrity:

- updating mechanical analyzes based, in particular, on significant changes in knowledge;
- updating the provisions to ensure that the integrity of the devices is maintained over time, taking into account their operating conditions and their evolutions.

In its position on the guidelines for the fourth periodic review of 900 MWe reactors [6], ASN asked EDF to complete its work program in terms of inspections and studies, in particular with regard to the mechanical strength of the reactors. tanks, taking into account the effects of the environment on the phenomenon of mechanical fatigue and the evolution of material properties.

4.3.1.2 Summary of studies carried out by EDF and identified modifications

4.3.1.2.1 Serviceability of reactor vessels

As part of the fourth periodic review of the 900 MWe reactors, EDF sent ASN a document justifying the in-service performance of the reactor vessels. This subject is of particular importance in the context of EDF's plan to continue operating the 900 MWe reactors beyond their fourth periodic review, insofar as the tanks are irreplaceable equipment whose failure is not postulated in the safety demonstration and whose ferrules [12] located to the right of the heart zone, called "heart rings", are subject to aging by irradiation.

The justification for the service life of the tanks is based on an analysis of the risk of sudden rupture of the tank shells for operation up to ten years after their fourth ten-yearly outage. The risk of sudden rupture arises from the joint presence of three factors: the presence of a technological manufacturing defect, an insufficiently tenacious material and a significant thermomechanical load. The analysis of the risk of sudden rupture of the core shells of 900 MWe reactors therefore comprises the steps described below.

Determination of the fault dimensions to be studied

EDF carries out checks on all 900 MWe core shells during the fourth ten-yearly outage of each reactor. At the end of these checks, EDF ensures that there is no change in the faults compared to the results of the checks carried out during the third ten-yearly outage.

The risk of sudden rupture analysis is carried out for a hypothetical defect (called "generic defect") postulated at the most irradiated point of the core shells (hot point), as well as for all the defects detected by the non-destructive tests carried out on these ferrules.

The dimensions of the generic defect correspond to the dimensions of the largest defect which could not be detected by the qualified non-destructive testing process currently used by EDF.

[12] A ferrule is a hollow cylindrical component constituting part of the outer shell of the vessel.

The dimensions retained for the defects detected in the core shells of the 900 MWe reactors correspond to those determined by the checks carried out, increased by the associated uncertainties. The tanks affected by the presence of faults are reactors n ° 2 of the Blayais nuclear power plant, n ° 5 of the Bugey nuclear power plant, n ° B1 and n ° B2 of the Saint Laurent nuclear power plant and n ° 1 of the Tricastin nuclear power plant.

Evaluation of material characteristics

To assess the embrittlement by irradiation of the material in the core zone of the vessel, EDF set up, from the start of reactor operation, an irradiation monitoring program consisting of exposing test specimens placed in capsules. inside the tank, then extracting these specimens to subject them to mechanical tests. An indicator of embrittlement is the profile of change in resilience as a function of temperature, determined by means of Charpy test pieces. These measurements and the profile curve which is deduced from them make it possible to determine the evolution of the brittle-ductile transition temperature of the material under the effect of irradiation. This requires determining the neutron fluence received by the core shells, in particular that at the most irradiated point, as well as the level of the defects detected.

The evaluation of the neutron fluence received by the cell is obtained by means of neutron calculations and data from the irradiation monitoring program (PSI) of the cells. EDF has planned to introduce hafnium neutron-absorbing rods at the periphery of the core, in line with the hot spots, in order to reduce the neutron flux by around 45% near the hot spots. The level of flux reduction actually obtained can only be validated after analysis of the results of the experiment with and without hafnium neutron-absorbing rods currently being carried out in reactor n ° 3 of the Tricastin nuclear power plant.

Assessment of the loads liable to initiate the fault in all normal, incidental and accidental operating situations

EDF has carried out numerous thermal-hydraulic studies in order to show that all the situations presenting a risk of sudden rupture linked to a significant cold thermal shock on the core shells have been dealt with in its file. This check was carried out according to different approaches, in particular by taking into account the transients of the complementary domain and by the search for additional transients in the file of the situations obtained by cumulating an aggravating to the situations of second and third categories.

EDF selected primary pipe rupture accidents with a diameter of between 3 and 6 inches in the third category (previously studied under the fourth category). The classification of transients in a category has an impact on the justification for the resistance of the core shells because the value of the safety coefficients[13] depends on this classification.

For each category of situations, EDF characterized the loadings that penalize the most for the holding of the tank.

Application of the sudden rupture risk analysis approach

This approach consists of determining the stress intensity factor and comparing it with the toughness of the material in the aged state.

In addition, EDF has, as it committed to in 2015, decided to add residual stresses to the loadings due to normal and accidental situations in the circular welded joints in the core area. EDF sent at the end of 2018 an assessment of the knowledge available on the residual stresses

[13] The safety coefficients are defined by the order of 10 November 1999 [46]. Depending on the situation of the reactor and the damage considered, a safety coefficient between 1.1 and 2 is applied to the loadings, that is to say to the pressure or thermal expansion.

in the welded joints of the core ferrules. On this basis, EDF proposed to retain a level of residual stresses of 70 MPa.

4.3.1.2.2 Monitoring of the aging of the molded elbows of the main primary circuit

The branches of the main primary circuit of the 900 MWe reactors are fitted with elbows molded in austeno-ferritic stainless steel, sensitive to thermal aging (particularly those in the hot branch). These elbows, five in number per branch, are located on the so-called “hot” portion of the circuit at the inlet of the steam generator and on the so-called “cold” portion of the circuit, namely on the “U-shaped” branch, at the outlet. steam generator and at the inlet of the tank.

Furthermore, these elbows have defects inherent in the method of manufacture which could, combined with thermal aging, increase the risk of sudden rupture.

In accordance with the objectives defined within the framework of the review guidelines, EDF has completed its studies relating to the aging of the molded elbows of the main primary circuit on the following points:

- aging kinetics;
- mechanical analyzes of resistance of elbows to different loads; the
- qualification of non-destructive examinations;
- improving knowledge of faults present in service.

EDF also revised the in-service monitoring strategy for these components and the replacement of elbows.

4.3.1.2.3 Inconel zones of the main primary circuit

Nickel-based alloys, known as “Inconel”, are used in particular in the main primary circuit of reactors, as forgings, rolled parts or as welds and coatings.

These alloys, which contain approximately 15 to 20% chromium, have been shown to be sensitive to stress corrosion (SCC) in a primary environment. Since 1989, new grades of Inconel alloys have been gradually introduced to replace the previous grades. These are alloys that contain 30% chromium, which is beneficial for their resistance to stress corrosion. To date, no case of stress corrosion has been discovered for these new Inconel alloys.

The safety issue associated with the phenomenon of stress corrosion is the loss of integrity of the second containment barrier, with the consequences of the risk of leakage in service or of rupture of the components concerned. Given the importance of the subject, EDF has created a file, called "Inconel zones of the main primary circuit", devoted to the in-service monitoring of these zones from the middle of the years. 90. This summary file presents for each component concerned the inventory of the design, the assessment of the risk of initiation of stress corrosion, the analysis of French and international experience feedback, the results of the analyzes. mechanical and safety studies, the inventory of the procedures for limiting the consequences and repairs available and the analysis of the adequacy of the maintenance program. This file also allows to update the state of knowledge on nickel-based alloys (in particular on the laws of initiation and propagation by CSC), the methods of mechanical analyzes, the development of specific non-destructive tests and the processes linked to the chemistry of the primary medium making it possible to slow the phenomenon.

The last update [14] of the “inconel zones of the main primary circuit” file was carried out over the period 2016-2018 and covers the experience feedback available at the end of 2017. This review was carried out before the fourth ten-yearly outages of the 900 MWe reactors, in accordance with the request issued by ASN [6].

[14] This file has already been the subject of three revisions, the first in 1995 and the following in 1999 and 2009.

The main changes compared to the previous version are the inclusion of French experience feedback with cases of stress corrosion detected on the bottom of vessel n ° 4 penetration of reactor n ° 1 of the Gravelines nuclear power plant and penetration of the bottom of vessel n ° 58 of reactor n ° 3 of the Cattenom nuclear power plant, the deployment of CCS prevention techniques, the development of new non-destructive tests, the improvement of knowledge of CCS mechanisms on the basis of the results of research and development projects and the taking into account of feedback from manufacturing experience of the reactor vessel cover adapters of the Flamanville EPR reactor.

In parallel with this file, EDF has drawn up a multi-year maintenance program for the Inconel zones of the main primary circuit which is updated every year. This program aims to define the nature and frequency of non-destructive tests and maintenance operations to be carried out in these areas, taking account of experience feedback.

4.3.1.2.4 *Regulatory reference files*

The regulatory reference files are required by articles 4 and 5 of the decree of 10 November 1999 [46]. They bring together the documents relating to the design, manufacture and operation of nuclear pressure equipment constituting the main primary circuit and the main secondary circuits of pressurized water nuclear reactors. EDF is required to update these files to take account of the actual use of the circuits, their possible evolution during operation and in particular the evolution of the properties of the materials and the defects observed, as well as experience feedback.

Assessment of sensitive areas

An area is said to be sensitive when the latter is identified as sensitive to fatigue or sudden rupture. The fatigue phenomenon of an area is evaluated using the wear factor. This factor is an indicator of the fatigue damage suffered by the equipment. With regard to the risk of sudden rupture, the aim of the studies is to analyze the capacity of an area to withstand the presence of large conventional faults during the most penalizing transients.

Sensitive areas are monitored using qualified non-destructive testing procedures. For the specific case of rounding of tank tubing, EDF has developed more efficient examination means than the means implemented up to now.

Loadings related to transients

EDF assessed the consequences of specific transients occurring on operating reactors on the damage to the materials of the equipment constituting the main primary circuit and the main secondary circuits. EDF has planned to update the situation file and has undertaken to analyze the impact of the update of the behavior analysis files on the mechanical strength of the equipment concerned and to adapt in-service monitoring if necessary to the end of 2020 deadline.

In addition, EDF has developed a method which aims to better assess the thermohydraulic loadings in the auxiliary piping of the main primary circuit subjected to thermal stratification.

Aging of materials

EDF has carried out test programs in order to know the properties of materials for up to 20 years after their fourth ten-yearly outage for each of the areas of the main primary circuit and main secondary circuits affected by aging phenomena. EDF has also initiated research and development programs aimed at strengthening the representativeness of these tests. These programs relate in particular to the effects of strain hardening on the aging of austenitic-ferritic stainless steel elbows left in place after a steam generator replacement operation and the aging of the welded joints of the main primary circuit.

Assessment of transients considering the situations and delays before the first intervention of the operators of the Flamanville EPR reactor

EDF analyzed the situations selected for the design of the Flamanville EPR reactor and examined the impact on the 900 MWe reactors of a delay before the operators' first intervention extended from 20 to 30 minutes with regard to the resistance of the heart zone of the tank, known to be the most sensitive. EDF also plans to study the consequences of taking this delay into account on the transients in the generic justification file for the elbows of the cold branch at the inlet of the vessel and of the tube plate of the steam generators.

Fatigue of austenitic and austenitic-ferritic steels

EDF has proposed a new benchmark for assessing damage linked to environmental fatigue on austenitic steels and austenitic-ferritic steels. EDF has undertaken, by the end of the third quarter of 2022, to quantify the conservatisms of this new reference system and to carry out additional tests in order to validate the extension of the approach to austenitic-ferritic steels.

EDF does not retain any environmental effect on the steels making up the main secondary circuits due to the dissolved oxygen level, considered insufficiently high.

Constraints generated by steam generator replacement operations

As part of the replacement of steam generators or primary pipes in the cold branch, EDF uses a mechanical calculation method making it possible to estimate more realistically the loadings induced, in the primary loops, by the so-called “secondary” stresses. EDF has therefore undertaken additional studies to verify with this method the absence of calling into question the mechanical design criteria of the loops of the main primary circuit following a replacement of the steam generator or a replacement of the primary piping in cold branch.

4.3.1.2.5 Primary and secondary circuit monitoring program

Taking into account changes in the state and operating conditions of primary and secondary main circuits is reflected in particular in the development of basic preventive maintenance programs (PBMP).

EDF sent ASN, in application of articles of articles 4 and 6 of the order of 10 November 1999 [46], the basic preventive maintenance programs of the main primary circuit and of the main secondary circuits of the 900 MWe reactors. , ahead of their fourth ten-year inspection.

4.3.1.3 ASN's position on achieving the objectives of the review

4.3.1.3.1 *Serviceability of reactor vessels*

The conclusions of the investigation were the subject of letters from ASN in references [51], [52] and [53] following the opinions of the standing groups of reference experts [92], [93] and [94], a summary of which is presented below.

ASN has no comment on the justification approach adopted by EDF, which consists of looking for the defects present, characterizing the properties of the materials and looking for the most penalizing transients.

Defects considered in the core ferrules

EDF has undertaken to rule, following the non-destructive tests carried out on the core areas of all the 900 MWe reactor vessels during their fourth ten-yearly inspection, on the absence of any evolution of the faults in the heart zone compared to the state observed during the checks carried out previously. In view of EDF's commitment, this point does not call for any comment from ASN.

Estimation of the fluence received by the vessel ten years after their fourth ten-yearly inspection

The effectiveness of hafnium rods in reducing the fluence of the vessel at the most irradiated point will be confirmed after the experiment on reactor n ° 3 of the Tricastin nuclear power plant for which EDF has undertaken to transmit the results to the end of 2020 deadline. Given EDF's commitment, and the conservatisms retained in the assumptions taken into account in the justification studies, this point does not call for any comment from ASN.

Characteristics of core shell materials subjected to aging under irradiation

EDF provided a large set of test results and characterizations of irradiated materials in response to ASN requests relating to the determination of the characteristics of materials subjected to irradiation.

As part of the irradiation monitoring program, EDF was required to exclude certain data deemed to be atypical. EDF attributes the atypical nature of these data to a sampling effect: the specimens used were taken from an area presenting a metallurgical singularity degrading their representativeness with regard to the behavior of the material of the vessel concerned. ASN asked EDF to check by means of toughness measurements that the envelope character of the minimum toughness curve of the vessel steel, resulting from the RCC-M code, was preserved. EDF carried out this check, which is satisfactory.

In addition, EDF produced a statistical analysis showing the negligible impact of its approach to excluding atypical data on the calculation of the standard deviation of the forecast law. Given the importance of the irradiation monitoring program and the data constituting it, ASN asked to carry out an exhaustive analysis of these atypical results in order to decide on their integration into the irradiation monitoring program. ASN also communicated additional requests for the tanks affected by an atypical result upstream of their fourth ten-yearly inspection, namely the tanks of reactors no.2 and no.4 of the Dampierre-en- nuclear power plant. Burly and reactor n ° B2 at the Chinon nuclear power plant.

Studies of thermohydraulic transients

EDF has carried out, on the one hand, an approach to select the most severe transients among all the operating situations that may be encountered by the vessel, and, on the other hand, the detailed characterization of the transients selected in terms of temporal evolution of temperature, flow and pressure.

With regard to the process for selecting the most severe transients, EDF has identified, for each category of situations considered, the transients likely to be the most penalizing for the risk of sudden rupture of the core zone. At the end of its investigation, ASN considers the categorization of primary pipe failure accidents proposed by EDF to be acceptable.

Taking into account the residual stresses in the welded joints of the core shells

EDF justifies the value of 70 MPa adopted by relying, on the one hand, on the design and operating codes used both abroad and in other fields, and on the other hand, on construction work. 'study and research presenting experimental or numerical evaluations of residual stresses. Most of the values resulting from internationally codified practices or studies in the literature are between 45 MPa and 100 MPa. However, these values cannot be directly transposed to welds on EDF reactor vessels.

ASN notes, on the basis of the elements presented by EDF, a certain variability in the levels of residual stresses retained in foreign design codes and in scientific publications, depending on the material of the shells and the filler material for the weld. , but also several parameters related to welding and stress relieving operations.

In the absence of any measurement or numerical simulation representative of the manufacturing process and the stress relieving heat treatment of welded joints in French tanks, ASN considered during the investigation that it was prudent to retain a level of residual stresses. envelope (100 MPa). EDF provided additional information to justify the envelope nature of the postulated value of 70 MPa. EDF is committed to continuing studies on this subject, notably by including the performance of measurements on representative models which can also be compared to numerical simulations.

These elements are deemed satisfactory by ASN insofar as the sensitivity of the analysis results of the risk of sudden rupture of the core zone to residual stresses is moderate.

Conclusion on the analysis of the risk of sudden rupture of the core zones of the 900 MWe reactor vessels

Taking into account the information communicated by EDF and the opinion of the standing group of experts for nuclear pressure equipment which met on September 8, 2020, ASN considers that the risk of sudden rupture of the core zone has been ruled out for the tanks. whose heart area has no proven defects. With regard to the risk of sudden rupture of the tanks concerned by the presence of proven faults, namely those of reactors n ° 2 of the Blayais nuclear power plant, n ° 5 of the Bugey nuclear power plant and n ° B1 and n ° B2 of the Saint-Laurent-des-Eaux nuclear power plant, EDF has undertaken to transmit the studies before the fourth ten-yearly outage of these reactors. For the reactor vessel n ° 1 of the Tricastin nuclear power plant, affected by proven defects,

4.3.1.3.2 Monitoring of the aging of the molded elbows of the main primary circuit

The conclusions of the investigation were the subject of the letter from ASN in reference [54] following the opinion of the standing group of experts in reference [96], a summary of which is presented below. .

ASN generally has a positive assessment of the studies and appraisals carried out by EDF on the thermal aging of molded elbows as part of the fourth periodic review of 900 MWe reactors.

However, certain points were the subject of requests from ASN, in particular on the prediction of the evolution kinetics, knowledge of the defects present in the elbows, the assumptions and methods used for the mechanical analysis of the bends. in-service performance of molded elbows, ductile tear strength, feasibility of elbow replacement, and in-service elbow tracking strategy.

EDF must therefore send additional justifications, particularly in terms of checks and calculations. Special attention is paid to a few particular elbows and elbows resulting from an atypical multiple casting. For elbows for which justification difficulties remain, EDF will have to define an appropriate treatment strategy, or even consider replacing them if necessary.

4.3.1.3.3 *Inconel zones of the main primary circuit*

The information transmitted by EDF concerning the sufficiency of the maintenance program for the Inconel zones of the main primary circuit was the subject of a meeting of the standing group of experts for nuclear pressure equipment on November 26, 2020.

ASN considers that EDF's maintenance strategy is acceptable and consistent with the lessons learned from reactors in operation. However, ASN considers that in-service monitoring of vessel bottom penetrations must be completed. As such, EDF will have to seek possible improvements to the current monitoring program and increase the frequency of inspections if experience feedback justifies it.

4.3.1.3.4 *Regulatory reference files*

ASN examined the assumptions and methods implemented by EDF in order to update the regulatory reference files for the equipment of the primary and main secondary circuits.

ASN considers in its letter in reference [55], on the basis of the opinion of the standing group in reference [95], that the global approach implemented by EDF in the context of updating the reference files regulatory framework is satisfactory. In particular, ASN considers that the approach to assessing sensitive areas implemented by EDF is suited to the challenges.

However, ASN asked EDF to reinforce certain examinations, in particular to check all the rounding of the vessel tubing according to the new examination procedures and to characterize the defects detected.

4.3.1.3.5 *Primary and secondary circuit monitoring program*

All of the basic preventive maintenance programs for the main primary circuit and the main secondary circuits of 900 MWe reactors were examined by ASN, which made comments and requests for additional information.

In particular, during the appraisal of the basic preventive maintenance program relating to the secondary part of steam generators, ASN noted that not all the connection welds of the casing shells are subject to periodic review. However, this secondary envelope is an element whose failure is not postulated in the safety studies. Although these areas are hardly stressed in terms of fatigue, ASN considers that their monitoring should be reinforced. In response to ASN's request [55], EDF has planned to strengthen this monitoring as part of its program of additional investigations.

4.3.1.3.6 Stress relieving heat treatment anomaly of the welds of steam generators

During 2019, EDF informed ASN of the discovery of manufacturing anomalies due to non-compliance with temperature ranges when performing stress relieving heat treatments (TTD). This heat treatment is carried out at certain welds by local heating processes.

These anomalies concern several steam generators installed on the reactors or intended to be so. EDF has undertaken to carry out checks on the welds concerned (thickness measurements, non-destructive tests to verify the absence of defects) and to provide justifications, before the reactors are put back into service or, where applicable, hydraulic tests carried out as part of periodic equipment requalifications.

This subject is therefore dealt with by ASN reactor by reactor.

4.3.2 Assessment of the state of containment

In a nuclear power plant, the safety function associated with containment aims, in normal, incidental or accidental operation, to avoid or, failing that, to limit the dispersion of radioactive substances inside the installation and in the environment.

This function is ensured:

- by the interposition of physical barriers, such as the containment enclosure of the reactor building, the tightness of which ensures static confinement of radioactive substances;
- by ventilation and filtration systems contributing to the dynamic confinement of radioactive substances and the recovery of potential leaks from static confinement barriers.

4.3.2.1 Specific objectives of the review

The reassessment of containment performance is one of the guidelines for the fourth periodic review of 900 MWe reactors [2].

The studies carried out and the modifications planned by EDF as part of the fourth periodic review of the 900 MWe reactors are intended, on the one hand, to demonstrate, in the context of the continued operation of the plants until the fifth periodic review, the ability of containment enclosures to perform their function and, on the other hand, to improve containment in order to reduce the radiological consequences in the event of an accident.

4.3.2.2 Summary of studies carried out by EDF and identified modifications

4.3.2.2.1 Mechanical behavior of the enclosures

The evolution of the mechanical behavior of the containments of the 900 MWe reactor buildings is monitored over time by an auscultation device which measures the deformations of the containment. This system is supplemented by a program of visual checks of the condition of the facings located on the outer wall, called the upper surface, of the enclosure (traces of corrosion, cracking of the concrete, etc.).

The auscultation device consists in particular of sensors, called extensometers, which measure the deformations of the enclosure. These sensors were initially embedded in concrete. Also, to compensate for the possible failure of certain sensors, EDF has installed new extensometers on all its reactors in operation, sealed to the upper surface of the enclosure wall. The implementation of these sensors was the subject of an ASN agreement.

The mechanical behavior of the enclosure is also monitored during the ten-yearly tests.[15], during which the interior of the enclosure is brought to a pressure representative of the accident conditions. During these tests, any leaks are characterized and, if necessary, repaired.

EDF studied the mechanical behavior of the enclosures on the basis of the deformations measured by the auscultation device under normal conditions and during the ten-yearly tests, as well as the faults which were observed during the inspection visits. This study responds to a request made by ASN in its position in reference [6] on the generic guidelines for the fourth periodic review of 900 MWe reactors.

EDF concludes that maintaining the structural strength of the containment is justified for the operating life of the reactors up to at least their fifth periodic review.

4.3.2.2.2 Mechanisms of enclosure aging

The enclosures are affected by several aging mechanisms:

- the loss of the prestressing of the concrete, which has an impact on the structural strength of the enclosures;
- corrosion of the metal skin covering the internal wall, which has an impact on the tightness of the enclosures;
- various pathologies which can create defects (cracks, porosity, localized swelling, etc.) and modify the mechanical characteristics of the enclosure; these defects may be such as to weaken the integrity of the reinforcing bars or the tension in the prestressing cables.

[15] The ten-year test of the enclosure consists in testing its resistance and tightness by applying an internal pressure of 4 bars relative to it. After inflation of the enclosure, when the pressure of 4 bars is reached, the leakage rate of the enclosure is measured. This rate must be lower than a limit value which results from the value indicated in the creation authorization decree (DAC). During this test, visual examinations and measurements of the deformation of the enclosure are also carried out.

4.3.2.2.3 Watertightness of the enclosure and the enclosure crossings

The purpose of the containment test is to ensure compliance with the sealing criterion of the creation authorization decree (DAC) during the following ten-year period. All the 900 MWe reactor containments complied with the maximum leak rate criterion during the test carried out during their third ten-yearly outage (maximum authorized leak rate: 0.162% per day).

For reactor n ° 5 at the Bugey nuclear power plant, repairs[16] of the containment were carried out in 2017 after non-compliance, during the test during the third ten-yearly outage, with a criterion relating to the evolution of the tightness between two ten-yearly outages. The leak rate and change rate criteria were met during the test carried out in 2017 following these repairs. EDF has also set up dedicated monitoring.

Crossings of the containment are unique points that can be the source of leaks. They are of three types: crossings which allow the passage of personnel or equipment, mechanical crossings (pipes) and electrical crossings. Their overall tightness is tested during the ten-year test. Each type of feedthrough is also subject to periodic leaktightness tests.

The bushings for personnel or equipment and the mechanical bushings are those which exhibit the greatest sensitivity with regard to the sealing performance of the containment enclosure. Their tightness contributes significantly to the overall performance of the containment in the event of an accident.

The airlock for personnel and the material access cover (TAM[17]) relies primarily on the integrity of their seal under normal and accident conditions. ASN authorized the installation of a new seal grade, given the obsolescence of the grade currently used.

In response to a request from ASN [14], EDF carried out an analysis of the leaktightness measurements of the TAM joints carried out during the openings and closings which are carried out during shutdowns for scheduled maintenance and renewal of the fuel of the 1,450 MWe reactors. EDF concludes that the tightness criteria are met during these operations, which makes it possible to guarantee the tightness of the TAM joints when the containment function of the enclosure is required by the general operating rules. EDF did not however carry out such an analysis on the 900 MWe reactors.

EDF has also carried out a process, called “sensitive crossings”, aimed at identifying mechanical crossings more sensitive to the risk of leaks. It made it possible to identify possible improvements to prevent the risk of leaks. In this context, EDF has rolled out a modification aimed at changing the valve technology which contributes to the sealing of certain mechanical crossings.

EDF has also assessed the resistance in the event of a serious accident of the elastomer seal of the only mechanical bushing of the 900 MWe reactors closed by a solid base, namely the tape of the transfer tube which connects the containment of the reactor. the building housing the spent fuel storage pool.

4.3.2.2.4 Monitoring of the containment seal during operation

The technical operating specifications of the general operating rules prescribe monitoring of the overall tightness of the containment during normal operation concerning the safety function associated with containment. The "SEXTEN[18] »Allows this monitoring by a measurement

[16] These repairs consisted in removing from the peripheral seal, which runs along the metallic sealing skin located at the bottom of the enclosure, the petroleum wax that it contained and replacing it with whitewash, which cuts off any possible leakage path and inhibits corrosion processes.

[17] The material access buffer is a circular steel door which serves to close the access through which bulky equipment and tools used during reactor shutdowns are brought inside the containment enclosure.

[18] SEXTEN: system for monitoring the containment leakage rate in operation.

daily and automatic enclosure leak rate. By these measurements, it indirectly detects any leaks occurring during the cycle.

If a leak is detected, the general operating rules require the operator to initiate a reactor fallback within 3 or 14 days depending on the extent of the loss of sealing detected. In response to the requests from ASN in reference [14], EDF defined calibration and maintenance requirements for this system. However, EDF considers that the SEXTEN is not necessary for the safety demonstration and, consequently, does not retain the SEXTEN as an important element for the protection of the interests (EIP) mentioned in article L. 593-1 of the environmental code.

4.3.2.2.5 Containment of peripheral buildings

EDF has also examined the containment of the peripheral buildings into which open the crossings of the enclosure which house circuits conveying radioactive materials. The confinement of these premises is based both on static elements (walls, doors, hoppers, cat flaps, inter-building joints, floor drains, etc.) and provisions contributing to dynamic confinement (air ventilation circuits, identification of the premises. at risk of the presence of iodine, iodine filtration circuits, etc.).

As regards the static elements involved in the containment of peripheral buildings, some of them have preventive maintenance programs that allow EDF to verify compliance with the requirements associated with containment.

With regard to the provisions involved in dynamic confinement and in particular the so-called "iodine-risk" premises [19] », EDF has implemented a new methodology aimed at updating the list of these premises in peripheral buildings. EDF also plans to roll out a modification aimed at connecting these premises to an iodine extraction and filtration circuit.

4.3.2.2.6 Risk of containment bypass

The first isolation valve for the water suction pipes from the sumps located at the back of the reactor building is located outside the reactor building. The sections of each of these pipes of the safety injection circuits (RIS) and water spraying in the enclosure (EAS) located upstream of their isolation valve thus constitute singular points with a risk of bypass. containment and are therefore designed with a double envelope [20]. Operating experience feedback from certain 900 MWe and 1300 MWe reactors has sometimes shown the presence of water in these double envelopes. If the origin of this water has not been identified, its presence is nevertheless likely to lead to the corrosion of the double envelopes and to cause their perforation, which would lead to a rupture of the containment. In response to the requests from ASN in reference [14], EDF implemented checks on these double envelopes (presence of water, thickness measurement) and created a new connection on the lower internal part of the horizontal sections. double envelopes to allow the introduction of visual inspection means. However, this modification only concerns a few 1300 MWe reactors at this stage.

During the third periodic review of the 900 MWe reactors, the probabilistic safety studies revealed a risk of core meltdown with the containment bypass in the event of a rupture of a coil of the thermal barriers of a motor pump set. primary [21] (GMPP). To reduce this

[19] Rooms at risk of iodine are rooms that may contain equipment which may contain iodine in gaseous form or which carries fluid potentially contaminated with iodine.

[20] The section of each pipe of the RIS / EAS circuits located at the intake of the sumps of the reactor building allows in an accidental situation the recirculation of borated water within the enclosure and to slow down the pressure build-up in the front enclosure. that it is not too great and requires depressurization inducing releases into the environment.

[21] The thermal barrier of the GMPP is cooled by the intermediate refrigeration circuit (RRI) which crosses the containment. A rupture of a thermal barrier coil can lead, if it is not insulated, to a rupture of the circuit.

risk, EDF has planned to make the automatic insulation of the thermal barrier more reliable. The implementation of this modification was authorized by ASN.

4.3.2.2.7 Extension of the third barrier

The extension of the third containment barrier includes portions of circuits and associated equipment that can convey radioactive substances from the inside to the outside of the containment, in particular in an accident situation.

As part of this review, EDF updated the list of circuits and equipment constituting the extension of the third barrier and updated the associated requirements (tightness, verification of resistance to temperature, pressure and irradiation, etc. .) so that these materials are functional in the situations where they are required. EDF verified compliance with these requirements for the circuits and equipment concerned, which led it to reinforce certain portions of the circuits or to replace certain equipment.

4.3.2.3 ASN's position on achieving the objectives of the review

4.3.2.3.1 State of containment

At the end of the investigation, ASN considers that the monitoring of the condition and behavior of the containment enclosures of the 900 MWe reactors is on the whole satisfactory.

In particular, ASN considers as satisfactory the conclusions of EDF relating to the mechanical behavior of the enclosures (limited deformation and compatible with the expected behavior requirements).

EDF has not, however, identified SEXTEN as an EIP because it considers that it is not necessary for the safety demonstration. ASN disagrees with this position. When the reactor is in operation, the SEXTEN is the only means of continuous monitoring of the containment state of the containment. The decree of February 7, 2012 defines EIP as follows: " *structure, equipment, system (programmed or not), material, component or software present in a basic nuclear installation or placed under the responsibility of the operator, providing a function necessary for the demonstration mentioned in the second paragraph of the article L. 593-7 of the Environment Code or checking that this function is performed* ". The SEXTEN participates in the control of the safety function associated with containment and makes it possible to detect any degradation that would occur during the operation of the reactor. As such, it must be an EIP, for which EDF must define defined requirements. These requirements will make it possible in particular to set a long-term framework for the measures to be taken when the SEXTEN measurements cannot be used or are not available (for example due to a faulty SEXTEN sensor).

This point is the subject of the ASN [CONF-E] prescription [48].

The tightness of the containment enclosure for reactor no.5 at the Bugey nuclear power plant will be the subject of special attention during its fourth periodic review, as this enclosure was the subject of a 2017 review. '' a repair aimed at restoring its seal.

4.3.2.3.2 Monitoring of containment vessels

The preventive maintenance programs implemented on the 900 MWe reactors before their fourth ten-yearly outage provide for the search for cracks and traces of corrosion, which requires the absence of debris or vegetation such as moss. These elements can not only obscure the facings and hamper inspection, but are also likely to accelerate the degradation of reinforced concrete.

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intermediate refrigeration unit (RRI) which is not dimensioned for the pressure and temperature of the primary fluid. This situation would lead to a non-isolable primary breach with containment bypass, due to the transfer of the primary water into the intermediate refrigeration circuit.

EDF presented the inventory of the cleanliness of the reactor building domes and the applicable preventive maintenance programs.

In addition, given the increased risk of premature aging of the prestressing cables in their anchoring zones when damage has been observed in the toroidal belt, ASN considers that an appropriate method of non-destructive investigation of the condition cables in this area should be researched to complement visual monitoring, periodic auscultation and overall analysis made on the basis of enclosure tests.

These points were the subject of a request from ASN [45].

4.3.2.3.3 Pathology of internal concrete swelling

The alkali-aggregate reaction (AAR) and internal sulphate reaction (RSI) phenomena, not postulated in the design and not having been the subject of special precautions during construction, are now taken into account in a DAPE. This "component DAPE" concerns the study of the structural behavior of structures affected by reactions of internal swelling of concrete (RAG or RSI) with a view to continuing the operation of these structures until at least the fifth periodic review, and without risk of cliff-edge effect beyond.

Although observations *in situ* are carried out to detect any internal swelling reactions of the concrete, ASN notes that there are no acceptability criteria associated with this monitoring. ASN notes the actions that EDF has taken to complete the state of knowledge presented in the DAPE relating to the risks of internal concrete swelling for its next review. However, ASN considers that the harmfulness of the pathologies must be proactively studied and that the thresholds should be clarified within the framework of the next review of the DAPE concerned, in order to judge the acceptability of the phenomena observed, with regard to the requirements and functions that civil engineering structures must fulfill (resistance, stability, containment).

This point was the subject of a request from ASN [45], which also applies to concrete structures other than the containment.

4.3.2.3.4 Improving the tightness of the containment and its crossings

ASN considers that all the changes planned by EDF within the framework of this review are likely to improve containment, in particular in the event of an accident with core melt, in particular:

- actions relating to the identification, improvement of waterproofing and planned checks of “sensitive crossings”;
- updating the list of circuits and equipment constituting the extension of the third barrier.

As regards the main passage through the enclosure, which is the material access buffer (TAM), ASN considers that EDF has not provided, for the 900 MWe reactors, the necessary justifications to guarantee its tightness. , when required by general operating rules, during certain reactor shutdown phases for scheduled maintenance and fuel renewal. This point is the subject of a request from ASN [49].

EDF carries out a tightness test after any maintenance operation likely to have an impact on the tightness of a mechanical crossing. ASN notes that a leak test is carried out before corrective maintenance operations but not before preventive maintenance operations. ASN considers that EDF must carry out an additional inspection campaign by carrying out, prior to any preventive maintenance operation likely to have an impact on the tightness of a mechanical crossing, a tightness test in order to identify any changes since the last test and learn from them. This point is the subject of a request from ASN [49].

4.3.2.3.5 Containment of peripheral buildings

ASN considers that EDF must complete its maintenance programs concerning the devices participating in static containment. In particular, EDF must ensure, during the inspections of the walls, that the faults that could be identified do not affect the requirements associated with containment. This point is the subject of a request from ASN [49].

4.3.2.3.6 Risk of containment bypass and extension of the third barrier

ASN considers, in the light of the probabilistic safety studies carried out as part of the fourth periodic review of the 900 MWe reactors, that the material measures, implemented following the third periodic review of these reactors, aimed at increasing the reliability of the reactor. automatic isolation of the thermal barrier from primary motor pumps is not sufficient. This subject is dealt with in paragraph 5.7.1.3.

In addition, ASN considers that the measures taken by EDF to check the double envelope of the emergency injection (RIS) and water spray in the containment (EAS) circuits, which constitutes an extension of the third containment barrier, are necessary but are not sufficient to ensure the absence of corrosion. These provisions therefore do not make it possible as they stand to demonstrate the integrity of this double envelope in an accident situation. At the end of the investigation, EDF undertook to complete the planned arrangements, which is satisfactory.

ASN notes that EDF has created an AVF associated with double envelopes, which is satisfactory.

4.3.3 Review of the conformity of the water recirculation function present at the bottom of the reactor building during a loss of primary coolant accident

In the event of a breach occurring on the primary circuit (loss of primary refrigerant accident or APRP), which cannot be compensated by the volumetric and chemical control system (RCV), the safety injection system (RIS) makes it possible to maintain the inventory in water in the primary circuit. During this accidental sequence, it may also be necessary to reduce the pressure in the containment by the water sprinkler system in the containment (EAS).

The borated water required to perform the functions of the RIS and EAS systems is taken from the tank of the swimming pool treatment and cooling circuit (PTR). When the water in this tank reaches a low level, the RIS and EAS systems then go into “recirculation”: they take water from the sumps at the back of the reactor building. In order to guarantee the operability of this recirculation function, the sumps are fitted with filters which prevent the transport of debris in the back-up circuits and the reactor core.

The recirculation of the RIS and EAS systems must be able to operate for a long time in order to guarantee the cooling of the fuel, including during the phase of long-term management of the accident.

Failure of the recirculation function can lead to core meltdown and significant radioactive releases to the environment.

4.3.3.1 Specific objectives of the review

International studies and experimental programs, carried out after an incident that occurred in 1992 at the Barsebäck nuclear power plant in Sweden, have raised questions about the risk of failure of the recirculation function of pressurized water nuclear reactors, in the event of clogging. sump filters located at the back of the reactor building.

EDF declared in 2003 a significant event for safety after having highlighted a risk of clogging of the filters of the sump sumps of the RIS and EAS systems in a fourth category PPRA situation [22]. After ASN expressed [88] reservations on its file, EDF modified its installations from 2005, in order to significantly increase the filtration surface area in the sumps.

Given the many questions that remained on the capacity to ensure water recirculation, ASN asked EDF to carry out a complete review of the recirculation function [4] then, as part of the fourth periodic review of 900 MWe reactors [6], to implement a work program relating to the evaluation of the recirculation function, including in particular:

- an in-depth justification of the reliability of this function, taking into account in particular the support functions of the RIS and EAS systems, any deviations affecting these systems as well as experience feedback;
- an analysis of the risks of loss of the recirculation function, taking into account the physical and chemical effects occurring upstream and downstream of the sump filters (risk of clogging), as well as the presence of air pockets in the pipes connecting the sumps to the pumps of the RIS and EAS systems.

EDF sent a work program to demonstrate the operability of the recirculation function in an APRP situation.

4.3.3.2 Summary of studies carried out by EDF

In response to ASN requests [6], EDF sent between 2016 and 2017 an update of its studies incorporating new assessments of the debris arriving on the filters, the quantity and nature of the debris passing through the filters and their impact on the cooling of fuel assemblies.

In this case, EDF concludes that there is no risk of loss of the recirculation function due to physical or chemical effects upstream or downstream of the filters. However, the expertise of this file having highlighted many questions, EDF has defined a new work program.

EDF has thus improved its demonstration of the reliability of the recirculation function and has initiated a test program relating to the qualification of filters and the cooling capacity of fuel assemblies. EDF in particular transmitted:

- an update of the characterization of the term source of debris upstream of the filters in line with the state of the 900 MWe reactors following the fourth periodic review;
- an assessment of the risk of pump cavitation, based on the margin in terms of minimum suction pressure (NPSH) of the pumps of the RIS and EAS systems, supplemented by studies specific to the reactors of the Bugey nuclear power plant;
- the specifications for basic chemical tests and filter qualification;
- the specifications for tests to demonstrate the cooling capacity of the fuel assemblies;
- a bibliographic study of the chemical effects on the clogging of filters and fuel assemblies;
- summary notes presenting the first results of its action plan as well as its position on the compliance of the recirculation function;
- a feasibility study of the possible modifications intended to ensure the efficiency of this function, as well as the modifications adopted in a risk reduction approach for the 900 MWe reactors.

[22] The sizing operating conditions are divided into four categories. This ranking results from the annual frequency of initiators. By way of illustration, “first category” accidents are associated with normal operation and “category 4” accidents are associated with the least probable initiators.

EDF's test program is still in progress. All the results will only be available
2022.

4.3.3.3 ASN's position on achieving the objectives of the review

ASN analyzed the main phenomena involved in the recirculation function and in particular:

- the nature and transport to the filters of the debris produced during an APRP;
- the nature of the debris passing through the filters and their harmfulness for the cooling of the fuel assemblies;
- the impact of the chemical composition of the water on the risk of clogging of filters and fuel assemblies;
- the risk of loss of the pumps of the RIS and EAS systems by cavitation and passage of

air. These points are addressed in turn below.

4.3.3.3.1 Characterization of the term source of debris upstream of the filters

Debris that can affect filtration can have several sources. This is primarily the debris generated by the destruction of the insulation installed on the equipment present in an area located around the breach in the primary circuit, elements destroyed by the high pressure and high temperature water jet (micro -paint debris, etc.), as well as debris and chemical compounds present on structures and materials leached by recirculating water.

Amount of insulation debris generated by the breach

The tests carried out by EDF and IRSN show that the composition of the insulation present and its mechanical conditioning have a strong impact on the operability of the recirculation function. In fact, the nature of the mechanical conditioning of the heat insulator determines the quantity of material which will be released, in particular under the pressure wave produced by the breach, and the composition of the heat insulator is a major factor in its susceptibility to generating chemical effects.

ASN considers that the approach proposed by EDF for evaluating the quantity of paint micro-debris generated by the jet effect is acceptable. In addition, EDF sent a comparative analysis with the American reactors in order to justify the assumptions made.

During the appraisal, EDF undertook to set up a follow-up of the inventory of heat insulators used and their location in the reactor building in order to ensure that the heat insulators present comply with the assumptions made in the demonstration of safety. ASN considers this commitment to be satisfactory.

To define the quantities of encapsulated insulation destroyed by the effects of the breach, EDF relies in particular on tests carried out on insulation used on certain reactors in the United States. At the end of the investigation, EDF specified that it would demonstrate the transposable nature of the results of the tests carried out in the United States on the “Temp-Mat” insulation for fibrous insulation installed on French reactors. ASN emphasizes that tests to determine the ZOD on the heat insulators installed on EDF reactors would make it possible to define a source term adapted to the situations actually encountered.

In the absence of heat insulators liable to generate chemical effects, the tests have shown that the reduction of fibrous heat insulators had in most situations a beneficial effect on the pressure drop of the filters.

EDF has set a benchmark of halving the thickness of the fiber bed per unit area on the filters and aims for a value comparable to international best practices. EDF has therefore decided to reduce the quantity of fibers that can be released in an APRP situation by replacing fibrous heat insulators located on the primary bottoms of the steam generators and the primary pipes with metallic heat insulating material and by installing, on reactors of the type CPY, strapping on the heat insulators of the large pipes connecting the RIS system accumulators and the pressurizer expansion line.

ASN considers that strapping is also necessary on the reactors of the Bugey nuclear power plant, given that the filters installed on these reactors are more sensitive to clogging.

At the end of the investigation, EDF undertook to carry out these modifications, which is satisfactory. **However, in view of the challenges, ASN supervises their deployment by prescription [CONF-C] [48].**

During the investigation, EDF indicated that it wished to retain, for the definition of the term source of debris, areas of breaches with limited deflection, in line with the applicable reference system for APRP studies. EDF has undertaken to complete its demonstration of the conservatism of the areas of breaches selected. ASN considers this commitment to be satisfactory.

Impact of "Microtherm" and "Protect 1000S" type heat insulators

The various tests carried out by EDF and IRSN in the presence of "Microtherm" and "Protect 1000S" type heat insulators show that these heat insulators have a very unfavorable effect with regard to pressure drops upstream and downstream of the filters and a significant impact on the risk of failure of the recirculation function due to their susceptibility to generate chemical effects.

ASN notes that EDF has undertaken to finalize the elimination of "Microtherm" type insulation and to significantly reduce the quantity of "Protect 1000S" type insulation on the pipes of the main primary circuit and its auxiliary pipes in the building. reactor building.

At the end of the investigation, EDF undertook to carry out these modifications, which is satisfactory. **However, in view of the challenges, ASN supervises their deployment by prescription [CONF-C] [48].**

Assumptions relating to the transport of debris

ASN considers that the assumptions relating to the transport of debris to the filters used by EDF in its demonstration are acceptable.

4.3.3.3.2 Characterization of the term source of debris downstream of filters and risk of clogging of fuel assemblies

EDF has not demonstrated the penalizing nature of the term source of debris used upstream of the filters to define the term source of debris downstream. EDF has undertaken to justify, through tests, the envelope character of the term source of debris considered downstream of the filters. ASN considers this commitment to be satisfactory.

The tests carried out by EDF confirm the very penalizing nature of "Microtherm" and "Protect 1000S" type heat insulators liable to generate chemical effects vis-à-vis the clogging of fuel assemblies. ASN considers that EDF must significantly reduce their quantity. This point is dealt with by ASN prescription [CONF-C] relating to the modification of the insulation [48].

4.3.3.3.3 Impact of the chemical composition of water on the risk of clogging of filters and fuel assemblies

Following the investigation, EDF undertook to complete its test program by taking into account the chemical conditioning of the water in the 900 MWe reactors as well as representative debris concentrations. EDF has also undertaken to carry out an additional program of full tests [23].

ASN considers these commitments to be satisfactory.

4.3.3.3.4 Risk of loss of the pumps of the RIS and EAS systems by cavitation and passage of air

In order to ensure the proper functioning of the recirculation function, EDF must ensure that there is no risk of cavitation in the pumps of the RIS and EAS systems.

ASN considers that the method proposed by EDF to verify the absence of risk of cavitation must be supplemented, in particular by the justification of the value of certain penalties retained in the studies, by the demonstration of the validity of laws used beyond of their usual field of application and by additional tests.

These points are the subject of requests from ASN [49].

In addition, EDF studied the risk of loss of RIS and EAS pumps by air suction in the lines and undertook to confirm its conclusions on the absence of harmfulness of this air present in these lines by tests and additional studies, which is satisfactory.

Special case of RIS and EAS pumps at the Bugey nuclear power plant

In an APRP situation, within two hours of the start of the accident, the EAS pumps at the Bugey nuclear power plant have a slightly negative minimum pressure value required for suction (NPSH) and the low pressure RIS pumps a significantly larger negative value.

To demonstrate the operability of the recirculation function during this period, EDF values the tolerance of the pumps to a cavitation regime, which it has verified by tests carried out on RIS pumps. ASN notes that these tests should be supported for the EAS pumps by more representative tests.

ASN notes that the NPSH value of the low pressure RIS pumps remains slightly negative despite the valuation of the containment pressure in the EDF studies. ASN notes that valuation in the pressure studies in the containment is, in principle, accepted by certain foreign safety authorities but rarely used; however, it does not correspond to the sizing rules which were applied to the RIS and EAS systems during the design of the reactors in the operating fleet. ASN therefore considers that the current situation of the low pressure RIS and EAS pumps of the reactors at the Bugey nuclear power plant is not satisfactory.

ASN notes that EDF has undertaken to perform cavitation tests on an EAS pump under representative conditions to verify the existence of sufficient margins, which is satisfactory. For low-pressure RIS pumps, which present the greatest risk of cavitation, ASN considers that EDF must justify that they are qualified to operate in recirculation, by implementing any necessary modifications. The tests carried out on the RIS and EAS pumps will have to integrate configurations making it possible to assess the capacity of these pumps to perform their function with and without valuation of the pressure in the containment chamber resulting from the loss of primary coolant accident.

These points are the subject of the ASN [CONF-C] prescription [48].

[23] Overall tests including in the same test filtration tests and fuel assembly clogging tests on a single experimental loop.

4.3.3.4 Conclusion on the reliability of the recirculation function

ASN underlines the important work carried out by EDF following the meeting of the standing group of experts for nuclear reactors held in 2019. The full results of the test program planned by EDF will be available in 2022. The investigation carried out as part of the fourth review, it was possible to define the acceptable assumptions to demonstrate the operability and reliability of the recirculation function with reasonable confidence. These elements will make it possible to update the safety reference system associated with the recirculation function.

EDF is committed to making major changes, as part of a risk reduction approach. These modifications will in particular contribute to a significant reduction in the chemical effects and in the quantity of fibers released, which will notably contribute to making the recirculation function more reliable.

ASN notes that the current test program is necessary for updating the safety demonstration, which will make it possible to conclude on the sufficiency of the modifications planned by EDF in its risk reduction approach.

ASN points out that the demonstration will have to *in fine* cover the entire spectrum of breaches studied in the safety demonstration, the three types of filter installed on the reactors and the chemical species dissolved in the recirculation water by the leaching of heat insulators, materials and structures.

These points are incorporated into the ASN [CONF-C] prescription [48].

4.3.4 Diesel power balance

The 900 MWe diesel engine (GES) standby generator sets power the back-up systems in the event of loss of external power supplies. These systems must make it possible to reach and maintain the reactor in a safe state. Each reactor is equipped with two emergency generators. Taking into account the rules adopted for the safety demonstration, the achievement and maintenance of a safe state must be ensured by a single emergency generator set. The purpose of the balances between the electrical power of the generator sets and the power consumed by the backup systems is to ensure that the power delivered by each emergency generator set is sufficient to supply all of the equipment that it helps.

4.3.4.1 Specific objectives of the review

As part of the fourth periodic review of the 900 MWe reactors, new equipment important to safety and backed up by diesels is added. This addition of electrical consumers makes it necessary to check that the power delivered by each emergency generator set is greater than the power consumed called by the consumers, for all the situations provided for in the safety demonstration, including in the event of high outside temperature. .

4.3.4.2 Summary of studies and tests carried out by EDF

With the aim of updating the electrical power consumed by the various consumers, EDF has carried out studies aimed at:

- define the actual maximum power consumed by certain equipment, instead of their maximum nominal power, and, in certain cases, adapting it to the accident situation considered (for example, the consumption of fans in winter is reduced);
- determine the power consumption by means of measurements *in situ* for certain emergency lighting systems.

In addition, EDF has carried out studies to reassess the power that can be delivered by emergency generators. The estimate of the available power is based on the revision of theoretical models predicting the temperature of diesel coolants as a function of the

outside temperature. Tests in high outside temperature conditions, carried out during the summer of 2019 on certain emergency generators, were used to adjust these models.

In order to increase the margins between the power that can be delivered and the power consumed, EDF has implemented modifications allowing:

- on the one hand, to reduce the electrical power consumed; EDF replaced certain equipment with low consumption equipment and planned to deploy modifications allowing, in certain accidental situations, to shed unnecessary equipment;
- on the other hand, to increase the power delivered by emergency generators; EDF has deployed CPY type reactors for all emergency generators [24], devices making it possible to limit the phenomena of vertical recirculation of hot air within the refrigeration system. These devices allow a gain in power in the event of high outside temperature.

4.3.4.3 ASN's position on achieving the objectives

For the evaluation of the electrical power consumed by the equipment, ASN notes that certain conservatisms (taking into account of the maximum power consumed, accumulation of non-simultaneous consumption) have been applied. However, certain phenomena such as aging, line loss and power variation when the equipment is put into tension have not been taken into account by EDF.

To assess the power that can be delivered by the emergency generators, EDF has revised its predictive models of the temperature of the diesel fluids as a function of the outside temperature. This revision is based on the test campaign carried out during the summer of 2019. These models are based on certain modeling assumptions. These subjects were the subject of requests from ASN [56] [49] in order to obtain conservative power values.

ASN notes that the margins [25] between the power delivered by each emergency generator set and the power consumed by the rescued equipment, calculated by EDF at the end of the generic phase of the fourth periodic review of the 900 MWe reactors, are, in certain situations, of the order of by a few percent. ASN considers that the minimum value of this margin must be greater than 5% to ensure, with a satisfactory level of confidence, the power supply to all the equipment backed up.
This point is the subject of the ASN [CONF-D] prescription [48].

At the end of the investigation, EDF undertook to implement a modification on the CPY type reactors to reduce the power consumed (this modification aims to inhibit the simultaneous operation of equipment). In addition, for the reactors at the Bugey power plant, EDF has undertaken to offload certain equipment and to study new modifications allowing an increase in margins.

In accordance with the recommendations of the association of heads of nuclear safety authorities in Western Europe (WENRA), EDF will study, at the end of phase B of the deployment of the modifications associated with the review, the power balance diesels for cumulative situations between a “heat wave” aggression, the loss of external electric power supplies and an aggravating factor (corresponding to the loss of a diesel).

[24] This deployment was carried out on all reactors except those of the Cruas power plant for which this problem does not exist given the specific features of this site.
[25] The margin corresponds to the difference between the power delivered by each emergency generator set and the power consumed by the equipment rescued, divided by the power delivered by the generator set.

4.4 SUMMARY AND REQUIREMENTS RELATING TO THE CONFORMITY OF INSTALLATIONS AND THE CONTROL OF AGING AND OBSOLESCENCE

Actions contributing to maintaining compliance and controlling aging (monitoring, maintenance, control, treatment of deviations) must be carried out on a daily basis on the installations. Since the conformity of the installations is an essential condition for their safety, its verification constitutes a fundamental objective of the periodic reviews.

As part of the fourth periodic review, EDF has planned to implement a reactor conformity review program which in particular makes it possible to ensure the correct application of existing preventive maintenance programs. EDF has also supplemented its actions with field visits carried out by multidisciplinary teams in certain premises including systems important to safety necessary in an accident situation to reach and maintain the reactor in a safe state. The fourth periodic review was also an opportunity to re-analyze the compliance of certain equipment or systems with regard to their safety requirements. In this regard, EDF has in particular checked:

- the ability of standby generators (diesel) to provide the required electrical power, in the high outdoor temperature situations considered in the safety demonstration; ASN prescribes the minimum value of the power margin of this equipment;
- the capacity of the borated water recirculation in the event of a loss of primary coolant accident. EDF has carried out significant R&D and studies to better understand the physical phenomena involved. EDF is committed to improving the reliability of the recirculation function by implementing modifications aimed at reducing the term source of debris liable to damage. to be transported by water as well as the risk of chemical effects. These modifications to the installations will ensure, with reasonable confidence, that the means provided for the recirculation of borated water in the event of an accident will be able to perform their functions. ASN prescribes their deployment schedule.

To complete the actions planned to verify that the reactors remain in conformity after around 40 years of operation, EDF has undertaken to carry out specific tests on equipment important for safety. However, ASN considers that this test program should be completed and prescribed additional tests to EDF.

Furthermore, since the third ten-yearly outages, EDF has implemented a process to control equipment aging and obsolescence, which contributes to maintaining reactor compliance. This approach no longer calls for comment in its principles. It is based on a generic analysis of aging and its consequences and on a local analysis specific to each reactor, in particular during its ten-yearly outage.

To justify the holding of the tanks up to ten years after the fourth ten-yearly outage, EDF has carried out studies of resistance to sudden fracture, taking into account the evolution of the characteristics of the materials and will carry out checks to ensure the absence of harmful defects in the steel during the ten-yearly outage of each reactor. The studies carried out make it possible to conclude that the capacity of the tanks without defect to operate for ten additional years. For tanks, for which checks carried out in the past have shown that they contain manufacturing defects [26], specific studies will be carried out before the ten-yearly outage of each of the reactors concerned. This was particularly the case for reactor n ° 1 at the Tricastin nuclear power plant.

The approach implemented by EDF to justify the behavior of the equipment in the primary and secondary circuits (regulatory reference files) is satisfactory. In particular, the approach

[26] Reactors n ° 1 of the Tricastin power station, n ° 2 of the Blayais nuclear power plant, n ° 5 of the Bugey nuclear power plant, n ° B1 and n ° B2 of the Saint Laurent-des-Eaux nuclear power plant.

assessment of areas sensitive to fatigue or sudden rupture by EDF is adapted to the challenges: these areas are subject to special monitoring by non-destructive tests.

EDF has revised its studies on the thermal aging of molded elbows in the primary circuit as part of the review and must provide additional justifications. With regard to elbows for which justification difficulties remain, EDF will have to define an appropriate treatment strategy, or even consider replacing them if necessary.

EDF reassessed the performance of the containment. ASN considers that the monitoring of the containment enclosures and their behavior is satisfactory. However, it requires certain additions, in particular on preventive maintenance programs, control of the premature aging of certain prestressing cables, and on the pathologies observed in concrete. In addition, the actions planned within the framework of this review will improve the containment at the level of the crossings of the enclosure as well as the peripheral buildings.

Finally, EDF has undertaken to give priority, in the event of a discrepancy being detected, to bringing it back into conformity rather than justifying its maintenance as it is. In particular, EDF has planned to correct, at the latest during the fourth ten-yearly outage of each reactor, any deviations having an impact on safety which will have been identified beforehand, which is satisfactory. Any deviations detected during the ten-year inspection will be corrected as soon as possible, taking into account their importance for safety.

In conclusion, EDF's program to check the conformity of its reactors as part of their fourth periodic review, supplemented by ASN's requests, is satisfactory. The application of this program to each reactor will have to be the subject of special attention on the part of EDF. ASN has therefore planned to carry out specific inspections on each of the reactors, in particular during the ten-yearly outage.

The control program and verifications planned by EDF, supplemented by ASN's requests, will make it possible to achieve the objectives set for the review.

*

At the end of the examination, EDF undertook to carry out most of the necessary additions that the ASN examination revealed. ASN prescribes [48] the implementation of the major safety improvements planned by EDF as well as certain additional measures that it considers necessary to achieve the objectives of the review.

Resorption of detected deviations

[CONF-A] Without prejudice to the provisions of section 6 of title II of the abovementioned order of 7 February 2012, the operator shall absorb, at the latest during the ten-yearly inspection preceding the submission of the report concluding the review, the deviations having an impact on safety which will have been identified prior to this. In the event of a particular difficulty, the operator justifies, in the file accompanying the request for agreement mentioned in article 2.4.1 of the appendix to the aforementioned decision of July 15, 2014, the postponement of the elimination of these deviations to - beyond the ten-year inspection and the associated schedule.

For the deviations detected during this ten-year inspection which could not be corrected during this inspection, the operator justifies the timetable for their elimination in the context of the file mentioned in the first paragraph.

Specific tests

[CONF-B] I.– No later than December 31, 2021, in order to ensure that reactors remain in compliance with the applicable safety requirements, to verify the fulfillment of safety functions and

to identify any deviations, the operator completes its specific test program with the following tests:

1. tests to verify the operation of the emergency power supply system for steam generators (ASG) in specific configurations of accident situations:
   - the capacity of the turbopump of this system to operate with a low level of the supply tank in order to ensure, under these conditions, the absence of phenomena liable to jeopardize the water supply to the steam generators . The test program includes a test on at least one reactor of the Bugey nuclear power plant and one CPY type reactor,
   - the capacity of the turbopump of this system to operate in a durable and prolonged manner without ventilation of its room in a situation of total loss of electric power supplies. The test program includes a test on at least one reactor of the Bugey nuclear power plant and one CPY type reactor;
2. tests to verify the capacity of the emergency generators (LHG and LHH systems for the Bugey nuclear power plant and LHP and LHQ for the CPY type reactors) to operate for a prolonged period of at least 48 hours. The test program includes an in situ test on at least one reactor of each nuclear power plant comprising 900 MWe reactors;
3. tests making it possible to verify the effectiveness of the measures implemented after a loss of track A of the ventilation system of the premises housing the electrical equipment (DVL) making it possible to ensure the operation of the electrical equipment; the test program includes a test on at least one CPY type reactor, after the deployment of the modifications planned during the ten-yearly outage preceding the submission of the
4. review conclusion report; tests to verify the hydraulic characteristics of the pumps of the water sprinkler system in the containment (EAS) under conditions as close as possible to their operation in an accident situation; the test program includes a test on at least one reactor of the Bugey nuclear power plant and one CPY type reactor.

In this context, it justifies the choice of reactors, and where applicable of the equipment, on which the tests will be carried out, as well as the associated schedule with regard to the objectives of these tests and their conditions of realization.

II.– For each of the tests appearing in its specific test program to be carried out on CPY type reactors, the operator carries out at least one test before December 31, 2024.

For each of the tests appearing in its specific test program to be carried out on reactors at the Bugey nuclear power plant, the operator carries out at least one test before December 31. 2025.

Reliability of the water recirculation function present at the bottom of the reactor building during a loss of primary coolant accident

[CONF-C] I.– No later than December 31, 2023 for ten reactors and December 31, 2025 for the others, the operator installs safety straps on the heat insulators of the pipes connecting the fuel injection accumulators. safety on the main circuit, as well as on the pressurizer expansion line.

II.– The operator:

1. carry out the necessary readings on the primary pipes and the primary bottoms of the steam generators with a view to replacing the fibrous heat insulators which are liable to release fibers in the event of a breach at the foot of the steam generator;

2. replaces these fibrous heat insulators. It checks that the temperature conditions remain compatible with the operation of the equipment necessary for the safety of the installation in a normal, incident or accident situation and implements any necessary modifications.

III.– The operator:

- carry out, no later than December 31, 2023, the investigations necessary to identify the lines containing microporous heat insulators of the "Microtherm" type in the reactor building and the auxiliary lines of the reactor building equipped with "Protect 1000S" type fibrous heat insulators including the diameter is greater than 50 mm;
- complete, no later than December 31, 2025, the replacement of the “Microtherm” type microporous heat insulators in the reactor building. At the same time, it replaces the “Protect 1000S” type fibrous insulation for all the auxiliary lines in the reactor building, the diameter of which is greater than 50 mm. It checks that the temperature conditions remain compatible with the operation of the equipment necessary for the safety of the installation in a normal, incident or accident situation and implements any necessary modifications.

IV.– No later than December 31, 2021, the licensee checks that the low pressure pumps of the safety injection system (RIS) of the reactors of the Bugey nuclear power plant are qualified to operate in recirculation, taking into account their risk. cavitation. If necessary, it defines the modifications to be implemented and the associated schedule.

No later than December 31, 2022, the operator checks, by tests on a representative pump, the capacity of the pumps of the containment sprinkler system (EAS) of the reactors of the Bugey nuclear power plant to perform their functions in cavitation situations likely to occur.

The tests carried out on the pumps of the safety injection system and of the containment spraying system include configurations enabling the capacity of these pumps to be evaluated to perform their function with and without valuation of the pressure in the containment. containment resulting from a loss of primary coolant accident.

V.– No later than December 31, 2024, the licensee updates its demonstration of the reliability of the water recirculation function present at the bottom of the reactor building after a loss of primary coolant accident. This update incorporates the lessons learned from filtration tests carried out under conditions representative of the installations and the accident situation.

Power margin expected for emergency generators

[CONF-D] The operator ensures, with a high level of confidence, the supply of all the equipment rescued by each emergency generator set in all situations of the safety demonstration. As such, the power balance of each emergency generator set has a margin of at least 5%. The operator implements any necessary modifications.

Enclosure containment monitoring system

[CONF-E] The operator establishes the defined requirements of the containment leak rate monitoring system in operation (SEXTEN), which constitutes an important element for the protection which participates in the monitoring of the containment when the masses air in the containment are stable.

5 ASN'S POSITION ON THE SAFETY Reassessment

5.1 MODIFICATIONS TO THE FACILITIES PLANNED BY EDF

In order to meet the objectives of the fourth periodic review of the 900 MWe reactors, EDF has planned to implement modifications to its installations and to modify their operating conditions.

To take into account the constraints linked to the control of the volume of work on the installations, to industrial capacities, as well as to the capacity of the teams in the field to integrate the various changes to the installations, EDF informed ASN in February 2017 of its industrial strategy, which consists of deploying the modifications associated with the fourth periodic review of 900 MWe reactors in several phases.

EDF therefore plans to deploy these modifications on each reactor mainly in two or three phases:

- a first phase or “phase A”: the corresponding modifications will be carried out before or during the ten-yearly outage of the reactor, that is to say before the submission of the report concluding the review. This phase brings together most of the modifications;
- a second phase or "phase B": the corresponding modifications will be made no later than five years after the submission of the report concluding the review;
- an additional phase, six years after submission of the review conclusion report, only for reactors carrying out their review before the end of 2021, in order to deploy certain additional modifications defined by EDF at the end of the review. These modifications will be deployed during phases A or B for the other reactors.

The tables below provide a list of the main changes associated with the review, according to four main categories:

- those related to the study of accidents without core meltdown, in order to prevent accidents with core meltdown;
- those related to improving the safety of the fuel storage pool; those linked to
- improving the robustness of installations in the face of attacks; those related
- to limiting the consequences of accidents with core meltdown.

The fourth review is also an opportunity to finalize the implementation of the "hard core", defined after the accident at the Fukushima nuclear power plant. This hard core of robust material and organizational measures aims in particular, in the event of an extreme situation, to prevent an accident with fuel melting or to limit its progression and to limit massive radioactive releases (see paragraph 5.8).

Management of accident situations without core meltdown

Goal	***Main changes***
Limitation of consequences radiological effects of accidents without core meltdown, including in the event of an attack, which should therefore no longer require the implementation of actions to protect the population	The studies sent by EDF take into account in particular: - increasing the flow rate of the turbine bypass and atmospheric relief valves (GCT-A); - the replenishment of the emergency steam generator supply tank (ASG) with water from the fire-fighting system; - the diversification and strengthening of one way of the emergency water supply system of the steam generators to the requirements of the "hard core"; - the installation of a boremeter on the discharge line of the chemical and volumetric control system of the main primary circuit (RCV); - increasing the minimum volume required in the borated water tank of the REA make-up circuit; - the replacement of the heads of the primary circuit pressurizer valves in order to increase their discharge capacity at low pressure; - the replacement of the electric power supply by the emergency turbo-alternator by an emergency diesel power supply; - the addition of an electrical architecture allowing the replacement of the ultimate backup diesel by the ultimate backup diesel from the neighboring reactor, if necessary. At the end of its studies and examination, EDF undertook to implement additional changes consisting in particular: - to increase the pressure of the injection accumulators safety of reactors using “MOX parity” fuel management; - to lower the initial internal pressure of the fuel rods of the “MOX parity” and “Cyclades” management systems; - to add shutdown clusters for the reactors at the Bugey nuclear power plant; - to make the recirculation function of the water present at the bottom of the reactor building more reliable, in particular by modifying certain heat insulators; - to add, in the "hard core", a pump allowing the back-up of the injection at the joints of the motor-pumps of the primary circuit.

Fuel storage pool

Goals	***Main changes***
Improvement of the provisions planned to manage accidental or stressful situations affecting the storage pool	The studies sent by EDF take into account in particular: - the creation of a diversified mobile cooling system (PTR bis); - automating the closing of a valve in the event of a breach a "very low" water level in the swimming pool. At the end of its studies and examination, EDF undertook to implement additional changes consisting in particular: - in the redundancy of the automatic isolation of the line suction of the swimming pool water treatment and cooling system (PTR).

Assaults

Goal	***Main changes***
Improved consideration of internal and external attacks on installations, by considering more severe attacks than those previously used and by postulating the failure of an equipment	The studies carried out by EDF made it possible to identify modifications to be deployed, such as: - the raising of certain dikes and protective embankments against floods; - improving the ventilation of electrical rooms; - modification of the valve control circuit of the primary circuit pressurizer to prevent them from opening in the event of an untimely order caused by a fire; - the fire protection of cables controlling the switching between the draw-off transformer and the auxiliary transformer, as well as of the power cables of an electrical box allowing the operation of the installation in a situation of total loss of electrical sources; - modification of the control circuit of the emergency turbopump of the emergency power supply circuit of the steam generators in order to prevent its inadvertent triggering; - separation by a flame-resistant screen of the redundant pumps of the swimming pool water treatment and cooling system (PTR); - the installation of a passive autocatalytic hydrogen recombiner in the battery rooms. At the end of its studies and examination, EDF undertook to implement additional changes consisting in particular: - by creating alarm devices on fire doors.

Management of accident situations with core meltdown

Goals	***Main changes***
Reduction of the risk of an accident with core meltdown and limitation of the consequences of this type of accident, in particular by limiting the situations that would require venting the containment and by reducing the risk of a breakthrough in the bottom of the this enclosure by the corium.	EDF has notably planned the implementation of: - a new device for spreading the corium in the back of the reactor building; - a device for flooding the spread corium; - of the EASu device allowing the evacuation of the power of the damaged core without it being necessary to open the ventilation and filtration device of the containment enclosure. At the end of its studies and examination, EDF undertook to implement additional changes consisting in particular: - by placing baskets of sodium tetraborate in the sumps in the reactor building; - by implementing a substitution of the EASu system for middle term ; - by setting up instrumentation in order to allow crisis teams to properly manage accidents with core meltdown - by reinjection of effluents from the fuel building to the reactor building; - in modifications to prevent and limit the contamination of groundwater.

5.2 REASSESSMENT OF RISKS ASSOCIATED WITH INTERNAL AND EXTERNAL AGGRESSIONS IN THE SECURITY DEMONSTRATION

The general approach to re-examining the risks associated with assaults includes reassessing the levels of assaults to be considered in the light of experience acquired and the development of knowledge, as well as examining the sufficiency of the provisions for protection against assaults.

As part of the fourth periodic review of the 900 MWe reactors, this reassessment also takes into account the new reference levels defined by the WENRA association.

5.2.1 Reassessment with regard to the reference levels defined by the WENRA association

5.2.1.1 Specific objectives of the review

In 2014, the WENRA association updated its reference levels applicable to operating reactors [47] and in particular introduced a new chapter specific to attacks of natural origin. In particular, the WENRA association has introduced the following points into the process of taking into account attacks of natural origin in the safety demonstration:

- the frequency of exceeding the intensity of attacks of natural origin to be used to size the protections must be less than 10^{-4} per year and per reactor;
- more severe aggressions than those defined in the dimensioning must be considered. The operator must verify that there is no cliff-edge effect and identify the means that make it possible to ensure the availability of safety functions to cope with such a level of aggression.

With regard to the general approach for taking into account attacks, ASN formulated, during the orientation phase of the fourth review of the 900 MWe reactors, its expectations by asking (SUR request n ° 22 [6]):

- the analysis of the positioning of the hazard levels retained in the context of this review compared to the target recommended by the 2014 reference levels of the WENRA association;
- in the event that the operator is unable to justify that the frequency of exceeding the hazard selected for the sizing meets the target recommended by the 2014 reference levels of the WENRA association, proof of the capacity of the installations to face hazards significantly greater than those used for the sizing

The reference levels of the WENRA association [47] also specify that the safety demonstration must analyze the risks induced by attacks of internal and external origin by adopting an approach similar to that adopted for internal events.[27] taken into account in the design domain. Thus, equipment failure, independent of the consequences of the triggering event and the most unfavorable for the management of this event, must be taken into account as an aggravating factor in stress studies.

During the orientation phase of the fourth periodic review of the 900 MWe reactors, ASN thus asked EDF (SUR request n ° 23 [6]) to apply the recommendation of the WENRA association concerning the taking into account of an aggravating factor in aggression studies. In addition, ASN has clarified its expectations with regard to its variation for passive equipment.[28] (for example the doors

[27] Events caused by a failure of a component of the installation or human error.

[28] A passive safety system or equipment is essentially characterized by:

- recourse to natural phenomena (gravity, pressure difference, etc.) to ensure its operation;
- the absence of support functions necessary for its operation;
- the absence of need for human intervention for its activation and functioning during the duration of its mission;
- a limitation of the use of active components to activate its operation.

firewalls, hoppers) by indicating that the failure of an equipment can only be excluded if it has a high level of reliability and that it must be considered systematically if it represents the most penalizing case in a study of safety, except to justify that the components are designed, manufactured, operated and maintained in accordance with a high level of quality and that they are not affected by the attack studied.

5.2.1.2 Summary of studies carried out

Hazards considered

EDF has defined a “WENRA 2014” hazard and positioned the hazard levels retained for the fourth review of 900 MWe reactors in relation to this one. It studied, for certain attacks, the capacity of the installations to cope with levels of attacks significantly higher than the hazards selected for the design when these are lower than the “WENRA 2014” hazard.

These elements are presented in the paragraphs associated with each assault.

Consideration of an aggravating factor

The method adopted by EDF for taking an aggravating factor into account in stress studies considers two types of equipment: active equipment (i.e. equipment that must change state to ensure its protective function) and equipment. passive.

The active equipment required to control the risks associated with an attack is called by EDF “aggression disposal equipment” (EDA). EDF's methodology assumes that equipment failure occurs the first time it is used in a stressful situation. However, EDF excludes the failure of certain active equipment, such as equipment implemented in advance for predictable attacks (heat wave, extreme cold, etc.).

In the stress studies carried out for the fourth periodic review of the 900 MWe reactors, EDF identified the passive equipment whose failure in the event of fire, explosion or flooding of internal origin would lead to significant consequences. on the installation. It has made special arrangements to make this passive equipment highly reliable.

5.2.1.3 ASN's position on achieving the objectives of the review

ASN's position on the hazard levels retained by EDF is presented in the paragraphs dedicated to each attack.

For aggravating factors, ASN considers that EDF's taking into account of a postulated failure of active equipment in its studies relating to attacks of internal origin (fire, explosion, load drop and collision, original flooding). internal) and external (flooding of external origin, extreme heat, extreme cold, attack on the cold source) increases their robustness and therefore improves the safety demonstration of the installations. This is a significant improvement over previous periodic reviews. The exclusion of the failure of certain active equipment is acceptable as part of a first exercise of taking into account an aggravating factor.

With regard to the approach adopted by EDF for passive equipment, the measures implemented to make certain equipment more reliable (fire doors, floor drains, etc.) also constitute a significant improvement for safety. The taking into account of such a failure only concerns the studies carried out by EDF for fires, explosions and floods of internal origin, which are detailed in the dedicated paragraphs. ASN emphasizes that EDF will have to carry out the studies to which it undertook during the appraisal with regard to taking into account the failure of passive equipment, in particular for other hazards.

5.2.2 Sensitivity of studies relating to attacks to the delays before the operators' first intervention

The delay before the first intervention of the operators constitutes a conventional assumption of the studies of the operating conditions of sizing of the reactors. For EDF reactors currently in operation, the response time is 20 minutes if the first action is to be carried out in the control room, and 25 to 35 minutes if this action is to be carried out at the level of the equipment concerned. For the Flamanville EPR reactor, these times are respectively 30 minutes and one hour.

As part of this review, EDF examined the sensitivity of the stress studies of the 900 MWe reactors to the delays before the first intervention of the operators selected for the studies of the Flamanville EPR reactor. In practice, these sensitivity studies were carried out for fires and floods of internal origin; these studies are presented in the paragraphs relating to these attacks.

For other attacks, either no particular action is required on the part of the operators, or the actions can be anticipated (predictable attacks), or the time available to carry them out are long.

5.2.3 Taking into account the evolution of knowledge for climatic aggressions

The climate watch carried out by EDF consists in evaluating the possible changes in hazards resulting from climate change and in ensuring that these changes are not likely to call into question the sizing of the facilities with regard to climate hazards.

5.2.3.1 Specific objectives of the review

As part of the fourth periodic review of the 900 MWe reactors, ASN requested, during the review orientation phase [6], that EDF update the levels of climatic hazards based on the state of knowledge most recent scientists.

5.2.3.2 Summary of studies carried out

In response to ASN's request, EDF sent an approach to take into account climate change for natural hazards.

EDF has defined two sub-objectives for its climate watch approach:

- identification of climatic hazards whose evolution is plausible or certain, which could lead to reassessing the values of the benchmark;
- monitoring of the achievement of criteria triggering an in-depth analysis (notion of major climatic event), in order to guarantee the robustness of the values of the benchmark between two reviews.

EDF has classified the various natural attacks according to the degree of certainty of changes in hazards and the conservative nature of the current levels used:

- hazards whose evolution is certain and for which it is possible to make projections: hot air and water temperatures and sea level;
- hazards whose evolution is possible, but whose projection is uncertain: low water;
- hazards for which no trend has been identified in the metropolitan area: heavy rains, exceptional river flows, wind and tornadoes (storms in general);

- the hazards whose identified evolution makes the current situation conservative: cold water and air temperatures, frazil and snow.

Depending on the classification of the attack, EDF implements an adapted climate watch. This mainly consists of collecting data on hazards, then validating the projections used.

The climate watch process is carried out by EDF with the same frequency as the publication of the reports of the Intergovernmental Panel on Climate Change (IPCC).

EDF has declined its approach to:

- hot weather: it reassessed the “long-term temperatures” and “exceptional temperatures” (see paragraph 5.2.5). EDF defines reaching the exceptional temperature as a “major climatic event”;
- sea level: it re-assessed the sea level taking into account ASN guide no. 13 [85] and adding a margin so as to cover its evolution until the next periodic review. EDF defines the millennial premium as a “major climatic event”;
- low water levels: in the absence of consensus on the modeling of this phenomenon, EDF proposed a method to characterize the flows and associated water levels.

5.2.3.3 ASN's position on achieving the objectives of the review

ASN considers that the state of knowledge on which the climate watch approach implemented by EDF for the fourth periodic review is based is satisfactory.

However, ASN notes that the “major climatic events” triggering specific analyzes have not been defined for certain hazards, in particular for attacks relating to external flooding caused by rain, wind, tornadoes, extreme cold and cold. to the snow. ASN considers that EDF must define such events for all attacks. More generally, the criteria associated with “major climatic events” must correspond to a regional record or to an event with an estimated return period of 100 years. This point is the subject of a request from ASN [49].

ASN considers that EDF's reassessment process for “long-term” and “exceptional temperatures” complies with its SUR request no. 24 [6]. However, the investigation showed that EDF relies on statistical methods in order to carry out its climate trend extrapolations, without taking into account the results of existing climate models. Consequently, ASN requests that EDF compare the air temperatures evaluated from the statistical models and the temperatures evaluated by other climate models, during the next update of the climate watch. This point is the subject of a request from ASN [49].

For low water, the method used by EDF is based on an estimate of the flow rates of watercourses in a steady state, without taking into account changes over time. ASN considers that EDF must provide, at the next climate watch update, a quantified assessment of the possible effects of climate change, in particular concerning the risk of loss of the cold source in a low water situation. This point is the subject of a request from ASN [49].

5.2.4 Risks associated with the earthquake

The characterization of the seismic hazard with which each basic nuclear installation must be able to cope is based on a deterministic approach, detailed in the fundamental safety rule (RFS) n ° 2001-01 of May 31, 2001 [83]. This rule is supplemented by ASN guide 2/01 [84], which defines the earthquake-resistant design provisions for civil engineering structures.

The hazard characterization method consists of:

- first determine the “maximum historically probable earthquake” (SMHV), which corresponds to a return period of approximately 1000 years. This level of earthquake can be considered as the most intense "in living memory" recorded in the region considered; then define the
- “safety increased earthquake” (SMS), which corresponds to an increase in the magnitude of the SMHV of 0.5. In addition, the SMS is placed at a flat rate, in the seismotectonic zone to which it belongs, as close as possible to the nuclear site.

The SMS is therefore increased compared to the historical earthquake recorded in the region considered: it is more severe and it is placed as close as possible to the nuclear site. For some sites, taking paleoseismicity data into account can lead to completing the movements associated with SMS.

After the accident at the Fukushima Daiichi nuclear power plant (detailed in paragraph 5.8), ASN also asked EDF to check the robustness of its nuclear power plants to an even greater earthquake level, the “hard core earthquake”. (SND), for which the main safety functions must be able to be performed.

5.2.4.1 Specific objectives of the review

The work on earthquake-related risks, carried out as part of the fourth periodic review, has two components:

- verification of the facility's ability to cope with the SMS retained in the safety demonstration; this check includes:
  - the reassessment of the SMS for all the sites in order to take into account the evolution of geological and seismological knowledge to be considered in accordance with the fundamental safety rule [83],
  - verification, when the seismic movements associated with the reassessed SMS are greater than those considered during the previous periodic review and the design earthquake [29], compliance with behavioral requirements (stability, resistance, etc.) attributed to equipment and civil engineering works;
  - the lessons learned from the Kashiwazaki-Kariwa earthquake (Japan) in 2007, in order to verify the robustness of the 900 MWe reactors to the effects of an earthquake, in accordance with ASN requests [6];
- checking the capacity of the "hard core" to perform its functions in the event of an extreme earthquake, defined following the accident at the Fukushima Daiichi nuclear power plant. To this end :
  - a "hard core earthquake" (SND) is defined. It is associated with a seismic response spectrum which must [5] be enveloping the site SMS increased by 50% and the site spectra defined in a probabilistic manner with a return period of 20,000 years and take into account the site effects. individuals [30] and in particular the nature of the soils,
  - the capacity of existing systems, structures and components of equipment (SSC) belonging to the "hard core", to perform their functions in the event of a SND, as well as the dimensioning of the new equipment at the SND, are checked,
  - the absence of aggression of the SSCs belonging to the “hard core” by the other SSCs is verified.

[29] The installations were designed by using a design earthquake (called “SDD”) for the SSCs of the nuclear island, applicable to all reactors of the same type. For each installation, the SDD was higher than the SMS in effect at the time of its construction.

[30] In general, effects of amplification of the seismic movement can be observed for certain sites located on thick sediments or those located on a “sediment basin”.

5.2.4.2 Summary of studies carried out and modifications planned by EDF

5.2.4.2.1 Reassessment of SMS studies

Re-evaluation of the seismic response spectra

EDF took into account, for the reassessment of seismic hazards, the updating of the seismotectonic zoning and the updating of knowledge related to the reference earthquakes. EDF bases its analysis on the SisFrance database developed in partnership with the Bureau of Geological and Mining Research (BRGM) and IRSN.

EDF presented the characteristics of the SMS selected and the associated seismic spectra for the eight sites of the 900 MWe reactors, namely Blayais, Bugey, Chinon, Cruas, Dampierre-en-Burly, Gravelines, Saint-Laurent-des-Eaux and Tricastin .

The approach adopted by EDF is identical to that adopted in previous reviews. However, the methods used to estimate the magnitudes and depths of historical earthquakes have been updated in order to take into account an ASN request relating to the laws used to define the magnitude and depth of earthquakes according to their intensity [57]. Consequently, EDF proposed three regional laws calibrated according to all the earthquakes listed in France.

In the end, compared to the SMS retained for the third re-examination, the seismic spectra have changed:

- on the rise, for the Blayais, Bugey, Chinon and Gravelines sites;
- downward, for the Cruas, Dampierre-en-Burly and Tricastin sites;
- downwards at low frequencies and upwards at high frequencies for the Saint-Laurent-des-Eaux site.

Following the Teil earthquake on 11 November 2019 near the Cruas and Tricastin nuclear power plants, ASN asked EDF [44] to determine whether this event would be likely to lead to a reassessment of the level of seismic hazards. selected for the safety demonstration. In response, EDF considers that:

- the Teil earthquake has no impact on the definition of the SMS for the Tricastin site;
- the SMS from the Cruas site may be reassessed. This reassessment requires additional field investigations and should be completed by 2022. Pending the results of these investigations, EDF is proposing a new temporary dimensioning spectrum. This spectrum will be used to launch the seismic reassessment studies associated with the fourth periodic review of this site.

Specific site effects

ASN asked EDF [59] to take into account the specific site effects concerning the Blayais, Golfech, Gravelines and Tricastin sites.

In response and as part of improving the characterization of site effects, EDF has undertaken to instrument its sites and in February 2020 sent a first study for the Tricastin site. The latter concludes that there is no site effects for the Tricastin site, located on the eastern edge of the Messinian basin. EDF however considers a possible site effect in the center of the basin, where the sediment depth is greater.

Maintenance of systems, structures and components in SMS

As part of this review, EDF is using a seismic reassessment process for equipment known as “DERESMA”, already used in the context of the third periodic review of the 1300 MWe reactors. This approach aims to classify the equipment according to two levels, "high" or "moderate" according to the seismic requirements retained during their design and their role for the fallback and the maintenance in the safe state of the reactor after an earthquake. The approach leads to carrying out a seismic reassessment based mainly on:

- for equipment classified as “high”, on an analysis of existing margins or earthquake resistance calculations;
- for equipment classified at the “moderate” level, on inspections of the installation and condition of the equipment.

In its letter of 20 January 2015 [60], ASN made requests concerning this approach concerning:

- better consideration of materials providing the containment function by granting them a "high" level classification in the hierarchy of materials to be studied; the use of a
- conventional deterministic method calling on the criteria (coefficients and depreciation rate) used during the design of the equipment;
- the implementation of the inspection procedure for the location and condition of the equipment, so that all the stages in the justification of the seismic capacity of the equipment are detailed and that the acceptability of the changes adopted in relation to the to the method developed by the SQUG (Seismic Qualification Utility Group) and the EPRI (Electric Power Research Institute).

In its letter of April 20, 2016 on the guidelines for the fourth review of the 900 MWe reactors [6], ASN reminded EDF that it had to take into account its requests made in the context of the third periodic review of the 1300 MW reactors. MWe on the DERESMA approach before applying it to 900 MWe reactor equipment. EDF has therefore updated its approach.

As regards civil engineering structures, EDF has also drawn up, as part of the review, a methodological guide for the seismic verification of the civil engineering structures of buildings which play a role in safety.

Finally, in response to the letter from ASN [39], EDF carried out an analysis of stressful situations, in the event of an SMS, of a building which plays a role for safety by a building not dimensioned for the earthquake.

Consideration of experience feedback from the Kashiwazaki-Kariwa earthquake

On July 16, 2007, an earthquake measuring 6.6 on the Richter scale occurred in Japan near the Kashiwazaki-Kariwa nuclear power plant. During this earthquake, the earthquake-resistant measures aimed at guaranteeing a safe shutdown of the reactors played their role correctly. However, this earthquake caused a large number of anomalies (around sixty), in particular:

- a fire at an auxiliary transformer. The earthquake led to the cutting of the electric cables causing a short circuit, the sparks of which ignited the transformer oil. This fire, external to the buildings, had no direct consequence on the safety of the installation;
- an overflow of the fuel storage pool for reactor no. 6, with a wave height estimated at one meter. The overflowing water reached a cable crossing, then made its way through various casemates and pipes until it was discharged into the sea;
- the rupture of part of the anchorages of a water tank with a capacity of 900 m^3.

At the request of ASN [24], EDF defined an action plan aimed at taking into account the lessons of this earthquake.

In this context, EDF has planned to strengthen the controls or define new controls for the anchorages of certain reservoirs. In addition, EDF carried out studies and concluded that there were no consequences for nuclear safety:

- loadings induced in the event of an earthquake by the water present in the swimming pools on the doors and cofferdams of the reactor building and the fuel building as well as on the components of the fuel loading machine;
- overflows associated with induced waves in the fuel storage pool; a significant
- transformer fire.

5.2.4.2.2 "Hard core earthquake"

"Hard core" spectrum

The so-called “hard core earthquake” (SND) seismic spectrum is, in accordance with ASN decisions [5], the envelope of a spectrum corresponding to the SMS increased by 50% and of a probabilistic spectrum.

The probabilistic evaluation of the seismic hazard is based on an approach which consists in evaluating the probability of exceeding a given acceleration in a determined location. In accordance with ASN decisions [5], EDF has defined for each of its sites a seismic response spectrum associated with a return period of 20,000 years. The EDF study initially provided for the use of “CAV filtering” (Cumulative Absolute Velocity) of the spectra in order to retain only the seismic movements potentially damaging to the structures of the nuclear sites. Following a request from ASN, EDF finally gave up the use of this filtering.

Maintenance of systems, structures and components at SND

EDF has developed methodological guides to verify the performance of the existing “hard core” SSCs, in accordance with the prescription [ECS-ND9] of ASN decisions [5]. These guides deal with the seismic capacity of civil engineering structures and equipment such as tanks, valves, electrical equipment, piping, handling equipment or ventilation ducts.

As part of the fourth periodic review of the 900 MWe reactors, EDF plans, if necessary, to reinforce certain equipment at the SND. For example, EDF plans to reinforce the polar bridges, as well as reinforce the entire extraction network of certain ventilation systems for the reactors of the Bugey nuclear power plant.

5.2.4.3 ASN's position on achieving the objectives of the review

ASN examined the seismic hazard for the various sites and the guides proposed by EDF to justify the resistance of the systems, structures and components to the SND. The effects of earthquakes on each of the installations will be the subject of an investigation as part of the review of each reactor.

5.2.4.3.1 Seismic risk reassessment (SMS)

After examining the EDF file, ASN considered in 2016 [59] that the SMS reassessed by EDF were acceptable, for the sites:

- from Bugey, Cruas, Dampierre-en-Burly and Saint-Laurent-des-Eaux;
- de Blayais, Gravelines and Tricastin, subject to specific site effects being taken into account.

Requests have been made to reassess the SMS at the Chinon site.

In addition, EDF did not send any information in response to the request that ASN formulated during the review guidelines (SUR request no.22 of [6]) on the justification for reaching the probabilistic target. defined by the WENRA association (target exceedance frequency less than 10^{-4} per year and per reactor). This point is the subject of a request from ASN [49].

Case of the Chinon site SMS

EDF has chosen the Lanvaux (1930) and Langeais (1706) earthquakes as historical reference earthquakes for the Chinon site.

EDF also analyzed the Sainte-Maure earthquake of 1657, but using a lower intensity than that indicated in the SisFrance database. ASN therefore asked EDF to review its choice of reference earthquakes to determine the SMS for the Chinon site and to take into account the macroseismic intensities identified in the SisFrance database. In 2020, EDF sent a reassessment of the Chinon SMS based on the values in the SisFrance database. Following the instruction, EDF undertook to modify the accelerations considered at low frequencies, which is satisfactory. ASN considers that this spectrum must be considered as the SMS for the Chinon site.

Developments related to the Teil earthquake of November 11, 2019

The reassessment of the seismic spectra of the Cruas and Tricastin nuclear power plants following the Teil earthquake will be the subject of a subsequent position statement by ASN.

Specific site effects

ASN asked EDF [59] to better characterize the specific site effects, upstream of the fourth periodic review of the reactors of the Blayais, Golfech, Gravelines and Tricastin nuclear power plants.

EDF's analysis of the site effects for the Tricastin nuclear power plant transmitted in February 2020 will be examined as part of the examination of the elements transmitted by EDF following the Teil earthquake. EDF will have to complete its analysis by taking into account all the lessons learned from the Teil earthquake.

Resistance of structures and components to SMS

The instruction of EDF's approach to seismic reassessment of equipment (DERESMA) was carried out by ASN within the framework of the third review of the 1300 MWe reactors. ASN underlines the improvements made to this approach for the fourth periodic review by EDF and considers this approach acceptable.

However, ASN notes that, although the DERESMA approach assigns a “high” level to the function of confinement of radioactive substances, it does not however detail the list of equipment concerned, as ASN had requested in its letter [60]. ASN emphasizes that:

- the ventilation and air conditioning system of the backup auxiliary building (DVS) ensures the dynamic containment of the premises of the safety injection system equipment;
- the fuel building ventilation and air conditioning system (DVK) participates in the internal dynamic containment of this building in normal operation and in accident situations.

These systems contribute to the containment safety function and must therefore be classified as “high”. They must be subject to a seismic reassessment based on an analysis of the seismic margins or earthquake resistance calculations. This point is the subject of a request from ASN [49].

The guides relating to the resistance of civil engineering structures to SMS and to the analysis of stressful situations of a building which plays a role for safety by a building not dimensioned in the event of an earthquake have not been examined within the framework of of the generic phase of the review. These subjects will be the subject of further instruction.

Taking into account the lessons of the Kashiwazaki-Kariwa earthquake

ASN considers that the lessons learned from the Kashiwazaki-Kariwa earthquake are satisfactory on all subjects, with the exception of transformer fire situations following an earthquake.

Regarding the assessment of the consequences of a fire in a transformer initiated by an earthquake, additional information is still expected. In particular, EDF is committed to:

- complete the list of important elements for the protection of interests that may be damaged by this type of event and analyze their vulnerability;
- assess the consequences for safety of the penetration of fire smoke through the fresh air inlets of the premises of the rescued raw water circuit and of the water supply circuit of the fire network of the pumping station of reactor n ° 4 of the Tricastin nuclear power plant[31];
- identify the nuclear island ventilation systems likely to be exposed to fire smoke and determine any operating arrangements to be implemented in order to ensure the availability of the required safety functions for the duration of the fire .

Finally, ASN considers that the effectiveness of the measures put in place by EDF to control potential oil spills from transformers, making it possible to prevent the spread of a fire, must be assessed. This point is the subject of a request from ASN [49].

5.2.4.3.2 "Hard core earthquake"

"Hard core" spectra

EDF carried out a detailed probabilistic assessment, carried out within the tight deadlines imposed by the schedule for setting up the “hard core”. ASN notes the very important work carried out by EDF to establish the probabilistic spectra for all of its sites.

In 2016, the standing group of experts for nuclear reactors “ *noted that certain assumptions retained by EDF are not the subject of a consensus even though they have a significant influence on the calculation of the hazard [...]. By taking other assumptions that it considers more appropriate, IRSN has carried out its own calculations and proposed its own spectra. In a certain number of cases, the probabilistic spectra proposed by EDF without filtering by the CAV parameter on the one hand and by IRSN on the other hand are very similar. The Permanent Group considers that it is then appropriate to retain this common estimate as the probabilistic component of the spectrum representing extreme “hard core” aggression. Otherwise, the Standing Group does not consider itself in a position to decide between the two approaches, and therefore between the two results.* "[70].

Following the opinion of the permanent group of experts for nuclear reactors, ASN considered [59] that the 20,000-year return period probabilistic spectra determined by EDF for the definition of the SND (without using a " CAV filtering ”) are acceptable for the Dampierre-en-Burly, Gravelines and Saint-Laurent-des-Eaux sites.

On the other hand, the probabilistic spectra were not considered acceptable for the sites of Blayais, Bugey, Cruas, Tricastin and Chinon.

EDF has proposed, for these sites, a new “hard core” verification process, which no longer consists of considering the “hard core” spectrum in a raw manner, but in extracting two more realistic “seismic scenarios”. ASN considers that this approach, known as the “scenario approach”, is likely to give rise to many questions about the choice of scenarios retained, which would not allow a conclusion to be drawn for this review.

[31] The configuration associated with this reactor is special: the pumping station is located near a transformer and its facade, which is potentially exposed to the effects of fire, is fitted with air inlets.

For the Bugey, Cruas and Tricastin sites, ASN therefore asked EDF, first of all, to specify what vulnerabilities would be observed on these plants in the event of a "hard core earthquake". as defined by EDF in 2014, without adopting a scenario-based approach and, secondly, indicating what would be the possibilities of reinforcement which would make it possible to push back any cliff-edge effects at higher earthquake levels. EDF transmitted in May 2020 the conclusions of an initial analysis on these sites:

- on the Tricastin site, EDF indicates that the resistance of the SSC should be acquired for higher earthquake levels after carrying out certain additional studies, or even after certain reinforcements, with the exception of the resistance of the engine room building . This building is liable to attack buildings important for safety;
- on the Bugey site, EDF indicates that SSC resistance should be acquired for higher earthquake levels after certain additional studies, or even after certain reinforcements; in particular, EDF has identified certain risks of local collisions between buildings, for which justifications must be provided;
- on the Cruas site, the verification studies are less advanced, but EDF's preliminary conclusions are similar to those obtained for the Tricastin site.

ASN considers that this approach, which consists of verifying the SND withstand as defined by EDF in 2014 and identifying the possibilities of reinforcement in order to push back the cliff-edge effects to higher earthquake levels to take account of the uncertainties on the determination of the extreme hazard and any specific site effects, needs to be consolidated for the Tricastin, Bugey and Cruas sites, and to be extended to the Blayais and Chinon sites.

This point is the subject of the ASN [AGR-F] prescription [48].

Methodological guides for verifying the resistance to SND of existing structures, systems and components (SSC) of the "hard core"

To demonstrate the capacity of the SSCs to carry out their missions in the event of an SND, EDF has provided methodological guides.

In general, ASN considers satisfactory, in principle, the graduated approach used by EDF in these methodological guides. However, it is necessary to ensure beforehand that the SSCs comply with their reference system. Thus, the systematic and exhaustive checks carried out periodically *in situ* on the equipment, their support and their anchors are essential to help demonstrate this conformity.

However, ASN's examination of these methodological guides raised questions relating to the relevance and sufficiency of the justification methods used. These do not always make it possible to identify any weaknesses in structures and equipment for which simple reinforcement or limited justification could be provided.

The conditions of application of these guides need to be specified. In the case of containment enclosures and swimming pools, they must in particular take into account the requirements associated with the retention or confinement functions.

The assumptions made in these guides also require additional demonstrations, in particular concerning the evaluation of the behavior of anchorages and handling equipment.

The examination of these points, which is in the process of being finalized, is likely to give rise to requests from ASN.

5.2.5 Risks associated with high temperatures

The increase in temperatures during a scorching episode can have consequences for nuclear safety. Indeed, a nuclear power plant must maintain in its premises an ambient temperature compatible with the operation of the equipment necessary to ensure the three safety functions. If certain temperature thresholds are exceeded, any degradation of this equipment is likely to lead it to no longer perform its safety function or to perform it in a degraded manner. For example, reaching too high temperatures in the premises can lead to the failure of certain pumps providing a fuel cooling function.

Following the scorching episodes of 2003 and 2006, EDF defined new rules to be applied, grouped together in a repository, known as the “hot weather” repository. It led to the revision of the safety studies, notably considering higher temperatures as assumptions. The “hot weather” benchmarks consider two types of sizing situations:

- a so-called “resizing” situation for which the “resizing” temperatures are applied permanently to the installation;
- a situation of "heat wave aggression" consisting in studying the effect of temperatures higher than "resizing temperatures" but of a shorter duration to take into account possible heat waves.

Taking account of the experience feedback from the heatwave episodes of 2003 and 2006 also led EDF to create operational control procedures known as “special rules of conduct” (RPC) making it possible to initiate early actions to limit the risks associated with high temperatures or the effects of a heatwave event (such as electrical outages[32] or the installation of mobile air conditioners).

The “hot weather” benchmarks were examined between 2006 and 2013, with the ASN taking a position in 2013 [61].

The application of this standard has led EDF to identify a large number of necessary modifications: replacement of certain refrigeration units, improvement of the thermal conditioning of certain premises with insufficient margins, protection of certain equipment located outside, etc. Their implementation has been authorized by ASN.

5.2.5.1 Specific objectives of the review

As part of the fourth periodic review of the 900 MWe reactors, the objective is to reassess the temperatures to be considered in the safety demonstration, to study the consequences of these temperatures on the installation and to define and integrate any necessary modifications. . In addition, to respond to ASN requests [6], these re-evaluated temperatures must be positioned in relation to the “WENRA 2014” hazard (see paragraph 5.2.1). If these do not comply with the “WENRA 2014” hazard, EDF must study the capacity of the facilities to cope with temperatures significantly higher than those of the design.

5.2.5.2 Summary of studies carried out and modifications planned by EDF

EDF has reexamined the protection requirements vis-à-vis severe hot weather by integrating the latest elements of climate watch and the lessons learned from the previous instructions. EDF carried out new thermal studies for the conventional and nuclear islands of 900 MWe power plants, taking into account ASN's requests made in 2013 on the methodology and studies.

[32] Stopping of equipment carried out deliberately in the event of high temperature in order to avoid saturation of the electrical power supplied by emergency diesel generators.

In this context, EDF reassessed the temperatures to be used for resizing and heatwave situations associated with its benchmark. EDF has also defined a temperature that goes significantly beyond the heatwave temperatures used in its reference system, by retaining a target of a decamillennial return period.

EDF's approach aims to verify that the temperatures reached in the premises are compatible with the temperature guaranteeing the availability of the safety classified equipment located there. The temperatures reached in the premises are evaluated by software (ThBat) for outside temperatures corresponding to the two reference situations (“resizing temperature” and heat wave).

The studies show that the calculated temperatures exceed the admissible temperatures for 1,100 materials out of the 10,000 analyzed for CPY type reactors and for 200 materials out of the 9,000 materials analyzed for the Bugey nuclear power plant.

EDF distinguishes between two definitions of permissible equipment temperatures:

- the Tr is "the temperature acceptable to the equipment for operation limited to a few hundred hours per year, each year until the end of life of the reactors concerned";
- the Td is “the maximum temperature acceptable by the equipment in a steady state, throughout its lifetime. The steady state corresponds to the normal operation of the equipment " [33].

If the loss of this equipment in a situation of high temperatures does not call into question the achievement of a safe state, this equipment is considered by EDF as customs cleared. For other equipment, EDF plans to make changes to the equipment, as well as to operations (system monitoring and maintenance measures). In particular, EDF has planned:

- improving the thermal conditioning of rooms ventilated by the electrical room ventilation system;
- the installation of an air heater in the cold unit rooms;
- the replacement of the fan heaters of the emergency generator sets with equipment qualified at higher temperatures;
- the classification of many ventilation equipment to ensure a more important follow-up.

5.2.5.3 ASN's position on achieving the objectives of the review

The “hot weather” benchmarks were examined as part of the fourth periodic review of 900 MWe reactors. ASN underlines the extent of the studies carried out and the modifications planned by the licensee to protect its installations. ASN considers that the application of the “hot water” reference system constitutes a major step forward for the safety demonstration, although additions are expected and are the subject of prescriptions which could lead EDF to define additional modifications.

EDF defines for each site the high air temperatures corresponding to three distinct regimes:

- for "resizing temperatures", a steady state associated with a "long term" temperature;
- for the "heat wave aggression":
    - a short exceptional regime associated with an “exceptional temperature”, which is applied for 12 hours to equipment located outdoors or in buildings with low thermal inertia;

[33] For the majority of equipment participating in the safety demonstration, Td and Tr are combined; for other equipment the Tr is greater than the Td.

- an exceptional regime of longer duration, associated with a sinusoidal temperature cycle defined over 24 hours for 14 days, between the “exceptional temperature” and the minimum temperature during the heat wave.

ASN considers that the “resizing temperatures” used by EDF are acceptable in the context of this review. On the other hand, the temperatures of the exceptional regimes must be reassessed taking into account a return period of one hundred years, and not three years as proposed by EDF.

The investigation showed that EDF must retain, *at a minimum,* the following values for the definition of the situation associated with the heat wave in its "hot weather" reference system:

- an exceptional temperature greater than or equal to 41 ° C and a minimum temperature greater than or equal to 26 ° C for the Gravelines site;
- an exceptional temperature greater than or equal to 44 ° C and a minimum temperature greater than or equal to 29 ° C for the Blayais site;
- an exceptional temperature greater than or equal to 45 ° C and a minimum temperature greater than or equal to 27 ° C for the Cruas site;
- an exceptional temperature greater than or equal to 44 ° C and a minimum temperature greater than or equal to 26 ° C for the Dampierre-en-Burly site;
- an exceptional temperature greater than or equal to 44 ° C and a minimum temperature greater than or equal to 26 ° C for the Saint-Laurent-des-Eaux site;
- an exceptional temperature greater than or equal to 43.9 ° C and a minimum temperature greater than or equal to 29.3 ° C for the Chinon site;
- an exceptional temperature greater than or equal to 45.7 ° C and a minimum temperature greater than or equal to 27.3 ° C for the Tricastin site;
- an exceptional temperature greater than or equal to 44.4 ° C and a minimum temperature greater than or equal to 27.5 ° C for the Bugey site.

In addition, the temperatures selected must integrate the temperatures obtained from experience feedback from each site. This feedback will integrate the temperatures reached during exceptional events, such as those encountered for example during the summer of 2019, which experienced two exceptional heat waves due to their intensity.

At the end of the investigation, EDF undertook to revise its temperature assessment studies, which is satisfactory. **However, taking into account the stakes, ASN supervises their implementation through the prescription [AGR-A] [48].**

Concerning the temperatures reached in the premises to be compared with the permissible temperatures of the equipment, it appears that around 600 items of equipment have, at the end of the simulations, margins of 1 or 2 ° C and around a hundred items have no margin. These results do not take into account the uncertainties that exist in the various stages of the demonstration of the protection of the safety functions against “hot weather”, in particular the uncertainties associated with the input data of the thermal studies, the models selected and the the definition of the outside temperatures used by EDF. EDF has undertaken to resume, at the end of 2021, studies for premises with significant safety issues and low temperature margins " *by quantifying the margins* ". ASN considers that the thermal studies must be revised, taking into account the aforementioned uncertainties. In addition, for premises containing equipment presenting a particular safety issue, the existence of a margin of 2 ° C must be demonstrated. Otherwise, EDF will have to define the measures that would be necessary to respect the maximum allowable temperature of the equipment present in these premises. At the end of the investigation, EDF undertook to carry out these studies, which is satisfactory.

In addition, ASN notes that certain assumptions made in the calculations and likely to have a significant impact on the temperatures reached in the premises are not sufficiently substantiated (these are:

for example, reduction of heat input in the event of a lack of external voltage). These points are the subject of requests from ASN [49].

Regarding the availability of equipment, EDF considers that the operation of equipment between Td and Tr only has a reasonable impact on the service life of the equipment but not on its performance. ASN considers that the rules making it possible to manage the unavailability of equipment must lead to limiting the operating times beyond Td. At the end of the investigation, EDF undertook to change these rules, which is satisfactory. However, EDF has restricted the development of these rules to cases of the unavailability of ventilation systems in the premises of the nuclear auxiliaries building and of the cabling tween-decks and battery rooms. ASN will examine the need to expand the list of ventilation systems concerned as part of the review of changes to the general operating rules.

Concerning the equipment considered as cleared by EDF, the investigation showed that the majority of the analyzes are acceptable with the exception of those relating to the equipment required in the event of an accident with core melt. For this equipment, EDF has undertaken to carry out a systematic control *a posteriori* when the "long-term" temperature has been exceeded or when an event liable to generate an acceptable temperature overrun by the equipment has occurred (for example in the event of loss of ventilation, in the event of loss of external electrical sources ...), Which is acceptable.

In addition, EDF did not study the situations in the complementary area in the event of "hot weather" on the grounds that these situations do not fall under the "hot weather" benchmarks. ASN considers it necessary for EDF to check the capacity of its installations to cope with a situation of total loss of electrical sources (external electrical power supplies and main emergency generators), in the event of a “resizing temperature”.

This point is the subject of the ASN [AGR-B] prescription [48].

To respond to ASN's requests, EDF also presented proof of the facilities' capacity to cope with temperatures significantly higher than those used for the heat wave for the sizing purposes (in response to the SUR request n ° 22 of the letter [6]). For these studies, EDF considers normal operating situations and uses more realistic assumptions for its thermal studies (for example on ventilation flow rates). However, as for the design studies, EDF has not shown that the results obtained in the thermal studies make it possible to cover the uncertainties associated with the modeling. In addition, the outside air temperature values considered (+ 2 ° C compared to the design values) do not appear sufficient, in view of the uncertainties associated with the evaluation of a temperature taking into account a decamillennial return period. Consequently, ASN considers that the capacity of the installations to withstand outside temperatures significantly higher than those used for sizing has not been demonstrated. In addition, ASN considers that EDF will have to check its ability to manage these situations in the event of a joint loss of the external power supplies.

These points are the subject of the ASN [AGR-C] prescription [48].

5.2.6 Risks associated with external flooding

In 2013, ASN published a guide taking into account progress in knowledge of the risk of flooding from external sources [85]. This guide defines the reference situations against which basic nuclear installations must be protected.

At the request of ASN, EDF finalized at the end of 2014 the deployment of works and protection measures for all of its nuclear installations identified as necessary in the context of experience feedback from the 1999 Blayais site flooding. .

In addition, the strengthening of the protection of nuclear power plants against rains and floods induced by the failure of internal equipment on the site under the effect of an earthquake, decided following

the accident at the Fukushima Daiichi nuclear power station, was carried out between 2014 and 2017. This reinforcement led to the installation of new flood protection (copings, devices to prevent the entry of water into the buildings, etc.) on all sites.

Finally, following the accident at the Fukushima Daiichi nuclear power plant in March 2011, ASN asked EDF to carry out additional safety assessments on all of its reactors in order in particular to assess the robustness. of its facilities to deal with flooding situations of external origin, beyond the dimensioning risks covered by the experience feedback process for the 1999 Blayais site flooding or the requirements set out in the guide n ° 13 [85] which was then in the process of being finalized. In 2012 and 2014, ASN adopted prescriptions aimed at strengthening the protection of nuclear power plants against the risk of flooding from external sources for so-called “hard core” extreme situations (decisions [3] and [5]) .

5.2.6.1 Specific objectives of the review

As part of the fourth periodic review of the 900 MWe reactors, the objective is to reassess the reference situations for the risk of flooding on the basis of ASN guide n ° 13. In addition, to respond to ASN requests [6], these reassessments must be positioned in relation to the “WENRA 2014” hazard (see paragraph 5.2.1). If these do not comply with the “WENRA 2014” hazard, EDF must study the capacity of the facilities to cope with floods of external origin that are significantly greater than those of the design.

In 2016, ASN also asked EDF to justify the integrity of the inter-building joints.[34] (requests ON # 25 and ON # 26 [6]).

5.2.6.2 Summary of studies carried out and modifications planned by EDF

EDF has planned to transmit its studies on the application of ASN guide No. 13 [85] for each of the sites one year before the first fourth ten-yearly outage of a reactor on the site. EDF aims to make the changes necessary to comply with the recommendations of the guide before submitting the report concluding the periodic review of each 900 MWe reactor.

EDF recalled that the application of ASN guide n ° 13 enabled it to meet the recommendations of the WENRA association for design sizing hazards.

For the Tricastin nuclear power plant, for which studies have been finalized, EDF has identified three modifications necessary to achieve the safety objectives:

- the elimination of a risk of volumetric protection bypass[35] in case of rains;
- protection of the pumping station against overflows and by-passes;
- isolation of the raw water pumping and circulation system in the event of detection of a layer of water on the nuclear island platform following an earthquake the level of which exceeds that used in the reference system sizing.

Furthermore, EDF transmitted the methodological approach adopted to characterize the sea levels to extreme be taken into account, as part of the sizing of the "hard core" defined following the accident at the Fukushima Daiichi nuclear power plant, for the two seaside sites (Gravelines and Blayais sites), as well as the values used for the static sea level (excluding dynamic wave effect). These studies allow EDF to size new peripheral protections for these sites.

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[34] These joints consist of a rubber blade sealed in the concrete walls. These joints must allow the buildings to move independently from one another, in the event of differential settlements. They also make it possible to prevent water infiltration at the bottom of the building, in particular in the event of a rise in the water table.

[35] Protective volume made watertight by sealing the openings located in the outer walls of this volume, in order to prevent water from entering the premises housing important safety equipment.

EDF also sent the responses to requests SUR n ° 25 and SUR n ° 26 [6] concerning inter-building joints. In this context, it provided for an extension of the preventive maintenance programs and justified the integrity of these seals until 2030.

5.2.6.3 ASN's position on achieving the objectives of the review

ASN considers that all the measures implemented following the flooding of the Blayais site in December 1999 and in the context of taking account of experience feedback from the Fukushima Daiichi nuclear power plant makes it possible to provide 900 MWe nuclear power plants with a high level of protection against the risk of flooding from external sources.

Application of the recommendations of ASN guide no.13 [85] will make it possible to further improve this level of protection, insofar as the reference situations defined aim, in order of magnitude, at an exceeding frequency of 10^{-4} per year and makes it possible to respond to the positioning with regard to the recommendations of the WENRA association. The deadlines set by EDF for carrying out the studies taking these recommendations into account and the deadlines for the resulting modifications are acceptable in view of the existing provisions.

The examination of the studies already sent by EDF showed that certain approaches adopted for the application of guide No. 13 [85] were not acceptable. Indeed, ASN considers that:

- the methods adopted to define the hydrographs generated by the failure of a hydraulic structure upstream of nuclear power plants must change;
- additional justifications must be provided concerning the models retained to calibrate the hydrodynamic models in transient regime around nuclear sites;
- justifications must be provided concerning the state of the dikes modeled (taking into account or not of breaches) to assess the water levels at the site or, in the absence of justification, the state which increases the water level at site law must be withheld.

At the end of the investigation, EDF undertook to integrate these requests, which is satisfactory.

For the Tricastin site, the information transmitted by EDF relating to the methods for evaluating the reference situations for the risk of flooding (flooding, rain, rupture of hydraulic works, etc.) are generally satisfactory.

For the other sites, the analysis of all the reference situations will be carried out as the studies are submitted and ASN will adopt a position in the context of its analysis of the report concluding the review of each reactor.

Concerning the static sea levels used by EDF, ASN considers that all the available historical data were not taken into account by EDF for the calculation of the excess.[36] regional millennium of the Gravelines and Blayais sites. The integration of this additional data is likely to modify the value of the premium obtained. ASN nonetheless considers that, for the Gravelines site, the excess value retained for the sizing of the protection measures is satisfactory. On the other hand, ASN considers it necessary for EDF to reassess its excess cost calculations for the Blayais site. EDF is committed to it.

In addition, ASN considers acceptable the information provided by EDF relating to the justification until 2030 of the tightness of inter-building joints, in normal operation as well as in the event of an earthquake.

[36] The surge is defined as the difference between the sea level actually observed and the predicted tide level (theoretical tide). The surge is mainly induced by meteorology (variations in atmospheric pressure accompanying the passage of a meteorological disturbance and the action of the wind at the surface of the sea).

5.2.7 Risks associated with air transport and the industrial environment

The risks associated with air transport and the industrial environment have been taken into account in the design of nuclear power plants. The safety demonstration thus covers the following sources of potential attacks:

- air traffic broken down by three families of aircraft, namely general aviation (small civil aircraft with a mass of less than 5.7 tonnes), commercial and military;
- the industrial environment external to the site with:
    - fixed industrial installations (oil, petrochemical, gas, explosives storage, etc.);
    - pipeline transport (gas pipelines, oil pipelines, etc.);
    - the different modes of transporting hazardous materials (road, rail, river or sea transport).

Fundamental safety rules (RFS) n ° I.2.a [106] and I.2.d [107] specify, in the form of recommendations, the practices that ASN deems satisfactory for ensuring the protection of nuclear power plants against these assaults.

5.2.7.1 Specific objectives of the review

As part of the fourth periodic review of the 900 MWe reactors, **I** The objective is to reassess the industrial and aviation risks in application of RFS I.2.a and I.2.d and taking into account the update:

- accident data;
- data specific to the environment of each nuclear power plant, namely the location of airways or aerodromes, the proximity of communication routes, industrial installations and data on air traffic or the transport of hazardous materials;
- virtual surfaces [37] civil engineering works for air risk.

Furthermore, during the generic guidelines for the fourth periodic review of 900 MWe reactors, ASN asked EDF *"By mid-2017, to demonstrate the practical elimination of the risk of melting fuel stored in the fuel building pools with regard to the risk of general aviation aircraft falling, without ruling out these situations on the sole basis of a probabilistic consideration ".*

5.2.7.2 Summary of studies carried out and planned modifications

5.2.7.2.1 Risks associated with air transport

EDF's air risk analysis aims to apply the fundamental RFS I.2.a safety rule, which recommends a probabilistic assessment of the risk of unacceptable release of radioactive substances in the event of an accidental fall from an aircraft.

In this regard, EDF has proposed an update of its aviation risk assessment methodology, including changes concerning:

- evaluation of the probability of an airplane crash for the different families defined in RFS I.2.a [38];
- the definition of the list of safety targets concerned by this risk as well as the calculation of the virtual surfaces associated with each of them;
- analysis of the effects induced by the accidental fall of an airplane other than the mechanical impact.

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[37] The virtual surface of a building corresponds to the probable average surface of the cylindrical projections on the ground of a building following the fall of the airplane as a function of the possible directions of fall of the airplane, from the apparent surface of these buildings and their location in relation to other buildings.

[38] RFS I.2. Has defined three aviation families: general aviation, which corresponds to civil aircraft with a mass of less than 5.7 t, commercial aviation, which includes civil aircraft of a commercial nature with a mass greater than 5.7 t and military aviation.

EDF also examined the risks associated with the accidental fall of a helicopter.

In addition, in response to the request from ASN [SUR-29], EDF examined the consequences of the crash of a general aviation aircraft on the fuel building for all the 900 MWe reactors. EDF concludes that the fall of a general aviation aircraft does not lead to a situation that could lead to the fusion of the fuel assemblies stored there.

5.2.7.2.2 Risks associated with the industrial environment and communication routes

The analysis carried out by EDF aims to apply the fundamental safety rule RFS I.2.d. In this regard, EDF has proposed an update of its risk assessment methodology in a methodological guide which includes the following steps:

- identification of feared hazards;
- deterministic assessment of the consequences of the scenarios selected;
- the probabilistic assessment, if applicable, of the critical scenarios selected and the comparison of the probabilistic results with the objectives set by the RFS I.2.d.

In this methodological guide, EDF has modified the calculation of the conditional probability that a given dangerous phenomenon (fire, on-site explosion, explosion of a drifting cloud, drift of a toxic cloud) occurs, knowing that an accident involving the transport of hazardous materials a leak of the transported material has occurred. This modification makes it possible to take into resulting in accident data relating to vehicles transporting hazardous materials may lead to this account only the dangerous phenomena concerned and thus not to reduce the risk. EDF also justified guide all the hazardous phenomena not selected for the risks associated with the transportation in hazardous materials. Finally, EDF provided details on the assessment of the consequences of blast of the ignition a cloud of hazardous materials inside a site, in order to cover both the effects and thermal effects.

Site-by-site studies will be carried out when re-examining each of the reactors.

5.2.7.3 ASN's position on achieving the objectives of the review

ASN's analysis mainly focused on the methods implemented by EDF, with regard to the recommendations of the Fundamental Safety Rules (RFS) I.2.a and I.2.d. At the end of its examination, ASN considers that the approaches adopted are consistent with these rules.

ASN considers that the methodology proposed by EDF for the assessment of air risk is on the whole satisfactory, taking into account the additions made during the examination. ASN will adopt a position, within the framework of the specific reviews of each reactor, on the application of this methodology as well as on the acceptability of the risks associated with the fall of an aircraft.

For the risk of uncovering the fuel assemblies stored in the fuel building pools in the event of a fall from a general aviation aircraft, EDF has carried out studies which deterministically take into account the fall of this type of aircraft. . EDF studied the consequences of such a drop on the fuel building, by verifying the ability to maintain a sufficient water level in the swimming pool, as well as the cooling of the assemblies. ASN considers that the conclusions of this study are satisfactory.

With regard to the methodology proposed by EDF for determining the risks induced by potential attacks due to the industrial environment and to communication routes, ASN underlines the progress made by the new methodology transmitted by EDF at the end of 2019. However, l 'ASN considers that certain assumptions should be revised in the methodology note in order to:

- reassess the probabilities of dangerous goods transport accidents using statistically representative databases and on this basis, reassess the conditional probabilities of dangerous goods transport accidents resulting in a leak of the transported material as well as those of accidents not causing leakage of the transported material. EDF is committed to it;
- to consider areas for identifying the potential dangers present within a radius of 10 km around each nuclear power plant.

These points are the subject of requests from ASN [49].

5.2.8 Risks associated with strong winds

The effects of wind on equipment and structures can be:

- direct, affecting the resistance of buildings or equipment located outdoors due to pressure effects;
- indirect, via projectiles generated by strong winds (PGVV).

Only the power stations

The direct effects of strong winds on buildings were taken into account in the design of nuclear power plants in application of the “snow and wind 65” rules [89].

5.2.8.1 Specific objectives of the review

As part of the fourth periodic review of 900 MWe reactors, the objective is to study, on the one hand, the direct effects of strong winds on buildings and structures located outside, considering re-evaluated wind speeds greater than those considered at the design stage, on the other hand the indirect effects of these violent winds (projectiles), including the protection of targets located inside weak buildings, as well as the risks of overspeed induced for ventilation systems by violent winds which could lead to their failure (SUR request n ° 39 [6]).

In addition, to respond to ASN requests [6], these reassessments must be positioned in relation to the “WENRA 2014” hazard (see paragraph 5.2.1). In the event that these do not comply with the “WENRA 2014” hazard, EDF must study the capacity of the facilities to cope with strong winds that are significantly greater than those of the design.

5.2.8.2 Summary of studies carried out and modifications planned by EDF

The wind speeds used for the analysis are those taken from the 2009 edition of the “snow and wind 65” rules [89]. The envelope projectiles selected are:

- an automobile dragged on the ground;
- a plank of wood and a sheet of siding located at an elevation and in a direction any.

The studies transmitted by EDF define the level of hazard retained for the verification of the sizing of the reactors at the Tricastin and Bugey sites and the protective measures to cope with these winds, the requirements associated with these measures, as well as the modalities of their management. For the other sites, the studies will be sent before the submission of the review conclusion report.

EDF's studies integrate the requests formulated by ASN within the framework of the third periodic review of the 1300 MWe reactors [62] (variability of wind speed, local amplification of wind speed and direct and indirect effects of wind on ventilation systems, attacks induced by the failure of unprotected equipment, dependency between a strong wind and a situation of loss of the cold source by clogging) and cover both the direct and indirect effects of the wind on:

- the external equipment important for safety necessary for the fallback and the maintenance in a safe state of the reactor in a situation of loss of the external electric power supplies (situation called "lack of external voltage" or MDTE) or, as part of the defense-in-depth approach , in a situation of total loss of the heat sink (“H1” situation);
- external equipment important to safety and classified, for situations other than the management of an MDTE or an “H1” situation;
- potential targets located inside buildings;
- the risk of fan failure generated by overspeed induced by high winds.

At the end of the studies, EDF identified [23] that “ *the pumping stations at the Bugey, Tricastin, Gravelines and Blayais sites, the demineralization station at the Bugey site and the electrical rooms adjoining the pumping stations at the Gravelines site present localized weaknesses which could lead to potential aggression of safety located inside. EDF therefore plans to reinforce or add robust Civil Engineering structures to PGVVs of the metal frame structure type with protection systems (such as sheet metal, grating, protective net, double skin cladding). Other weaknesses are addressed by strengthening or replacing existing ventilation equipment* ".

For the conventional island of Tricastin, the work consists of installing grids to protect against projectiles generated by strong winds.

As part of the achievement of the decamillennial target defined by the WENRA association (see paragraph 5.2.1), EDF has retained the levels of “high WENRA winds” by adding a margin of 20 km / h to the instantaneous wind speeds of the 200-year return period, resulting from a study by the Scientific and Technical Center for Building. Depending on the site, this value is greater or less than the reference value used for sizing studies.

For the indirect effects of the wind, EDF considers that the current approach to studying projectiles generated by strong winds, which takes into account projectiles generated by wind speeds defined in its reference system, includes a large number of conservatisms. EDF therefore considers the decamillennial target reached and has not carried out a specific study in accordance with the recommendations of the WENRA association.

5.2.8.3 ASN's position on achieving the objectives of the review

ASN considers that, having regard to the knowledge and the rules of the art in force, the methodology for defining the speeds of strong winds for the verification of reactor sizing, and its application to the Tricastin and Bugey sites[39], the nature and characteristics of the induced projectiles retained, as well as the justification for the correct behavior of the fans in a situation of high winds are satisfactory.

In practice, the approach adopted by EDF is an alternative approach to that proposed by European standards for the sizing and justification of building and civil engineering structures (Eurocode). It leads to values of "high WENRA winds" higher than those of "high winds" in the reference system only for the sites of Blayais (+ 18 km / h), Dampierre-en-Burly (+ 5 km / h), Saint-Laurent-des-Eaux (+ 23 km / h) and Chinon (+ 5 km / h). For the other sites, the “wind” hazard adopted for the sizing according to the 2009 revision of the “snow and wind 65” rules [89] is greater than the “high winds WENRA” level.

In the current state of knowledge, for the fourth periodic re-examination of the 900 MWe reactors, ASN considers the approach adopted by EDF and the conclusions resulting from the application of this approach to be acceptable.

[39] For the other 900 MWe reactor sites, the validity of the winds selected will be assessed as part of the examination of the first report concluding the review of each of the sites concerned.

However, ASN considers that work must continue to gain a more detailed understanding of the uncertainties linked to the evaluation of wind speeds associated with a decamillennial return period and to define a wind speed with a margin making it possible to cover these uncertainties. This work is part of the working group initiated by ASN on the "snow and wind" theme, which has brought together ASN, IRSN, BNI operators and experts in the field since September 2019.

ASN considers that, pending the conclusions of this work, the measures planned by EDF within the framework of this review are satisfactory.

5.2.9 Risks associated with tornadoes

The tornado phenomenon corresponds to a very infrequent meteorological phenomenon, of limited duration and extent, but whose effects of dynamic pressure due to strong winds, depression in the center of the vortex, as well as the projectiles generated are likely to affect buildings or equipment located outside.

In 2012, EDF sent an assessment of the probability of tornadoes occurring in France and defined an associated tornado level. ASN adopted a position in 2014 on this reference system and in particular considered that the definition of the reference tornado then proposed by EDF (tornado level EF3[40] on the Fujita scale) and associated projectiles were generally satisfactory [63] for the fourth periodic review.

5.2.9.1 Specific objectives of the review

The protection of reactors against tornadoes was not taken into account when sizing the installations and constitutes one of the additional subjects selected at the request of ASN when defining the objectives of the fourth periodic review of the installations. 900 MWe reactors [6].

In addition, to respond to ASN requests [6], these reassessments must be positioned in relation to the "WENRA 2014" hazard (see paragraph 5.2.1). If these do not comply with the "WENRA 2014" hazard, EDF must study the capacity of the facilities to cope with tornadoes that are significantly greater than those of the design.

5.2.9.2 Summary of studies carried out and modifications planned by EDF

EDF updated the tornado risk analysis and sent in November 2015 an update to its reference system aimed at retaining:

- a benchmark tornado based on a benchmark probability of occurrence of 10^{-4} per year and per reactor, in accordance with the 2014 recommendations of the WENRA association;
- an extreme level tornado (or "hard core" tornado) in order to meet the ASN [3] requirements adopted after the accident at the Fukushima Daiichi nuclear power plant.

EDF reassessed the level of tornadoes on the basis of a probabilistic approach, which led it to retain a reference tornado level EF0 (notably lower than the EF3 level proposed previously). It considers that the effects of a reference tornado are covered by the effects induced by strong winds and that it is not necessary to initiate specific studies.

[40] The "Improved Fujita Scale" empirically ranks tornado levels (in terms of wind speed ranges) based on observed damage. This scale is based on observations of tornadoes in the United States. It includes six levels of damage corresponding to the following maximum wind speed ranges: EF0 [29-38 m / s], EF1 [39- 49 m / s], EF2 [50-61 m / s], EF3 [62- 74 m / s], EF4 [75-88 m / s], EF5 [> 88 m / s].

5.2.9.3 ASN's position on achieving the objectives of the review

ASN considers that simply taking into account a probabilistic objective is not sufficient to define the intensities and wind speeds of the reference tornado. Indeed, if the WENRA association specifies that the hazards must have a frequency of occurrence less than 10^{-4} per year and per reactor, it also indicates that the hazard must cover extreme historical events, with a sufficient margin. While it is not relevant to retain for a given site the worst regional experience feedback (two EF5 level tornadoes in France), given the rare nature and limited extent of the tornadoes, ASN nevertheless considers that the installations must be able to cope with reference tornadoes representative of regular regional experience feedback. Given the tornadoes recorded throughout mainland France, ASN considers that the reference tornado must *at least* cover a tornado of intensity EF2, defined by the average wind speed characterizing this intensity, namely 55.5 m / s.

In addition, ASN considers that the extreme tornado levels used by EDF (EF3 or EF4 depending on the site) for the “hard core” are acceptable. However, ASN considers that, for level EF3 tornadoes, EDF must retain an average wind speed characterizing this intensity of 68 m / s. These levels of hazards make it possible to respond to the recommendations of the WENRA association.

At the end of the investigation, EDF undertook to retain these tornado levels, which is satisfactory.

EDF's proposals relating to the calculations of the characteristics of the projectors and their speed do not call for any comment from ASN.

5.2.10 Risks associated with fires of internal origin in facilities

A fire can damage components essential to maintaining reactor safety. Measures must therefore be implemented to protect sensitive parts of installations against fire.

5.2.10.1 Specific objectives of the review

On the occasion of the fourth periodic review of the 900 MWe reactors, ASN asked EDF [6] [73] to thoroughly review its demonstration of control of the risks associated with fire, in order to take into account the numerous requests that it has formulated on the subject, in particular as regards the method and the assumptions retained for the justification of the dimensioning of the sectorization, the taking into account of a better knowledge of the effects associated with the fire (effects of smoke , pressure increase, propagation by re-ignition of unburned gases, etc.). These requests also included the performance of additional studies to study the effects of taking into account an aggravating factor and the increase in the time limits set for the operators' first intervention.

In addition, following the additional safety assessments carried out following the accident at the Fukushima Daiichi nuclear power plant, ASN adopted in 2012, prescription [ECS-12] [3] which requires in particular:

- assess the earthquake resistance with increased safety of structures and equipment contributing to the nuclear safety of fire sectorization, fire detection and fixed extinguishing systems, initially subject to a design half-earthquake withstand requirement[41];

[41] This is half of the so-called design earthquake. The installations were designed by using a design earthquake (called “SDD”) for nuclear island equipment, applicable to all reactors of the same type. During the construction of the plants, the SDD was higher than the site SMS.

- for elements whose resistance to earthquakes with increased safety could not be justified, present a program of modifications to guarantee the protection of safety functions against fire in the event of a safety-related earthquake.

5.2.10.2 Summary of studies carried out and modifications planned by EDF

To respond to ASN's requests, EDF sent studies relating to:

- the justification of the resistance of the elements ensuring the fire sectorization;
- the taking into account of the effects induced by the fumes on the operation of the equipment;
- taking into account the impact of pressure effects occurring during a fire on fire sectorization;
- assessing the risk of fire spreading due to reignition of unburned gases;
- application of the requirement [ECS-12] of ASN decisions [3];
- assessment of the consequences of taking into account the delay before the operators' first intervention selected for the Flamanville EPR reactor;
- the application of an aggravating agent in the studies.

In addition, EDF shed a probabilistic light on the risks, in the event of fire, core melt or discovery of fuel assemblies stored in swimming pools, as well as discharges.

Finally, EDF presented avenues for the development of its organization in terms of fire response resources.

5.2.10.2.1 Fire resistance of the elements of the fire sectorization

EDF has developed a new justification method [42] fire sectorization, which comprises two stages:

- a first stage of selection of the premises, based on the degree of fire of the sectorization element. The sectorization of the premises not selected at the end of this selection is considered robust with respect to the fire;
- a second stage of analysis of the premises, for which the sufficiency of the fire resistance of a sectorization element is verified by comparing its failure temperature with the temperature reached in the room in the event of a fire. If necessary, an analysis of the potential consequences of a break in sectorization is carried out.

This new approach was applied by EDF to 900 MWe reactors. For the electrical building, who bears the main risks in the event of a fire, EDF concludes that the fire sectoring elements are correctly sized, apart from certain electrical cable protections. EDF therefore plans to replace this equipment with new equipment with suitable fire resistance.

[42] When designing the 900 MWe reactors, EDF used conventional temperature rise curves in the premises to assess the maintenance of the integrity of the elements of the fire sectorization. Thus, EDF had in particular applied the curve known as “DSN 144” in order to determine the resistance criteria of the sectoring elements to fire. This curve is not very representative of fires in a confined and ventilated environment, corresponding to nuclear installations, and was considered unsuitable for the configuration of the premises of nuclear power plants. Thus, in 2003, ASN asked EDF to revise its method for evaluating the resistance of sectoring elements [75]. EDF has therefore developed, for the Flamanville EPR reactor, a new approach to justify fire sectorization. ASN considered that this method required several additional justifications but that its principle was acceptable [72]. However, in response to ASN requests ([64], [71], [72], [6], [73]), EDF indicated that this method could not be directly transposed to reactors in operation and proposed an alternative approach to justify the fire sectorization for these reactors.

5.2.10.2.2 Impact of fumes on equipment operation

The soot contained in fire smoke is liable to lower the resistance limits of elements important to safety. Equipment exposed, in the event of fire, to temperatures exceeding these limits should be considered to have failed. EDF relies on tests aimed at better characterizing the effects of smoke on the operation of the electrical and electronic equipment required in the event of a fire.

For electronic equipment, EDF has set a thermal failure criterion of 65 ° C and has developed a method to determine whether the malfunction temperatures of electronic equipment are reached. On the other hand, for electrical and electromechanical equipment, which is less sensitive to thermal effects as to smoke effects, the evaluation of the effects of smoke for this equipment therefore remains based on standard effect distances.

5.2.10.2.3 Impact of the effects of pressure on the elements of sectorization

As part of the third periodic review of 1300 MWe reactors, EDF developed a methodology for identifying fire volumes[43] in which a fire is likely to cause pressure variations such as to cause failure of the elements of the fire sector. The application of this approach has led EDF to draw up a list of the volumes of safety fires at risk; these have been the subject of a detailed study. EDF concludes that there is no risk associated with the effects of pressure in the event of a fire for the 900 MWe reactors. Therefore, EDF considers that no modification is necessary.

5.2.10.2.4 Assessment of the risk of fire spreading due to reignition of unburned gases

EDF has identified volumes of fire in which a fire is likely to produce unburned gases which can propagate to another volume of fire and ignite there, thus causing the fire to spread outside the limits supposed to contain it. These at-risk fire volumes were the subject of a detailed study. EDF concludes that there is no risk associated with the re-ignition of unburnt gases produced in the event of fire for the 900 MWe reactors. Therefore, EDF considers that no modification is necessary.

5.2.10.2.5 Application of ASN prescription [ECS-12]

In 2012, EDF developed a method to assess the earthquake resistance with increased safety of structures and equipment contributing to nuclear safety of fire sectorization, fire detection and fixed extinguishing systems, initially subject to a design half-earthquake withstand requirement.

The application of this method to 900 MWe reactors has led EDF to identify fire doors whose earthquake resistance needs to be reinforced. EDF has also identified fire dampers whose earthquake resistance needs to be reinforced for the Bugey nuclear power plant. With regard to fire detection, EDF concludes that no modification is necessary.

In addition, for fixed extinguishing systems, this method has been used by EDF for structures and equipment located inside the reactor building:

[43] Fire volume: one or more rooms delimited by walls (physical separation) or borders (without physical separation) ensuring separation between combustible materials and equipment and preventing the spread of the fire. EDF distinguishes between two types of safety fire volumes: the safety fire sector (delimited by a physical sector) and the safety fire zone (delimited according to distance criteria).

- reactors no. 2, no. 3 and no. 4 of the Bugey nuclear power plant, for which EDF concludes that no reinforcement is necessary (this variation has not yet been carried out for reactor no. 5);
- of reactor n ° 1 of the Tricastin nuclear power plant, for which EDF concludes that it is necessary to strengthen the earthquake resistance of a pipe in the fire protection network.

The application of this approach to the other 900 MWe reactors, as well as to the other buildings of the Bugey and Tricastin nuclear power plants, is continuing. EDF plans to carry out the necessary reinforcements, upstream of the submission of the review conclusion report, for the pipes located inside the reactor building and, at the latest during phase B of the deployment of the modifications associated with the review, for pipes located in other buildings.

5.2.10.2.6 Taking into account the delay before the first intervention of the operators

EDF studied the actions to be taken in the event of a fire by the operators, in the control room and locally. EDF has not identified a cliff-edge effect (namely, a significant change in the consequences of a fire) if the delay before the first intervention by operators is taken into account for the Flamanville EPR reactor. In its study, EDF highlights a modification, carried out outside the review, aimed at automating the sprinkling in the event of fire in the premises housing the pumps of the volumetric and chemical control circuit of the primary circuit, which makes it possible to rule out any effect associated with the intervention times of operators in these premises.

5.2.10.2.7 Application of an aggravating agent in fire-related studies

EDF has applied its approach to take into account the most penalizing aggravating factor, presented in paragraph 5.2.1.2 of this report, in its studies aimed at assessing the risks associated with the fire.

Regarding active provisions[44], EDF does not retain any aggravation on those it deems reliable. For the other active provisions (fire dampers or fire doors whose closing is slaved to fire detection), EDF concludes that their failure, as an aggravating factor, does not cause the simultaneous loss of two equipment ensuring redundantly a fundamental safety function. In addition, EDF concludes that taking into account an aggravating factor cannot call into question the operation of the water pumping systems of the fire protection network and of the fixed sprinkler systems. Therefore, EDF considers that no modification is necessary.

Regarding passive provisions[45], EDF relied on its probabilistic safety studies (fire) to determine the failures to be considered and identified non-slaved fire doors whose maintenance in the closed state should be made more reliable. At the end of these studies, EDF defined modifications to detect the prolonged holding of these doors in the open position.

5.2.10.2.8 Probabilistic lighting

EDF has assessed the risk of core meltdown, or the discovery of spent fuel assemblies stored in swimming pools, in the event of a fire. These probabilistic assessments are presented in general in paragraph 5.7. The values obtained for the risk of core meltdown are $1.2.10^{-5}$ per year and per reactor, without considering the implementation of the "hard core" and $6.7.10^{-6}$ per year and per reactor, with the "hard core". For swimming pools, the risk of uncovered assemblies is 6.10^{-8} per year and per reactor, without considering the implementation of the "hard core" and 3.10^{-8} per year and per reactor, with the "hard core".

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[44] In the case of protection against fires of internal origin, these are in particular extinguishing water pumping systems, valves, sprinkler heads and fire doors and dampers slaved to fire detection. .

[45] In the case of protection against fires of internal origin, this concerns in particular hoppers for the passage of cables and pipes, floor drains, or even fire doors and valves not slaved to a detection system.

EDF has incorporated, in its studies, certain modifications associated with the fourth periodic review of the 900 MWe reactors, making it possible to reduce the probability of occurrence of the main sequences that could lead to these situations:

- modification of the control circuit of the primary circuit pressurizer valves to prevent their opening caused by an unwanted order issued in the event of a fire;
- the fire protection of cables controlling the switching between the draw-off transformer and the auxiliary transformer, as well as of the power cables of an electrical box allowing the operation of the installation in a situation of total loss of electrical sources;
- modification of the control circuit, as well as of the cable fire protection, to prevent inadvertent tripping of the emergency turbo pump of the emergency power supply circuit of the steam generators;
- separation by a flame-resistant screen of the redundant pumps from the treatment and refrigeration circuit of the fuel storage pool.

In addition, these studies, supplemented by deterministic considerations, enabled EDF to identify the most sensitive premises in the event of a fire (namely the premises in which the loss of all the equipment would lead to a significant increase in risk. core melt). EDF therefore implemented in 2019, on all the 900 MWe reactors, operating measures aimed at improving the control of fire-related risks with regard to these premises and improving the monitoring of protective measures (fire dampers, fire doors, etc.) in order to prevent the spread of a fire to these premises.

EDF completed its approach by identifying fire doors, the loss of which is likely to significantly increase the risk of core meltdown. This concerns in particular the doors separating two volumes of fire from different security routes. EDF has defined additional modifications (in particular material) to detect that these doors are kept in the open position for a long time.

In addition, EDF has assessed the frequency of situations of significant release of radioelements into the environment, following a fire leading to an accident with core melt, which are presented in paragraph 5.7.2.

5.2.10.2.9 Means of intervention

EDF's current organization for fire intervention is based on:

- the intervention of the agent known as "removal of doubt" in the event of an alert. Its mission is to confirm the fire and check the state of the sectoring elements in the event of a fire being detected;
- the so-called “intervention” team, made up of site agents, which is deployed as a second step and has the task of implementing the appropriate extinguishing means. Its role, in the event of a major event, is limited to monitoring the evolution of the situation (the responders do not have the means to manage a developed fire) and to initiate, as far as possible, actions aimed at limiting the fire propagation and to maintain fire sectorization;
- the intervention of the departmental fire and rescue services (SDIS), which have the necessary resources to fight against a developed or fast-kinetic fire.

ASN inspections and significant event declarations regularly show anomalies in the management of the fire sectorization and combustible materials, as well as non-conformities in the sectorization equipment, on which the safety demonstration is based. In such situations, in application of the principle of defense in depth, ASN considers that it is necessary to guarantee the rapid intervention of competent people, trained and equipped, in order to prevent the fire from spreading to high volumes. adjacent fire. ASN therefore asked EDF [68] [69] to study the advisability of changing its organization in order to have permanent means at each of the nuclear power plants to enable rapid intervention and fight against the fire, especially in the case of developed fires,

In response to these requests, EDF has undertaken to double the workforce (sending two people) to carry out the duties of the doubt removal agent. This doubling has the particular effect of strengthening the effectiveness of the fire confirmation missions and the verification of the state of the elements of fire sectorization.

EDF also analyzed the availability of human and material resources of the SDIS to fight against fires developed in the event of demand by nuclear power plants. EDF plans to:

- put in place means of evaluating the effectiveness of fire fighting; strengthen
- cooperation between nuclear power plants and SDIS;
- modify the methods of solicitation of the SDIS in order to avoid the wrongful sending of fire-fighting means by these services;
- set up "emergency and fire centers" in all nuclear power plants. These centers are intended to reduce the number of firefighters to be mobilized by the SDIS in the event of demand. To do this, EDF plans to mobilize volunteer firefighters working in nuclear power plants to supplement the staff sent by the SDIS.

5.2.10.3 ASN's position on achieving the objectives of the review

ASN considers that the modifications already carried out or planned by EDF will significantly improve the safety of the installations with regard to the risk of fire.

However, ASN considers that EDF must include in its studies:

- all the premises;
- envelope modeling hypotheses making it possible to determine the temperature curves reached in the premises for fires in electrical cabinets and electrical cable trays likely to be encountered. In particular, for electrical cabinet fires, it uses a fire growth coefficient independent of the ignition conditions for electrical cabinet fires and for electrical cabinet fires representative of the achievement of a combustion phase. self-sustaining.

These requests are likely to lead to the identification of additional safety fire volumes to be studied in depth with regard to compliance with fire sectorization, the impact of smoke on the operation of equipment and the risk of rupture. fire sectorization following pressure variations induced by a fire.

These points are the subject of the ASN [AGR-D] prescription [48].

5.2.10.3.1 Fire resistance of the elements of the fire sectorization

The principles of the methodology adopted by EDF to justify the sizing of the equipment participating in the sectorization are deemed satisfactory by ASN. In addition, EDF has undertaken to provide additional information concerning:

- the scope of application of the justification method, which EDF initially limited to certain buildings and certain sectoring equipment;
- the justification for the fire sectorization of the premises initially excluded from the method but which were identified as presenting a major safety issue when carrying out the probabilistic safety studies;
- the verification of the existence of a sufficient margin between the failure temperature of the sectorization equipment and the temperature reached in the room in the event of a fire in order to take into account the modeling uncertainties and the aging of the sectorization elements.

ASN considers that, for one of the premises of the electrical building, the margin between the failure temperature of the sectoring equipment and the temperature reached in the room in the event of a fire is insufficient and that EDF must carry out additional studies. to check the correct sizing of the elements of the fire sectorization. This point is the subject of a request from ASN [49].

In addition, the late transmission of studies relating to buildings other than the electrical building does not allow ASN to take a position, in the context of this report, on the conclusions of these studies. They will be the subject of a subsequent investigation.

5.2.10.3.2 Impact of fumes on equipment operation

With regard to taking into account the impact of fumes on the operation of electronic equipment, the principles of EDF's new method are deemed satisfactory by ASN. This method constitutes a notable development, insofar as it allows better consideration of physical phenomena by evaluating the effect of fumes on these materials, and makes it possible to demonstrate the absence of faults in equipment sensitive to fumes ensuring the same safety function in case of fire and located in different fire volumes.

Given the challenges and the progress made by these studies, ASN considers it acceptable, for the fourth periodic review of the 900 MWe reactors, that EDF has limited the scope of its study to the most sensitive equipment, namely electronic equipment.

5.2.10.3.3 Impact of the effects of pressure on the elements of sectorization

With regard to taking into account the effects of pressure on the elements of sectorization, the principles of EDF's methodology are deemed satisfactory by ASN. The studies carried out by EDF in particular made it possible to identify the fire volumes most sensitive to these effects. However, ASN considers that certain assumptions do not make it possible to guarantee an envelope assessment, in particular with regard to the discharge coefficient (namely the leaks considered at the doors) used by EDF to characterize the leaks of the shut-off doors. fire. This point is the subject of a request from ASN [49].

5.2.10.3.4 Assessment of the risk of fire spreading due to reignition of unburned gases

ASN considers that EDF will have to add, during the next periodic re-examination, to its method aimed at identifying the volumes of fire in which a fire is likely to produce unburnt gases which can propagate to a another volume of fire and ignite there. Indeed, this phenomenon appears to be of less importance than the other subjects concerning the demonstration of control of the risks associated with the fire. ASN therefore considers that this is not a priority subject for the fourth periodic review of 900 MWe reactors.

5.2.10.3.5 Application of ASN prescription [ECS-12]

EDF does not retain, in the safety demonstration, the occurrence of a fire just after an earthquake. EDF considers that a fire can occur 15 days after the earthquake and the fire risk control equipment was not designed with seismic withstand safety requirements (SMS). ASN had asked in 2012 to verify the behavior of this equipment in the SMS.

ASN considers that the procedure for verifying the seismic resistance to increased safety of the elements of the fire sectorization, fire detection and fixed extinguishing systems makes it possible to significantly improve the robustness of structures and equipment contributing to nuclear safety. EDF plans to reinforce certain fire dampers and doors that are not earthquake resistant. At this stage, verification of the behavior of the fixed extinguishing systems is not carried out for all the buildings of the nuclear power plants. EDF has also undertaken to study, for the elements of sectorization, in particular of the type of sealing of crossings and protection of cable tray, a complementary approach of verification after an earthquake associated with repair operations.

ASN considers that the fire situations initiated by an earthquake (SMS) must be considered and plans to adopt a position on the measures planned by EDF, as well as on the associated modification schedule, as part of its position on the actions carried out 10 years after the accident at the Fukushima Daiichi nuclear power plant.

5.2.10.3.6 Taking into account the delay before the first intervention of the operators

ASN notes that in certain situations (such as, for example, a fire in the casemates of the primary motor-pump units), actions in the control room are necessary to prevent the spread of the fire to the adjacent fire volume (for example, by implementing the sprinkler system in the aforementioned casemates). In such a situation, it should be verified that the development of the fire before the intervention of the operator within the time allowed in the safety demonstration does not lead to the loss of redundant equipment necessary to achieve and maintain the safe state of the reactor.

In addition, it is necessary to ensure that there is no cliff-edge effect for the period before the first intervention by operators selected for the Flamanville EPR reactor. At the end of the investigation, EDF undertook to carry out all of these studies, which is satisfactory.

5.2.10.3.7 Application of an aggravating agent in fire studies

ASN considers that the application by EDF of an aggravating agent to studies relating to the fire makes it possible to significantly improve the safety of the installations. This has led EDF in particular to provide additional devices in order to keep the most sensitive fire doors in the closed position. However, EDF has not defined any operational monitoring requirements for these systems.

In addition, the method adopted by EDF calls for a number of comments, insofar as EDF does not systematically select the most unfavorable equipment failure, based on its reliability. EDF thus rules out the failure, in terms of aggravating factors, of certain provisions deemed reliable, whereas malfunctioning of these provisions (for example, on sprinkler systems) has been observed on several occasions in nuclear power plants. In particular, EDF must identify the premises most sensitive to the unavailability of fixed sprinkler systems, namely premises whose loss of sectorization would lead to a significant increase in risks;

These points are the subject of the ASN [AGR-E] prescription [48].

To identify the most sensitive fire doors, EDF relied on its probabilistic studies. ASN points out that certain systems (in particular ventilation systems) or specific operating actions (electrical outage plans) are not taken into account in these studies. Taking them into account could lead to the identification of other sensitive fire doors. EDF has undertaken to consider these elements in the context of the next reviews. In addition, for the fire doors already identified, ASN considers that EDF must assess the benefit of implementing more restrictive measures (such as, for example, door locks) on some of them. , whose open position in the event of a fire would lead to a significant increase in the risk of core meltdown.

5.2.10.3.8 Probabilistic lighting

During the fourth periodic review of the 900 MWe reactors, EDF carried out probabilistic safety studies to assess the risk of core meltdown, or of the fuel assemblies stored in swimming pools uncovering, following a fire. EDF also assessed the frequency of situations of significant release of radioelements into the environment, following a fire leading to an accident with core meltdown. ASN considers that this probabilistic light has significantly improved the safety of the installations. In fact, EDF has identified the premises and the measures most sensitive to this attack and has put in place measures aimed at making the control of the risks associated with the fire more reliable. Otherwise,

ASN considers that EDF must complete the list of premises identified as the most sensitive in the event of a fire (premises in which the occurrence of a fire contributes significantly to the risk of core meltdown or the discovery of fuel assemblies in the storage pool or premises for which sectorization is ensured by at least one door, the open position of which during a fire leads to a significant increase in the risk of core meltdown or to the loss of redundant backup means in water or means of cooling the fuel storage pool) and define the operating provisions specific to these premises (monitoring heat loads, management of works, etc.).

This point is the subject of the ASN [AGR-E] prescription [48].

For evaluations of the frequency of situations of significant release of radioelements into the environment, following a fire leading to a core melt accident, the results show that additional devices are necessary:

- in the event of a fire, a risk of common cause failure of the power supplies and the equipment necessary for switching to the emergency power source (DUS) has been identified. At the end of the investigation, EDF defined a modification in order to carry out certain electrical connections locally allowing the implementation of the so-called “EASu” corium stabilization measures;
- a fire could cause the loss of pressure measurement in the reactor building. This value makes it possible to trigger important actions for the mitigation of releases in a serious accident situation. ASN considers that the equipment enabling this measurement must therefore be protected from the effects of a fire.

This last point is the subject of the ASN [AG-C] prescription [48].

5.2.10.3.9 Means of intervention

ASN considers that the reinforcement of the staff mobilized (creation of a team) for the mission of confirming the fire and checking the state of the sectoring elements in the event of a fire being detected is satisfactory.

To deal with a developed fire, EDF plans to continue to rely mainly on the human and material resources of the SDIS, while strengthening the current internal system. This subject, which is not specific to 900 MWe reactors, will be the subject of a specific instruction.

5.2.11 Risks associated with explosions of internal origin in installations

5.2.11.1 Specific objectives of the review

During the fourth periodic review of the 900 MWe reactors, ASN asked EDF [6] to improve its safety demonstration relating to the risks associated with internal explosions, in particular with regard to the structuring of the defense-in-depth approach. In addition, EDF had to take into account the conclusions of the investigation carried out as part of the third periodic review of the 1300 MWe reactors. In this context, ASN asked EDF [76] in particular:

- assess the consequences of an explosion linked to an anomalous release of hydrogen, considering that a leak may occur outside the singularities of a removable nature of circuits containing hydrogenated gases;
- to take into account the risk of explosion inside circuits containing hydrogenated gases;
- to take into account the risk of transfer of an explosive atmosphere between premises, without being limited to transfers linked to the ventilation of the premises;
- complete the safety demonstration relating to the risks associated with explosions in the battery rooms;
- identify the systems to be protected from an explosion.

5.2.11.2 Summary of studies carried out and modifications planned by EDF

To respond to ASN's requests, EDF reassessed the risks associated with the internal explosion and took an aggravating factor into account in its studies.

In addition, EDF shed a probabilistic light on the risks, in the event of an explosion, core melt or discovery of fuel assemblies stored in swimming pools, as well as releases.

5.2.11.2.1 Risks of explosion of internal origin in the premises of the nuclear island

For the nuclear island, the main risk of explosion concerns circuits containing hydrogenated gases as well as processes releasing dihydrogen (batteries in particular).

EDF has verified that an explosion occurring in premises presenting a risk of the formation of an explosive atmosphere:

- does not call into question the performance of a safety function due to the loss of equipment located in the damage zone;
- does not port two volumes of safety fire.

Risk of explosion associated with circuits containing hydrogenated gases

A room crossed by circuits containing gases with a hydrogen concentration greater than the lower explosive limit (LEL) of this gas presents a potential risk of explosion. In fact, hydrogen leaks can occur at or outside the detachable singularities of these circuits. These circuits are also liable to be attacked by an earthquake, a shock, a rupture of high energy piping (RTHE).[46] or a fire.

[46] High energy pipes (THE) are pipes conveying fluids having a pressure greater than or equal to 20 bar or a temperature greater than or equal to 100 ° C.

In addition, there is a risk of transfer of an explosive atmosphere from the room in which the release of hydrogen gas occurs to other rooms, due to the leaks of the walls and ventilation ducts. EDF has therefore identified the premises in which an explosive atmosphere is likely to form due to these transfers. In particular, for the ventilation ducts, EDF concludes that these risks are controlled by the existing provisions for preventing the risk of ignition of an explosive atmosphere (presence of equipment qualified to prevent such ignition, ventilation ducts connected to the earth), with the exception of the radioactivity measurement chains in the ventilation ducts.

EDF has identified premises in the nuclear auxiliaries building and in the operating building in which an explosion, following a leak on a singularity, presents a risk to the safety of the installations. EDF plans to implement, in some of these premises, an operating condemnation at the level of the removable singularities of the hydrogenated circuits in order to avoid their erroneous removal. In addition, EDF is upgrading the new water injection circuit belonging to the “hard core” (SEG) in the event that an explosion in a group of rooms in the nuclear auxiliaries building would lead to the failure of the swimming pool's refrigeration system. fuel storage. This point is developed in the paragraph dedicated to the reassessment of the safety of the fuel storage pool (paragraph 5.4). For the hydrogenated circuits connected to the pressurizer, EDF specifies that they are not damaged in the event of an “earthquake event” or a rupture of high-energy piping (RTHE). Taking all these measures into account, EDF concludes that, for CPY type reactors, the measures to prevent the formation or ignition of explosive atmospheres are sufficient and that no additional modification is necessary.

In addition, EDF has identified the situations which could lead to the formation of an explosive atmosphere inside the hydrogenated circuits and which could lead to common cause failures of equipment redundantly providing the same safety function. Among these situations, EDF examined situations with a frequency of occurrence greater than 10^{-6} per year and per reactor and which may lead to core meltdown and has defined material modifications aimed at preventing these situations (scenario of air entering a gas tank of the gas effluent treatment circuit from the degassers of the system primary circuit effluent treatment, risk of supplying hydrogen to the gas tank of the volumetric and chemical control system of the main primary circuit while this tank contains air).

EDF has also developed a methodology for evaluating the consequences for nuclear safety of an explosion linked to an abnormal release of dihydrogen outside the detachable features of hydrogen circuits. EDF applied this method to the premises of the nuclear auxiliaries building. For CPY type reactors, EDF concludes that, for most of the premises, the explosion linked to an abnormal release of hydrogen has no consequences for safety and, for other premises, that existing provisions (for example , a large volume of rooms allowing leaks to be diluted, the presence of highly diluted dihydrogen in the circuits, stainless steel pipes, not very sensitive to shocks, corrosion or vibration fatigue) make it possible to limit the risk of forming an explosive atmosphere and therefore the risk of loss of a safety function. On the other hand, with regard to the reactors at the Bugey nuclear power plant, EDF has identified premises in which an abnormal release of dihydrogen outside the singularities is likely to lead to failures of common cause. EDF indicates that it will ensure that the methods of periodic inspection of the hydrogenated black steel circuits of these premises are suitable. EDF has identified premises in which an abnormal release of dihydrogen outside the singularities is likely to lead to failures of a common cause. EDF indicates that it will ensure that the methods of periodic inspection of the hydrogenated black steel circuits of these premises are suitable. EDF has identified premises in which an abnormal release of dihydrogen outside the singularities is likely to lead to failures of a common cause. EDF indicates that it will ensure that the methods of periodic inspection of the hydrogenated black steel circuits of these premises are suitable.

The rupture of a pipe under an earthquake can lead to more significant leaks than the leaks envisaged apart from the singularities. Before the fourth periodic review of the 900 MWe reactors, EDF assessed the increased safety earthquake resistance of the hydrogen circuits. In the premises located outside the reactor building, EDF carried out the necessary reinforcements. With regard to the reactor building, EDF relied on qualitative criteria (large dilution volumes, strong building ventilation and specific design of the hydrogenated circuits) to avoid the risk of an explosive atmosphere forming in the event of an earthquake. .

Risk in battery rooms

Batteries produce hydrogen during their charging phase. Electrically backed up ventilation, the operation of which is monitored, prevents the formation of an explosive atmosphere by limiting the accumulation of hydrogenated gases. EDF is committed to reinforcing the seismic resistance of the ventilation of these premises.

EDF has identified a battery room for which the effectiveness of the measures preventing the formation of an explosive atmosphere in the event of its ventilation failure is insufficient. EDF has therefore planned a modification aimed at limiting the accumulation of hydrogenated gas in this room by installing a passive autocatalytic hydrogen recombiner there.

5.2.11.2.2 Risk of explosion outside the premises of the nuclear island

Apart from the nuclear island, the main explosion risks concern the engine room, gas parks, technical galleries and networks conveying hydrogen gas located on the front of buildings, as well as, for sites by the sea, the electrochlorination room of the pumping stations[47].

Risk of explosion linked to the engine room, technical galleries and gutters

The alternator located in the engine room is cooled by hydrogen. EDF assessed the consequences of an explosion occurring following a complete emptying of the hydrogen contained in this equipment. These studies conclude that an explosion of the hydrogen jet is not likely to produce a level of overpressure calling into question the stability of the engine room. In addition, it considers that a scenario of an explosion of a dihydrogen slick would not affect a safety target.

EDF also assessed the consequences for safety of an explosion occurring in technical galleries and in the gutters in which pipes carrying dihydrogen circulate. EDF concludes that the risk of explosion associated with these facilities is under control. Therefore, it considers that no modification is necessary.

Risk of explosion associated with gas parks

EDF studied the potential consequences of an earthquake, projectiles induced by an extreme wind and a fire that could damage the hydrogen bottles stored in the gas parks and therefore lead to a risk of explosion. Following its analysis, EDF is planning changes in the context of the review aimed at:

- limit the quantities of gas stored;
- create a park dedicated to nitrogen storage;
- move gas storage away from safety targets likely to be attacked by an explosion and define a new location adapted to the potential effects of an explosion; guarantee the
- earthquake resistance of gas parks;
- put in place the necessary protections against the risk of projectiles, fire, or high energy pipe rupture (RTHE).

[47] Electrochlorination is an electrolysis process used to disinfect the circulating water (sea water) before it passes through the RRI / SEC exchangers. This process makes it possible to prevent the proliferation of marine flora and fauna in the circuits conveying seawater. This process produces dihydrogen.

In addition, EDF assessed, taking these modifications into account, the consequences for the safety of the installations of an explosion in the gas parks and of a vapor explosion from the nitrogen evaporator. EDF concludes that the risks associated with these situations are under control due to the remoteness of the safety targets.

Risk of explosion associated with the electrochlorination process

The electrochlorination process, necessary for the pumping stations of nuclear power plants located by the sea, results in the production of hydrogen by electrolysis reaction. EDF studied the different scenarios of attack (namely an earthquake, projectiles induced by an extreme wind, a lightning strike and a fire) that could affect this process and therefore cause the release of hydrogen.

In response to ASN requests [76], EDF demonstrated that a fire, projectiles induced by an extreme wind or a lightning strike would automatically stop the electrochlorination process, which makes it possible to prevent the risk. formation of an explosive atmosphere. In any event, if the process does not stop, EDF concludes that the effects of overpressure and the projectiles emitted in the event of an explosion in the room housing this process are not capable of damaging the safety targets.

Risk of explosion following the impact of lightning

In addition to the room housing the electrochlorination process, EDF has verified that the machine room, the gas park, as well as the technical galleries and gutters in which the networks carrying dihydrogen run are designed to withstand lightning strikes and that this phenomenon therefore cannot be the cause of an explosion.

5.2.11.2.3 Application of an aggravating agent in explosion studies

The application of an aggravating agent to the active provisions for controlling the risks associated with the explosion highlights the need for modifications. In fact, EDF concludes that the detection of dihydrogen, which makes it possible in particular to trigger actions to cut off the dihydrogen supply or the electrical supply to equipment in order to prevent the ignition of an explosive atmosphere, should be doubled. in order to ensure the realization of these actions. In addition, with regard to the battery rooms, EDF postulates, as an aggravating factor, the failure of the monitoring of the ventilation flow rate allowing the implementation of provisions to control the risks associated with the explosion in the event of an explosion. insufficient flow detection.

With regard to the static provisions for controlling the risks associated with the explosion, EDF has identified non-slaved fire doors whose maintenance in the closed state must be made more reliable in order to prevent the propagation of an explosive atmosphere. 'one room to another. EDF is therefore committed to making modifications to detect [48] keeping them in the open position for a long time. In addition, EDF has identified ventilation ducts and pipe protection devices conveying hydrogenated gases which must be the subject of reinforced operational monitoring (definition of a maintenance program, inspection intervals, etc.).

In addition, in order to improve the control of works in premises presenting a risk of forming an explosive atmosphere and to maintain the qualification of the equipment installed there against the risk of ignition, EDF has planned to impose an appropriate authorization. to all stakeholders.

[48] The list of fire doors, whose maintenance in the closed position must be made more reliable, is not the same as that adopted with regard to fire risks.

5.2.11.2.4 Taking into account the delay before the operators' first intervention

EDF has studied the actions to be carried out by the operators, in the control room and locally, to protect the installation in the event of an explosive atmosphere forming: actions are only necessary in the event of an accumulation of hydrogen in the battery rooms. EDF has not identified a cliff-edge effect if the delay before the operators' first intervention is taken into account for the Flamanville EPR reactor.

5.2.11.2.5 Probabilistic lighting

EDF has assessed the risk of core meltdown, or the discovery of fuel assemblies stored in swimming pools, in the event of an explosion. These probabilistic evaluations are presented in general in paragraph 5.7.1.2.3. The values obtained for the risk of core meltdown are $3.4.10^{-6}$ per year and per reactor. For swimming pools, the risk of uncovered assemblies is 1.10^{-9} per year and per reactor.

These values take into account new rules of conduct specific to battery rooms in the event of the detection of hydrogen in these rooms, making it possible to reduce the probability of an explosion occurring by preventing the formation of an explosive atmosphere. In addition, EDF is committed to improving the reliability of the electrical power supplies for the ventilation of the battery rooms. In addition, in one of these premises, EDF is planning the installation of a passive autocatalytic hydrogen recombiner.

These studies also enabled EDF to identify the most sensitive premises and explosion protection arrangements in the event of an explosion.

5.2.11.3 ASN's position on achieving the objectives of the review

EDF has proposed a structured approach to take into account the risk of internal explosions. In addition, it has incorporated into its studies the risks associated with an abnormal release of dihydrogen apart from the singularities of a removable nature of circuits containing hydrogenated gases, an explosion of internal origin in circuits containing hydrogenated gases and transfers of an explosive atmosphere between rooms. ASN considers that these changes constitute significant progress in controlling the risks associated with explosions. In fact, EDF's approach has until now been based solely on measures to prevent the formation and ignition of explosive atmospheres.

During the fourth periodic review of the 900 MWe reactors, the studies carried out by EDF made it possible to assess the consequences of an explosion for the safety of the installations by considering, in accordance with the defense-in-depth approach, that certain explosions occur despite preventive measures. These studies made it possible to identify the cases of explosion liable to lead to the loss of redundant resources.

EDF has thus identified measures making it possible to strengthen the provisions for the prevention of risks associated with the explosion in the battery rooms and in certain rooms of the nuclear auxiliaries building and the operating building in which the occurrence of a nuclear explosion. internal origin presents a risk to the safety of the installations.

In certain premises of the nuclear auxiliaries building and the operating building, EDF has not defined any additional measures to reduce the risks, whereas an explosion in these premises would lead to the loss of redundant equipment or, for explosions resulting in following leaks except singularity, effects outside the room. ASN considers that, for these premises, EDF must complete its analysis in order to identify, for explosions liable to lead to the loss of a safety function, the situations for which the availability of the equipment necessary for the breach and maintenance of the safe state of the reactor is not guaranteed and, depending on the challenges, propose additional measures to prevent explosions or limit their consequences. At the end of the instruction EDF undertook to carry out such a study when the number of premises affected by the fire caused by the explosion remains limited and, for the other premises, to put in place measures allowing reduce the risks. Depending on the challenges for safety, these provisions will have to be based on means that are not based solely on visual checks.

In view of the challenges, ASN supervises these studies through the prescription [AGR-G] [48].

ASN also considers that EDF must complete its studies relating to the risks of explosion of internal origin, in order to assess, in a quantified manner, the risks of forming an explosive atmosphere in the reactor building, including in the event of a of an earthquake, by studying the phenomena likely to occur near the leaks considered.

This point is the subject of the ASN [AGR-E] prescription [48].

In addition, ASN considers that the application by EDF of an aggravating agent to the explosion studies makes it possible to significantly improve the safety of the installations. Indeed, this approach made it possible to identify the most sensitive provisions for controlling the risks associated with the explosion and EDF is committed to making them more reliable. However, EDF did not identify the equipment whose failure when the attack occurred would lead to a cliff-edge effect. ASN also considers that EDF must define requirements for monitoring in operation of the additional devices making it possible to maintain the most sensitive fire doors in the closed position. **These points are the subject of the ASN [AGR-G] prescription [48].**

Studies relating to the inclusion of an aggravating factor in static protection provisions, submitted late, will be the subject of a subsequent investigation.

Finally, on the occasion of the fourth periodic review of the 900 MWe reactors, EDF carried out probabilistic safety studies to assess the risk of core meltdown, or the discovery of fuel assemblies stored in swimming pools, following a explosion. ASN considers that this probabilistic light has significantly improved the safety of the installations. Indeed, EDF has identified the premises and the arrangements most sensitive to this attack. In addition, EDF has planned, in the battery rooms, to strengthen and make the ventilation more reliable, to implement a hydrogen detection system and to modify the operating conditions of these rooms. For one of the battery rooms, EDF is planning the installation of a passive autocatalytic hydrogen recombiner.

5.2.12 Risks associated with internal flooding and high energy piping ruptures (RTHE)

The sources of flooding of internal origin are studied throughout the nuclear installation. In studies, these floods originate from:

- the rupture or the presence of a through crack in a pipe;
- sprinkling by fixed or mobile fire protection systems;

- sprinkling, including untimely, by the water sprinkling system in the enclosure used to limit the pressure build-up in the reactor building in certain accident situations;
- the emptying of the capacities containing a fluid (tarpaulins, tanks, etc.) liable to spill, including the quantity of fluid supplied by the make-up systems.

The studies relating to internal flooding and piping failures aim to ensure that these two attacks do not prevent the achievement and maintenance of the safe state of the reactor and of the storage pool of the fuel, regardless of the normal operating situation in which the reactor and the pool are located when the attack occurs. In practice, this amounts to verifying that the attack does not lead to a common mode risk on the equipment allowing, in a redundant manner, the achievement and maintenance of the safe state, as well as on their support functions (electrical distribution , instrumentation and control, ventilation, cooling, etc.).

5.2.12.1 Specific objectives of the review

As part of the fourth periodic review of the 900 MWe reactors, EDF reassessed the risks associated with internal flooding and pipe failure by studying the consequences of taking an aggravating factor into account, as well as the sensitivity of studies at the times considered before the first intervention of the operators (see paragraph 5.2.2). This reassessment responds to a request from ASN (SUR No. 30 [6]), formulated during the orientation phase of the review.

In addition, the re-examination must make it possible to verify the acceptability of the simultaneous discharge of the reservoirs not dimensioned to the earthquake, taking into account the effects of the propagation of such a flood from the reservoirs to the lower levels of the buildings.

5.2.12.2 Summary of studies carried out and modifications planned by EDF

In response to ASN's request (SUR n ° 30 [6]), EDF sent its methodology for analyzing internal flooding and pipe failures. It consists of :

1. determine in each room of the nuclear power plant the various possible sources of flooding;
2. define the effects induced by pipe failures (jet, whipping, degraded atmosphere);
3. define the failure hypotheses (type of breach, flow rate, etc.) according to the type of piping;
4. calculate the volume of water discharged into the room (taking into account the characteristics of the leak) until the leak is detected and isolated. The time taken into account in the studies between the detection of the leak in the control room and its isolation is 20 min when the isolation actions are carried out from the control room and 35 min when these actions are carried out in local. This period includes the search for the leak (diagnosis) and the time necessary for its isolation;
5. identify the equipment lost in this room (by sprinkling, immersion, etc.);
6. consider possible flood propagation routes and identify equipment lost during the flood propagation;
7. check that the loss of equipment ensuring, in a redundant manner, the same safety function does not jeopardize the ability to reach and then maintain the reactor and the swimming pool in a safe state.

Numerous studies have been carried out by EDF concerning the risk of internal flooding and pipe failure for this periodic review. They include the analysis of the consequences of the additional flooding induced by the rupture of a pipe carrying liquid which would be

attacked by the effects of the rupture of a high-energy piping. The induced flooding taken into account by EDF is that generating the most penalizing additional volume of water. These studies also take into account an aggravating factor on the isolation and detection organs.

EDF's new methodology was applied to the various nuclear power plant buildings with the exception of the reactor building. EDF did not carry out a new study for the reactor building, given the existing physical separation of the target equipment and the presence of anti-whipping devices. EDF also highlights the fact that the increased flooding in this building results from a rupture of the primary circuit and that, for this situation, no equipment necessary to ensure that the reactor is reached and maintained in the shutdown state. sure cannot be submerged. During the appraisal, however, EDF undertook to carry out this study to take into account the risks of flooding caused by a rupture of high-energy piping.

EDF also studied the simultaneous discharge of tanks not dimensioned during the earthquake, as requested by ASN.

During the performance of these studies, EDF identified several modifications necessary to reduce the risk of loss of redundant equipment and the risk of effluent discharges to the outside:

- the caulking of certain crossings to ensure their watertightness and to ensure the containment of effluents;
- the replacement of certain electrical boxes by equipment with increased tightness to protect them in the event of spraying;
- the application of new sealing requirements to so-called “mechanical” (for pipe passages) and “electrical” (for cable passages) hoppers in order to limit certain floods to a single safety channel;
- the replacement of certain electrical equipment to make them resistant to spraying.

EDF also undertook during the investigation to provide justifications and details on various aspects of its methodology.

Probabilistic lighting

In addition to these studies, EDF carried out probabilistic safety studies. These studies are described in the dedicated paragraph (paragraph 5.7).

EDF thus assessed the risk of core meltdown, or the discovery of fuel assemblies stored in swimming pools, in the event of internal flooding. The values obtained for the risk of core meltdown are $6.2.10^{-6}$ per year and per reactor following the third periodic review of the 900 MWe reactors, and $2.1.10^{-6}$ per year and per reactor, taking into account the modifications planned for the fourth periodic review of reactors including the "hard core". For fuel storage pools, the risk of uncovered assemblies is $5.8.10^{-10}$ per year and per reactor, taking into account the implementation of the "hard core" and the deployment of the means of the nuclear rapid action force (FARN).

Following these studies, EDF planned to install floor drains in the premises containing the switchboards on track B, allowing the flow passing through the clearance under the door located between the two safety tracks to be evacuated.

EDF does not plan to modify the installation with regard to the risk of internal flooding for the fuel storage pool.

In addition, EDF assessed the frequency of situations of significant release of radioelements into the environment, following an internal flood leading to an accident with core melt. EDF concludes that the consequences of this attack on the equipment necessary for the management of accidents with core melt are acceptable.

5.2.12.3 ASN's position on achieving the objectives of the review

For the fourth periodic review of the 900 MWe reactors, EDF introduced methodological changes to study the risks associated with internal flooding and piping failures. The study now includes the analysis of the consequences of flooding induced by the rupture of a pipe carrying a liquid and attacked by the effects of a high-energy pipe rupture (itself likely to generate a flood). The previously used methodology considered the failure of all piping assaulted by the effects of a high energy piping failure. Nevertheless, in view of the French and international experience feedback and the conclusions of several French and international research studies, this methodology was highly penalizing. The new calculations presented by EDF are more complete. The effect of an aggravating agent in studies is also considered.

These changes will help to significantly improve the safety demonstration of the installations.

5.2.12.3.1 Methodology

The methodology adopted for the fourth re-examination of the 900 MWe reactors differs from that adopted for the Flamanville EPR reactor on certain points. For the EPR reactor, the water depth in each room is calculated per time step according to the different incoming and outgoing flows while taking into account, as and when, the different insulation. For 900 MWe reactors, the total volume of water resulting from the flooding is assumed to flow instantaneously into the semi-sealed area.[49] and is distributed in proportion to the area in the premises located at the interface horizontally and vertically. This simplified method of calculating the water height is unrealistic and has advantages and disadvantages. For example, this method does not make it possible to verify whether the flooding spreads preferentially towards one room rather than another. On the other hand, it maximizes the water height in the semi-sealed area. In addition, EDF considers that all equipment is lost as soon as the water reaches a height of 15 cm in a room, which is a penalizing hypothesis.

ASN considers that EDF's methodology presents hypotheses which enable the risks associated with flooding to be treated in a sufficiently conservative manner. Nevertheless, this methodology calls for the following remarks.

Assumptions retained for piping failure

Contrary to the assumptions made for the Flamanville EPR reactor, EDF does not postulate a failure on pipes with a diameter of less than 25 mm, which is not consistent with operating experience feedback. EDF has undertaken to analyze the consequences in terms of internal flooding of the failure of purge lines with a diameter less than or equal to 25 mm, assuming a purge valve is left open.

Regarding medium-energy piping[50], ASN reiterates the importance of monitoring these non-safety classified piping[51]. A request to this effect was made by ASN in 2019 [77].

Assumptions relating to the watertightness of crossings

Following the investigation, EDF undertook to add a safety classification to all the floor or wall crossings valued in the studies as robust to a water load of 15 cm and for which the erasure was not considered. ASN considers this action to be satisfactory.

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[49] The semi-watertight zone is the zone comprising the room in which the flooding occurs and the rooms directly connected without physical separation (for example, existence of an opening without a door, or watertight hopper between the two rooms). The flooding is considered initially only on this zone of spreading in order to maximize the height of water there.

[50] Medium energy pipes (TME) are pipes conveying fluids with a pressure of less than 20 bar and a temperature of less than 100 ° C.

[51] Classified piping is particularly subject to specific monitoring requirements in operation.

Valued outflow arrangements (outlets, siphons)

During the investigation, EDF indicated that it is developing a test program to ensure the proper flow of the outlets and soil drains valued in studies of internal flooding. ASN considers this approach positive, given the observations made during its inspections. Depending on the results of these tests, EDF will have to re-examine the sufficiency of the requirements it applies to these systems. This point was the subject of a request from ASN [77].

Effects induced by pipe failures

EDF proposed a new methodology to consider the impact of high-energy piping whipping on surrounding equipment. This new methodology is based on the fact that the whipping and deflection effects, on certain high-energy pipes with a temperature less than or equal to 100 ° C, can be limited to only a few centimeters. EDF uses this methodology in certain studies of internal flooding, which has the effect of limiting the maximum water level reached in certain premises or of excluding situations of stress likely to lead to loss of water functions. safety. This methodology was sent late to ASN and will be reviewed in a dedicated framework.

Detection, diagnosis and isolation times for internal flooding

The total time taken into account in the studies of internal flooding for the detection, the diagnosis and the isolation of a leak is important insofar as it determines, in most cases, the volume of water which will be discharged into the premises. In the studies, these times are the same, regardless of the initiators and flood scenarios considered and regardless of the number of valves to be activated to stop the flooding. However, for none of the flood scenarios, EDF did not justify the ability of the operators to carry out the diagnostic and isolation steps within the allotted time of 20 and 35 minutes from the moment the flooding was detected in the room. control (detection is, in most cases, associated with reaching a certain water level in the sumps). If these deadlines are exceeded, the volume discharged into the premises would be greater, potentially leading to a propagation phase impacting more premises and therefore more equipment. The height of the water in the various flooded premises could also be greater.

The observations made by ASN during inspections show that the operators in the control room do not always have operating documents to aid in the diagnosis and to identify the components to be operated to achieve the isolation of a flood. of internal origin. In addition, during certain floods of internal origin that recently occurred on reactors in operation [52], the time taken to diagnose the source of the leak and isolate it was significantly higher than those used by EDF in the studies. ASN considers that EDF must place the emphasis on diagnostic assistance, training and staff awareness in this area.

As part of this review, EDF also examined the sensitivity of the studies of internal flooding of the 900 MWe reactors to the delays considered in the studies of the Flamanville EPR reactor (namely, from the location of the leak , 30 min when the isolation actions are carried out from the control room and one hour when these actions are carried out locally, see paragraph 5.2.2). This sensitivity study, carried out for a sample of ten premises, concludes that, with the exception of one local

[52] For example :

- leak in the Blayais nuclear power plant in September 2012 isolated 1 h 56 min after the appearance of the alarm;
- leak in the Saint-Laurent-des-Eaux nuclear power plant in September 2017, due to the incomplete closing of a valve by a worker, isolated in 45 min when the worker knew which room to go to and which body to act on ;
- leak in the Gravelines nuclear power plant in January 2016, isolated in 3 h 15 min after the alarm appeared.

for which taking into account a larger volume of water discharged leads to reinforced requirements to guarantee the holding of the hoppers, the taking into account of the EPR reactor delay has no impact on the analyzes of the flood studies of internal origin. However, the sample of the ten premises analyzed having been deemed too small, EDF sent in 2020 an additional sensitivity study. This study was not analyzed by ASN in the context of this report.

In general, ASN considers that EDF has not provided sufficient information to demonstrate the ability of the operators to isolate the leaks within the time limits considered in the safety studies relating to the risk of internal flooding.

At the end of the investigation, EDF undertook to verify the absence of a cliff-edge effect due to the extension of the fixed periods considered for leak isolation in the event of internal flooding, in increasing them by one hour when the flood is detected by monitoring the levels in the sumps, in order to take into account additional time to identify the origin of the leak. In addition, EDF is committed to proposing organizational or documentary arrangements to facilitate the processing of this type of event.

5.2.12.3.2 Taking into account the aggravating factor

With regard to the active equipment required to detect or isolate a leak causing internal flooding, EDF considered an aggravating factor leading to maximizing the volume of water, which is satisfactory.

On the other hand, unlike the studies of the EPR reactor at Flamanville which consider an aggravating factor for manual valves and motorized valves, EDF has not retained any aggravating factor for manual valves on the grounds of their high reliability. During the appraisal, EDF undertook to identify the manual valves whose failure has a significant impact on safety and to provide this equipment with a higher level of requirements. A new study was therefore sent in September 2019 which identifies two manual valves for which the monitoring requirements in operation will be reinforced. In view of these elements, ASN considers that the failure to take into account an aggravating factor on the manual valves is acceptable in the context of a first exercise.

Regarding passive equipment valued in studies of internal flooding, such as floor drains or watertight feedthroughs, EDF does not apply any aggravation to them either because of their high reliability. ASN considers that the absence of aggravating agent on the sealed hoppers is acceptable within the framework of a first exercise. Concerning the floor drains, EDF has identified the siphons whose failure would have significant consequences on the installation. It has proposed, for siphons presenting particular challenges, the installation of additional siphons, which is satisfactory.

5.2.12.3.3 Variation of the methodology adopted for the fourth periodic review of 900 MWe reactors

As part of the studies relating to the propagation paths of floods, EDF carried out analyzes concerning the stability of civil engineering under water load in the event of internal flooding:

- for the nuclear island, EDF considers that the hoppers or the doors will give way before the civil engineering structures in the event of high water levels;
- for the conventional island, EDF analyzes the water load stability of the separation veil between the two safety channels of the wells of the rescued raw water circuit for the Tricastin and Bugey sites, the configurations of which are considered by EDF penalizing compared to those of other sites.

ASN considers that the verification of the wall stability carried out by EDF (linked to the removal of the doors and hoppers) is acceptable for the nuclear island of all the sites and for the conventional island of the Tricastin sites. and du Bugey. On the other hand, the transposable nature of the

demonstration of the stability of the separation walls of the wells of the raw water circuit rescued from the conventional island to the other sites was not justified. This point is the subject of a request from ASN [49].

For six rooms in the building of nuclear auxiliaries for CPY type reactors, the study showed that internal flooding can lead to a situation of total loss of the heat sink (situation "H1") but also, for five of these six premises, the loss of the materials necessary to manage this situation. Following the examination of this study, EDF sent a more precise additional analysis, for reactors n ° 1 and n ° 2 of the Tricastin nuclear power plant, which makes it possible to conclude that the means of managing the situation " H1 ”would remain available. EDF specifies that similar analyzes will be carried out for the other reactors according to a schedule consistent with the ten-yearly outages. ASN considers the supplements sent for the reactors at the Tricastin nuclear power plant to be satisfactory.

Concerning the conventional island, the studies carried out for the Tricastin site are satisfactory.

For the reactors at the Bugey nuclear power plant, studies similar to those carried out for the CPY type reactors were sent by EDF. For the conventional island of the Bugey nuclear power plant, the studies submitted are satisfactory on the whole, but require certain additions concerning the operating documentation and the modifications adopted. EDF has undertaken to transmit these supplements, which is satisfactory. For the nuclear island, the late transmission of the studies did not allow their examination within the framework of the generic phase of the review. These studies will be the subject of an instruction in a dedicated framework.

Finally, the study of simultaneous discharge of tanks not dimensioned to the earthquake takes into account the effects of sprinkling and immersion on the materials present all along the path of the water to the bottom of the building. It also checks the containment of radioactive effluents. Floor drains and their piping are not valued in the study to evacuate effluents, given the lack of seismic resistance of these materials. ASN considers this study to be satisfactory.

5.2.12.3.4 Probabilistic lighting

During the fourth periodic review, EDF carried out probabilistic safety studies to assess the risk of core meltdown, or of the fuel assemblies stored in the pool being discovered, following an internal flood on a 900 MWe reactor. EDF also assessed the frequency of situations of significant release of radioelements into the environment, following an internal flood leading to an accident with core melt. ASN considers that this probabilistic light has significantly improved the safety demonstration of the installations.

In fact, EDF has identified the premises and the measures most sensitive to this attack and has put in place measures aimed at improving the reliability of the control of risks linked to internal flooding. EDF has in particular planned to implement modifications to significantly reduce the risk of core meltdown in the event of internal flooding.

EDF has undertaken to study the impacts associated with the flooding induced by a scenario of emptying the fuel storage pool, which is satisfactory.

With regard to level 2 probabilistic studies, the results show that additional devices are necessary. Indeed :

- a risk of common cause failure of power supplies and equipment necessary for switching to the ultimate emergency power source has been identified. ASN therefore considers that EDF must implement measures to avoid this situation, to which EDF is committed;

- internal flooding could cause loss of pressure measurement in the reactor building. This measure makes it possible to trigger important actions to limit releases in an accident situation with core melt. ASN considers that the equipment enabling this measurement must therefore be protected from the effects of internal flooding. **This point is the subject of the ASN [AG-C] prescription [48].**

5.2.13 Risks associated with collisions and falling loads

5.2.13.1 Specific objectives of the review

For the fourth review of the 900 MWe reactors, EDF took into account in the safety demonstration the risk of collisions and load drops in accordance with article 3.5 of the BNI order [1]. The safety demonstration includes the consequences of collisions and falling loads, the quality of the design, manufacture, in-service checks of handling equipment and, where applicable, additional means of preventing or limiting the consequences of these load drops.

Analysis of experience feedback has shown that load drops can occur even for handling equipment with increased requirements such as the polar bridge. Consequently, ASN asked EDF (SUR n ° 42 [6]) to assess " *the consequences of collisions and falling loads in the reactor building, including loads handled by the polar bridge* ", Without excluding these events on a single probabilistic basis.

5.2.13.2 Summary of studies carried out

As part of the fourth periodic review of 900 MWe reactors, EDF assessed the risks induced by a collision or a load drop using the following methodology:

- identification of potential aggressors among handling equipment;
- the analysis of the existing material or organizational arrangements relating to the handling equipment making it possible to exclude or prevent the risk;
- identification of the targets potentially impacted by a collision or a fall of loads during handling;
- functional analysis of the loss of identified targets to study the possible consequences on compliance with safety objectives; an analysis of the radiological consequences can, if necessary, be considered;
- if necessary, setting up a material or organizational countermeasure to prevent the risk or protect the target.

The scope of EDF's study concerns lifting and handling equipment that may present a risk of collision or load drop impacting important elements for the protection of the interests mentioned in Article L. 593-1 of the Code of the environment.

5.2.13.3 ASN's position on achieving the objectives of the review

ASN considers that the safety demonstration presented by EDF for buildings other than the reactor building is satisfactory. The case of the fuel building is dealt with in the chapter relating to the storage pool in paragraph 5.4.3.5.

On the other hand, ASN considers that EDF must provide additional information concerning the handling carried out in the reactor building.

ASN notes that EDF has not studied the risk of collision when using the pole bridge. ASN considers that EDF must study the consequences of the risk of collision during handling operations carried out using the polar bridge of the reactor building. At the end of the investigation, EDF undertook to complete its study, which is satisfactory.

In addition, the handling of a slab of the shutdown reactor cooling system (RRA) by the main winch of the polar bridge, in situations where the reactor is loaded with fuel assemblies, may present a risk in the event of a fall. At the end of the investigation, EDF undertook to prohibit handling of this slab when the reactor is loaded, which is satisfactory.

5.2.14 Risks associated with other attacks taken into account in the safety demonstration

The other attacks that EDF must take into account when demonstrating the safety of its nuclear power plants are listed in articles 3.5 and 3.6 of the BNI order [1].

In addition to the “falling loads”, “explosions”, “fires” and “internal floods” attacks developed in the previous paragraphs, these are the following internal attacks:

- projectile emissions, in particular those induced by the failure of rotating equipment;
- failures of pressure equipment;
- electromagnetic interference generated in the perimeter of the BNI;
- emissions of hazardous substances.

Concerning attacks of external origin, in addition to the attacks "risks induced by industrial activities and communication routes", "earthquakes", "hot weather" and "floods of external origin" developed in the previous paragraphs, it is:

- lightning and electromagnetic interference;
- extreme cold;
- cold source aggressors ("lower safety waters" (PBES), icing, siltation and silting of civil engineering works, frazil, hydrocarbons from fixed installations or ships, massive influx of clogging (AMC) which may come from fauna, flora, mineral or human origin (waste, etc.)).

5.2.14.1 Specific objectives of the review

The objectives of the review for the attacks dealt with in this part consist of verifying the sufficiency of the protective measures and, if necessary, defining new provisions making it possible to deal with the attacks, taking into account the French experience feedback. and international and, more generally, the evolution of knowledge and practices. ASN also asked EDF [6] to take into account the recommendations of the WENRA association. Some specific requests were also made by ASN during the orientation phase of the review:

- the integration, in the assessment of the risks associated with internal electromagnetic interference (EMI), of the electromagnetic compatibility standard (standard IEC 61000);
- the definition of a complete methodology for taking into account the risks associated with lightning;
- taking into account the risks associated with solar storms.

For heat sink aggressors, the new rules developed by EDF following several significant events that occurred in 2009 are applicable from this review. This reference system and the consideration of heat sink aggressors have already been the subject of several ASN instructions. On the occasion of the fourth periodic review of the 900 MWe reactors, EDF must therefore also respond to ASN's requests formulated in the context of these previous instructions.

5.2.14.2 Summary of studies carried out and planned modifications

EDF transmitted its assessment process for each of the attacks and the associated protection measures. The reassessed hazards take account of experience feedback, climate monitoring and ASN requests.

Additional protection measures have been defined by EDF for certain attacks:

- for lightning, the installation of lightning arresters or lightning rods, cable tray covers, connections of conductors to the earth network and the movement of equipment in areas that cannot be impacted by lightning;
- for very cold weather, around ten material modifications or operating rules, such as opening valves to create water circulation or installing insulation;
- for the frazil, the installation of a winter recirculation [53] on the Bugey, Tricastin, Gravelines and Blayais sites which did not have one at the design stage;
- for the massive influx of clogging, several modifications, such as, for example, the installation of level measurement sensors downstream of the filtration or the change of the filtration grids.

In certain cases, the evaluations may lead EDF, following functional analyzes, to clear certain equipment when the loss of this equipment in a situation of aggression does not call into question the achievement of a safe state.

Concerning solar storms, EDF considers that the risks are covered by taking into account the situation of loss of external power supplies (known as “MDTE”) for 15 days, postulated following an earthquake.

5.2.14.3 ASN's position on achieving the objectives of the review

Failures of tanks, pumps and valves leading to the emission of internal projectiles

The detailed studies of the risks induced by failures of tanks, pumps and valves generating internal projectiles carried out by EDF are satisfactory, with regard to the sample of projectiles, their speed of impact on civil engineering, the calculation of its perforation and analysis of the impact of projectiles on equipment.

However, EDF has not demonstrated that the classified safety equipment, present in the premises adjacent to the room emitting an internal projectile, is not damaged by the projections of flaking of concrete debris. EDF has undertaken to verify this point. EDF has also undertaken to complete its study of the impact of certain internal projectiles in the reactor building and in a room of the electrical building identified during the investigation.

Internal electromagnetic interference

The approach presented by EDF is a classic approach to managing internal electromagnetic interference, which complies with the usual standards in the field. ASN considers the approach adopted by EDF to be satisfactory.

Lightning and external electromagnetic interference

The “lightning” hazard selected for this review is acceptable given the capacity of the facilities to cope with a more severe hazard taken into account for the “hard core”.

[53] The winter recirculation device consists in injecting, at the level of the grids of the water inlets of a reactor, hot water coming from the discharges of the plant in order to prevent the formation of frazil at the level of these grids.

The protection approach implemented is satisfactory with regard to the direct effects of lightning and induced overvoltages. On the other hand, EDF does not demonstrate the protection of its reactors against the risks induced by fields radiated by lightning. EDF is committed to checking that the fields radiated by lightning do not call into question the safety objectives or, if not, to define appropriate protection. The conclusions of these verifications will be communicated in the review conclusion report for each reactor.

EDF did not take into account the failure of a surge arrester with a lightning strike (approach associated with taking into account an “aggravating”) but undertook to consider the effects of a cumulative lightning strike. the failure of a surge arrester at the end of phase B of the deployment of the modifications resulting from the review, which is acceptable.

Concerning solar storms, ASN considers that EDF should check that the risks associated with the MDTE postulated following an earthquake do cover the risks associated with the MDTE which would be caused by a solar storm. EDF has initiated a study to assess the geomagnetic currents induced by a solar storm and their effects on transformers. ASN agrees that the risks associated with solar storms do not have priority over other hazards. However, ASN considers that EDF must continue to develop knowledge of their effects.

Very cold

The hazard selected by EDF for the “extreme cold” aggression is satisfactory, as are the accumulations studied. In particular, the experience feedback from winter 2012 has been correctly integrated into the safety demonstration and the “extreme cold WENRA” temperature defined by EDF to meet the recommendations of the WENRA association is acceptable. Regarding the hypotheses of the thermal studies adopted by EDF, the investigation revealed some necessary improvements that EDF has undertaken to achieve, which is satisfactory.

Regarding the verification of the resistance of equipment to "extreme cold", the analysis presented by EDF is acceptable, nevertheless ASN points out that all the equipment recovered in the safety demonstration must be classified as safety. In addition, the analysis of the resistance in the event of "extreme cold" of equipment located outside buildings or in unventilated rooms must be integrated into the safety demonstration. These supplements are the subject of a request from ASN [49].

The changes related to “extreme cold” planned by EDF are satisfactory. In addition, EDF is committed to updating the special rules of conduct (RPC) "extreme cold"[54]. This rule will contain the list of equipment valued in the “extreme cold” studies.

Cold source aggressors

As mentioned in paragraph 5.2.3, ASN considers that EDF must provide, during the next update of the climate watch, a quantified assessment of the possible effects of climate change, in particular concerning the risk of loss of the cold source in a low water situation. This point is the subject of a request from ASN [49].

In addition, ASN considers that the protection of sites against frazil will be significantly improved following the fourth periodic review of the 900 MWe reactors. The specific modifications planned on each site will be the subject of an instruction before their implementation.

For the other stressors to the cold source, such as icing up, silting up and siltation, hydrocarbons and the massive influx of clogging, ASN considers, taking into account the assessments carried out by EDF and the measures implemented place to face these attacks and the planned modifications, that the demonstration of the capacity of the reactors to face these attacks is satisfactory.

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[54] The “extreme cold” RPC prescribes the rules to be incorporated into their “extreme cold” instructions for sites, the aim of which is to implement and ensure the availability of the equipment necessary for the protection of installations in winter and to verify during this period the proper functioning of equipment sensitive to cold.

5.2.15 Summary and prescriptions relating to the risks associated with attacks

EDF reassessed, for the fourth periodic re-examination of the 900 MWe reactors, the characteristics of the natural hazards considered as well as the measures planned to deal with them.

At the end of the appraisal, the hazard levels retained for the earthquake and tornadoes are acceptable for all the sites, taking into account the commitments made by EDF. For other hazards, the methods used to assess the hazards are acceptable, given the commitments made by EDF, in particular to assess the outside air temperatures in the event of a heat wave. The levels retained for each site will be presented by EDF in the report concluding the review of each reactor.

For natural hazards, the climate watch implemented by EDF is satisfactory: it defines in particular major weather events, the occurrence of which triggers a reassessment of the hazard levels to be considered. However, the thresholds associated with these events need to be revised.

The fourth periodic review was also an opportunity to ensure that the risk levels selected comply with the recommendations published in 2014 by the WENRA association of heads of nuclear safety authorities in Western Europe. In the event of non-compliance, EDF studied the capacity of the facilities to cope with hazards significantly greater than these.

During the generic phase of the fourth review, EDF also included, in the safety demonstration, the study of the consequences of equipment failure in the event of an attack, such as a fire door, for example, what is recommended by the WENRA association. This study makes it possible to identify the most important arrangements for dealing with attacks and to define means to guarantee their correct functioning, for example by setting up an alarm when a fire door is open. This approach constitutes a significant improvement compared to previous periodic reviews and makes it possible to increase the robustness of the installations.

For the control of the risks associated with the fire, the new method adopted by EDF to justify the sectorization of the premises constitutes a significant advance. Regarding the effect of fumes, EDF has developed a new method to identify, for electronic equipment, which is the most sensitive, situations in which fumes could attack equipment important for safety, which is satisfactory. The studies carried out have also made it possible to define operating measures to limit the risk of fire outbreaks in high-stakes premises.

For the control of the risks associated with the explosion, the studies carried out by EDF constitute a significant advance, insofar as EDF studied their consequences and considered that the leaks could occur, not only at the level of singularities, but also elsewhere. EDF has identified the situations likely to lead to the loss of redundant equipment. In most cases, EDF has defined measures to be implemented to bring the installation back to a safe state. However, EDF must complete its analysis for certain premises.

To control the risks associated with high outside temperatures, EDF has undertaken to improve its safety demonstration in order to better take into account the uncertainties associated with the calculations of temperatures in the premises. ASN prescribes the assessment of the capacity of the installations to cope with situations of loss of electrical power supplies, in particular in the event of extreme temperature.

For other hazards, the methods and assumptions used by EDF to carry out its studies are satisfactory. The modifications to the installations resulting from these studies will be implemented as part of the periodic review of each reactor.

Finally, EDF has carried out studies to shed probabilistic light on the attacks associated with fires, explosions, internal floods, earthquakes and external floods. This clarification made it possible to identify additional modifications to be implemented for each of these attacks, which will improve the level of safety.

ASN underlines the important work carried out by EDF to update all the stress studies. Certain studies have led EDF to define modifications; further studies are necessary in order to assess whether new provisions need to be implemented. All of these modifications will constitute a significant improvement in the control of risks associated with attacks, which will make it possible to achieve the objectives set for this review.

*

At the end of the examination, EDF undertook to carry out most of the necessary additions that the ASN examination revealed. ASN prescribes [48] the implementation of the major safety improvements planned by EDF as well as certain additional measures that it considers necessary to achieve the objectives of the review.

Hazards associated with outside temperatures

[AGR-A] The operator retains, in its "hot weather" reference system, the extreme temperatures TE and Tmin associated with the heat wave defined by considering:

- an annual exceedance frequency less than or equal to 10-2 (upper limit of the 70% confidence interval) including climate change until the next periodic review. This climate change takes into account the climate trends corresponding to a region relevant to the site concerned;
- the envelope values of the relevant experience feedback for the site.

Ability to cope with a situation of total loss of site power supplies in a high temperature situation

[AGR-B] I.– No later than December 31, 2023, the operator justifies the availability of the equipment necessary to manage situations of total loss of electrical power supplies (external power supplies and main emergency generators) affecting a reactor and those affecting all the reactors on a site for the "long-term" outdoor temperature (TLD) of its "hot weather" benchmark.

II.– The operator implements any necessary modifications.

Ability to cope with high temperature situation beyond sizing

[AGR-C] By December 31, 2022, the operator:

- defines a hazard going beyond the temperatures retained in its "hot weather" reference system, corresponding to a ten-year return period, and justifies it with regard to the uncertainties associated with its assessment;
- checks the availability of the necessary equipment to deal with this situation, including in the event of loss of external power supplies;
- identifies any modifications that would make it possible to achieve this objective.

Risks associated with fire

[AGR-D] I.– By December 31, 2022 at the latest, the operator takes into account in the fire risk control studies (justification of the sectorization, smoke effect, pressure effects):

- all the premises of the nuclear island and the pumping station;
- envelope modeling hypotheses making it possible to determine the temperature curves reached in the premises for fires in electrical cabinets and electrical cable trays likely to be encountered. In particular, it uses a fire growth coefficient for electrical cabinet fires that is independent of the ignition conditions and representative of the achievement of a self-sustaining combustion phase.

II.– The operator implements any necessary modifications.

[AGR-E] I.– The operator defines and implements suitable operating provisions, which include actions to control heat loads and control work that could cause a fire to start, in the following premises:

- premises for which a fire contributes significantly to the risk of core meltdown or of uncovering of the assemblies in the fuel storage pool;
- premises whose sectorization is ensured by at least one door, the open position of which during a fire leads to a significant increase in the risk of core meltdown or to the loss of redundant water back-up means or cooling of the fuel storage pool.

II.– The operator identifies, regardless of their reliability, the fire protection measures the failure of which leads to a significant increase in the risk of core meltdown or to the loss of redundant water back-up resources or resources. for cooling the fuel storage pool.

It implements means making it possible to reduce the risk of failure of these measures and defines the operating requirements associated with these means.

III.– The operator identifies the premises most sensitive to the unavailability of fixed sprinkler systems. It defines and implements measures to limit the risk of loss of fire sectorization in these premises.

Risks associated with the earthquake

[AGR-F] I.– The licensee identifies the systems, structures and components requiring reinforcements to ensure that the hard core can withstand the seismic hazard that it has defined in application of the prescription [ECS-ND7] of the 'annex to the aforementioned decisions of January 21, 2014.

II.– The licensee implements the modifications allowing the reinforcement of the systems, structures and components identified in I.

III.– For the reactors of the nuclear power plants of Blayais, Bugey, Chinon, Cruas and Tricastin, the licensee is studying the possibilities of reinforcement making it possible to cope with higher seismic hazard levels than those mentioned in I to take into account the uncertainties in determining the extreme hazard and any specific site effects. It defines any changes to be implemented with regard to the challenges for safety and the associated schedule.

Risks associated with internal explosion

[AGR-G] I.– No later than December 31, 2025, the operator:

- identifies, for explosions liable to lead to the loss of a safety function, the situations for which the availability of the equipment necessary to achieve and maintain the safe state of the reactor is not guaranteed;
- assesses, in a quantified manner, the risks of an explosive atmosphere forming in the reactor building, including in the event of an earthquake, by studying the phenomena likely to occur near the leaks in question;
- defines the possible measures to be implemented with regard to the challenges for safety and the associated schedule.

II.– By December 31, 2022, the operator:

- identifies, regardless of their reliability, the explosion protection arrangements, the failure of which leads to a significant increase in the risk of core meltdown or to the loss of redundant water make-up or pool cooling means fuel storage;
- defines the means to be implemented to reduce the risk of failure of these measures, the operating requirements associated with these means and the associated schedule.

5.3 RE-ASSESSMENT OF REACTOR ACCIDENT STUDIES

During the generic phase of the fourth periodic review of 900 MWe reactors, EDF re-examined all the studies associated with the various incidents and accidents that could occur on the reactor, called “operating conditions”. These are the so-called studies:

- the dimensioning field, namely studies of incidents and accidents resulting from a single failure (initiator). For these studies, hypotheses of studies penalizing and an aggravating factor, under the single failure criterion, are considered;
- the complementary field, namely studies of accidents resulting from multiple failures or not taken into account in the design. For these studies, no aggravating agent is considered;
- “Specific supporting documents”, which are produced by EDF in order to assess the robustness of the installation with respect to physical phenomena not taken into account in the design. These studies are carried out by considering specific study hypotheses.

The studies transmitted by EDF integrate the improvements resulting from the development of knowledge and the conclusions of the expertises which preceded the review. They take into account the evolution of several standards applicable for this review.[55] and the valuation of operational modifications and material modifications (see paragraph 5.1).

The radiological consequences of accidents are dealt with in paragraph 5.6.

5.3.1 Sizing operating conditions

5.3.1.1 Specific objectives of the review

EDF has adopted the objective of integrating the new study guidelines resulting from changes in knowledge as well as the conclusions of the instructions preceding the review into the studies of the sizing operating conditions. It also adopted the objective of moving towards levels of radiological consequences that do not require the implementation of measures to protect the population.

For this review, ASN asked EDF [6] to take into account the foreseeable state of the fuel, in particular the lateral deformation of the fuel assemblies in normal operation.[56,] the mechanical condition of the fuel rods[57] and the presence of leaking pencils.

ASN also asked [6] " *to evaluate [...] the behavior of the 900 MWe reactors for the events and operator delays of the EPR reference system, by applying the rules of the studies of the design operating conditions* "And" *in the event of non-compliance with the safety criteria associated with the design domain, [...] analyze the reasons for exceeding these criteria, identify any measures that could be implemented to remedy them and examine their feasibility and their interest* ".

[55] Main changes in the reference system: changes in criteria relating to fuel resistance, application of the new safety reference system for the loss of primary coolant accident (APRP reference), consideration of the clogging of the spacer plates of steam generators, taking into account account of the variability of refueling, application of the “refurbished complementary area” approach, application of the “criticality reference” and new methodology for assessing radiological consequences.

[56] Lateral deformation of the fuel assemblies: the fuel assemblies deform laterally during their irradiation in the reactor which leads to several effects, in particular an increase in the neutron power at the periphery of certain assemblies.

[57] Mechanical conditioning of the fuel rods: the mechanical conditioning state of the rods represents the initial thermomechanical state of the fuel rods during an accident study.

5.3.1.2 Summary of studies in the dimensioning field

EDF has done a very important job of resuming all of its studies, by developing a set of new standards and by integrating the lessons of the previous instructions. EDF has justified the qualification of the scientific calculation tools used to provide the safety demonstration.

These studies concern in particular:

- the reactivity insertion transients, including the dilution transients of the borated water present in the primary circuit;
- primary circuit cooling transients, including the opening of a valve on the secondary circuit;
- loss of primary refrigerant (PRA) accidents, including steam generator tube rupture (RTGV) accidents;
- temperature rise transients and flow loss transients; these transients do not call for remarks in the remainder of this chapter;
- the study of the transposition of the transients of the Flamanville EPR reactor and of the deadlines retained before the first intervention of the operators for this reactor.

The studies carried out take into account the variability of refueling and the presence of fuel assemblies from different suppliers (“mixed cores”).

EDF has integrated the state of knowledge concerning certain physical phenomena relating to fuel not considered until now. To do this, EDF carried out additional studies, taking into account in particular the foreseeable state of the fuel (lateral deformation of the assemblies, mechanical conditioning of the rods, presence of leaky rods in the core) in the safety demonstration.

As part of these studies or their instruction, EDF has assessed or defined changes that will be implemented for the fourth periodic review. These include in particular:

- the installation of a boremeter on the discharge line of the chemical and volumetric control system of the main primary circuit (RCV), in particular to detect accidental dilution sequences for states in normal shutdown without a primary pump unit in operation as well as for shutdown states for intervention and recharging. This modification makes it possible to correct an anomaly relating to the source level measurement chains (CNS) used for neutron monitoring of the core;
- the increase in the pressure of the safety injection accumulators of the reactors using “MOX parity” fuel management, taking into account the current reservations on the method relating to the study of the loss of primary coolant accident;
- the reduction of the initial internal pressure of the fuel rods of the “MOX parity” and “Cyclades” fuel management systems, taking into account the current reservations on the method relating to the study of the primary coolant loss accident;
- increasing the stroke of the regulating valves of the turbine bypass unit to atmosphere (GCT-a) in order to increase their discharge capacity when fully open, in order to maintain a significant cooling gradient, even for low pressures in steam generators;
- the refeeding of the tank of the emergency power supply system for the steam generators (ASG) by the fire water circuit, by creating a new backup line;
- increasing the tank volume of the water and boron make-up system (REA) and the free volume of the tank of the primary liquid effluent treatment (PET) system in order to restore margins in the control studies of responsiveness in shutdown states.

Finally, EDF implemented modifications or compensatory measures in order to correct all of the study anomalies known as of February 2018 calling into question the demonstration of compliance with the safety criteria, with the exception of the anomaly below during treatment.

The justification for the safety of MOX fuel is still affected by a study anomaly relating to a phenomenon of upward flux at the end of the fissile column, until then not taken into account, which, combined with faults in the pellets of MOX fuel linked to a difficulty in fuel fabrication, requires modification of the design and fabrication of the fuel. Corrective action is being deployed. In the meantime, EDF is implementing compensatory measures.

The development of the operating procedures in the event of small leaks on the tubes of steam generators (known as RTGV3 situations) proposed in the context of the fourth periodic review also requires additional demonstrations from EDF. This point was the subject of a specific request from ASN [58].

The studies provided demonstrate compliance with the safety criteria. For the study relating to the cluster ejection, the safety justification will be provided, taking into account limitations in the method, as part of each of the fuel refill justification files.

Special points

The behavior of the fuel assemblies is checked in accident conditions to ensure that their functional capacity is maintained: the insertion of the control rods into the guide tubes must always remain possible and rapid. On this subject, the limiting study concerns the resistance of the grids to horizontal stresses or the risk of buckling of the grids in the event of a loss of primary coolant accident (APRP) combined with an earthquake. The mechanical behavior of the “AFA 3GA” assemblies was reassessed with changes in the assumptions associated with the fourth review, in particular concerning the operating conditions of the reactor (cycle extension) and the new method associated with the loss of power accident. primary refrigerant.

The late transmission of the studies carried out for the fourth review corresponding to the fuel assemblies manufactured by Westinghouse, called "RFA ZIRLO" did not allow their investigation in the context of this review. They will therefore be the subject of a specific position statement by ASN in a dedicated framework.

Finally, the studies sent by EDF concern “Mox parity” and “Cyclades” fuel management. The transposable nature of some of the conclusions presented below to “Garance” fuel management, which concerns the reactors of the Cruas nuclear power plant and reactors n ° 3 and n ° 4 of the Blayais nuclear power plant, must be demonstrated. and justified by EDF at the latest when submitting the conclusion report for the reactors concerned. These elements will be the subject of a dedicated instruction.

5.3.1.2.1 Transposition of the PCC operating conditions of the Flamanville EPR reactor

EDF studied the so-called “Plant Condition Categories” (PCC) operating conditions of the Flamanville EPR reactor for 900 MWe reactors.

EDF has identified, among the forty-nine studies of PCCs for the Flamanville EPR reactor, thirty-one studies that have not been explicitly dealt with or are partially dealt with in the field of dimensioning of 900 MWe reactors. These PCCs concern either the reactor or the fuel storage pool (for the pool, these studies are discussed in paragraph 5.4.3.3).

Following the assessment of these events, EDF concludes that the safety criteria for the 900 MWe reactor design scope are met for most of the PCCs of the Flamanville EPR reactor transposed to the 900 MWe reactors.

EDF then analyzed the five situations for which these criteria were not met and identified any modifications that would make it possible to meet the criteria. These situations are:

- situations initiated by a breach in the primary circuit:
    - of diameter greater than two inches, occurring when the reactor is in normal shutdown on the steam generators (AN / GV). The criteria are exceeded only for breaches of four to six inches. EDF believes that the criteria can be met by reducing certain study conservatisms,
    - of diameter less than two inches, occurring when the reactor is in normal shutdown on the shutdown reactor cooling circuit (AN / RRA) or occurring when the reactor is shut down for service (API). EDF concludes that compliance with the safety criteria would require introducing into the technical operating specifications (STE) general operating rules new requirements relating to the availability of certain equipment, which would require prior adaptation of the rules and the STE design doctrine, in order to make them compatible with the operation of reactors;
- situations of dilution of borated water due to the rupture of a tube of the heat exchanger of the sealing circuit of the primary pumps, occurring in AN / GV or in AN / RRA. The introduction of these operating conditions in the dimensioning domain would require a material modification of the "REA bore" tarpaulins.[58] to increase their volume, which for EDF is not feasible in view of the size of the premises and the earthquake resistance of the floors and walls of the buildings;
- situations initiated by the loss of a line of the shutdown reactor cooling circuit (RRA), occurring when the reactor is shut down for intervention (API). EDF concludes that the resources available are sufficient to manage these situations while avoiding uncovering of the core;
- situations initiated by a breach in the cooling system of the shutdown reactor (RRA) with a diameter of less than nine inches, occurring in AN / RRA or API. EDF concludes that compliance with the safety criteria would require introducing into the technical operating specifications (STE) general operating rules new requirements relating to the availability of certain equipment, which would require prior adaptation of the rules and the STE design doctrine, in order to make them compatible with the operation of reactors.

In conclusion, non-compliance with the safety criteria by including an aggravating agent in the studies is, in general, due to insufficient availability requirements in the current operating rules. The safety criteria are nevertheless respected for these PCCs by using the accident study rules of the complementary field, that is to say without aggravating.

5.3.1.2.2 Transposition of deadlines before the first intervention of the operators of the Flamanville EPR reactor

For 900 MWe reactors, the time to be considered in the sizing studies before the operators' first intervention is 20 minutes if the first action is to be carried out in the control room, and 25 to 35 minutes if this action is to be carried out. locally, at the level of the equipment concerned. For the Flamanville EPR reactor, the times taken into account are respectively 30 minutes and one hour.

[58] The water and boron make-up system (REA) comprises reservoirs, called "REA boron tarpaulins", containing a dilute solution of boric acid at a concentration markedly higher than that of the primary circuit, in order to be able to add to the circuit primary, through the chemical and volumetric control system (RCV).

EDF applied the deadlines to be considered before the first intervention of the operators selected for the Flamanville EPR reactor to the design operating conditions of the 900 MWe reactors.

EDF has identified fifteen operating conditions for the sizing of 900 MWe reactors that are sensitive to operator intervention times:

- for eleven sizing operating conditions, the safety criteria are met by retaining the intervention times taken into account for the EPR;
- for three design operating conditions, the modifications linked to the fourth review (elimination of the anomaly relating to the secondary water reserves, new method of studying the accident of loss of primary coolant) allow compliance with the safety criteria by retaining the response times taken into account for the EPR;
- for the sizing operating condition relating to the uncontrolled dilution of boric acid in shutdown for intervention (API) or in shutdown for recharging (APR), the modification associated with the implementation of the boremeter of the chemical and volumetric control system (RCV) allows, for CPY type reactors, to meet the safety criteria by retaining the intervention times taken into account for the EPR. On the other hand, for the Bugey reactors, the modification is not sufficient and it would be necessary to reduce certain study conservatisms to meet the criteria.

5.3.1.3 ASN's position on achieving the objectives of the review

5.3.1.3.1 General position

In general, ASN considers the development of the study hypotheses, scientific calculation tools and methods used by EDF to meet the objectives of the review to be satisfactory in terms of their principles.

Although the investigation carried out by ASN revealed needs for improvement or additional validation, these reservations do not call into question the conclusions of the studies transmitted by EDF as part of the review. ASN considers that EDF must transmit the additional analyzes that it undertook to carry out during the appraisal and revise the safety report if the conclusions of the studies concerned are modified or if the penalizing situations to be considered change. If necessary, EDF will also have to implement modifications to its facilities in order to ensure compliance with the safety criteria.

5.3.1.3.2 Homogeneous dilution transients

An uncontrolled dilution of boric acid, the cause of which may be due to operator error or equipment failure, leads to an uncontrolled decrease in the boron concentration in the water in the primary circuit. This drop in boron concentration results in an insertion of reactivity which may, under certain conditions, lead to a risk of loss of integrity of the fuel. The consequences of dilution scenarios are studied by EDF in all reactor operating states.

In general, ASN considers that the modifications (boremeter on the discharge line of the chemical and volumetric control system of the main primary circuit (RCV), alarms) implemented by EDF as part of the review to limit the consequences of certain initiators of uncontrolled dilution of boric acid, constitute improvements for the safety of the 900 MWe reactors.

However, ASN considers that improvements are necessary to limit the consequences of certain dilution initiators and that EDF must improve the safety demonstration with regard to the points specified below.

Completeness of scenarios to be considered in the event of an accident

The initiator of the scenario of uncontrolled dilution of boric acid corresponding to the clear rupture of a tube of the exchanger of the sealing circuit of the primary pumps (" *CEPP scenario* ") Is considered by EDF to be a reference operating condition in the shutdown state for recharging (APR) or for intervention (API) for 900 MWe reactors. For other areas of operation, this dilution initiator is considered as an additional operating condition.

ASN considers that the " *CEPP scenario* »Is likely to have lower margins than those currently existing for the reference scenario [59] in normal shutdown state (AN) or when the reactor is in production (RP).

In the letter in reference [78], ASN had asked EDF, for the 1300 MWe reactors, to integrate the " *CEPP scenario* »The design operating conditions for all the operating states of the installation. ASN considers that this request must also be applied to the 900 MWe reactors, to which EDF has undertaken.

Sufficiency of the delays before the first intervention of the operators

ASN asked EDF by the letter in reference [77] to demonstrate that the deadlines set at a flat rate for the operators' first action in the study reference system in force were sufficient to carry out the actions necessary to stop the dilution of the primary circuit.

ASN considers that EDF must verify that the actions to be carried out to isolate the various sources of dilution can be carried out within the prescribed time limits. In this regard, ASN points out that the investigation carried out concerning the installation of the boremeter of the chemical and volumetric control system of the main primary circuit (RCV) revealed a situation in which compliance with the deadlines necessary for carrying out the actions isolation was not guaranteed.

EDF has completed its studies and identified two dilution scenarios for the Bugey reactors which will have to be verified through scenarios.

This point is the subject of the ASN [Study-A] prescription [48].

Completeness of aggravators considered in homogeneous dilution scenarios

The study rules require to consider in the design operating conditions, in addition to the initiating event, an aggravating factor. The most unfavorable aggravating factor is selected.

For transients of homogeneous power dilution, the most penalizing aggravating factor retained by EDF is the blocking of the most anti-reactive cluster in the high position during the automatic shutdown of the reactor. ASN considers that taking into account the aggravation on the valve of the so-called “bypassing the turbine to the atmosphere or to the condenser” line could prove to be more penalizing. This situation has not been studied by EDF. This point is the subject of a request from ASN [49].

5.3.1.3.3 Cooling transients

Completeness of uncontrolled hot shutdown cooling initiators likely to lead to criticality being reached

Reactor cooling accidents lead to an uncontrolled supply of reactivity in the core. These transients, initiated in the reactor shutdown states or in power, can induce a risk of boiling crisis or fuel melting.

ASN guide n ° 22 [86], relating to the design of pressurized water reactors, which is intended to be used for research into improvements to be made to existing reactors on the occasion of their

[59] Reference homogeneous dilution scenario currently considered in a normal shutdown state or when the reactor is in production: dilution via the demineralizers of the chemical and volumetric control system (RCV) of the main primary circuit or via the chemical additives circuit following human error.

periodic reviews, recommends preventing, in states where the vessel is closed and the reactor is shut down, the inadvertent impairment of criticality.

The investigation carried out by ASN within the framework of the fourth periodic re-examination of the 900 MWe reactors led to the identification of cooling transients in shutdown state leading to the criticality of the reactor being reached.[60] These situations were not identified by EDF in the safety report for the 900 MWe reactors associated with the fourth periodic review.

ASN therefore considers that EDF must, as part of the accident studies associated with the fourth periodic re-examination of the 900 MWe reactors, present a complete inventory of the uncontrolled cooling initiators in hot shutdown likely to lead to failure. '' reaching criticality and, if necessary, seeking safety improvements. This point is the subject of a request from ASN [49].

Accumulation of external voltage shortage

EDF has assessed the impact, on compliance with safety criteria, of taking into account, in studies of steam pipe rupture initiated in power, the loss of the external electrical network known as “lack of external electrical voltage” (MDTE). For these situations, EDF postulates the occurrence of an MDTE in accordance with the assumptions of the currently applicable study rules.[61]

ASN guide no. 22 [86] states that a good design practice consists in studying the accumulation of the MDTE at the most unfavorable moment. For the majority of transients, the taking into account of the conventional times of office plurality constitutes the penalizing case. However, in the event of a steam pipe rupture occurring when the reactor is at its nominal power, ASN considers that the cumulative MDTE at an instant between the initial instant of the transient and the instant of shutdown automatic reactor could be more penalizing. This operating situation must therefore be studied by EDF. This point is the subject of a request from ASN [49].

5.3.1.3.4 Intermediate Primary Refrigerant Loss Accident (APRP-BI)

The loss of primary coolant accident (PRCA) is characterized by a breach causing a loss of the water inventory in the primary circuit. Depending on the size of the breach, it is classified as Category 3 or 4 operating condition.

The accident studies described in the safety report for 900 MWe reactors consider “intermediate breaches” (APRP-BI) and are assessed using the CATHSBI method.[62] recently developed by EDF. This statistical method makes it possible to take into account the requirements of the new APRP study reference system considering in particular the evolution of knowledge on fuel behavior.[63]

The CATHSBI method is used for the first time by EDF as part of the fourth periodic review of 900 MWe reactors, replacing the realistic deterministic method (MDR).

This method was the subject of an investigation by ASN in 2016, which concluded [80] that, although it included notable improvements compared to the previous methods in certain aspects, it could not be considered acceptable. as it stands, taking into account the need for additional justification. In

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60 The targeted situations are steam pipe ruptures in the various shutdown states that do not require the safety injection. These are category 2 cooling transients known as “safety injection request interface breaches”.

61 The MDTE is applied, according to the study rules defined in the safety report, at the most penalizing moment between the following three conventional times: instant of occurrence of the initiator, instant corresponding to the automatic shutdown signal of the reactor , instant corresponding to the safety injection signal (IS) into the core.

62 CATHSBI: Statistical CATHare intermediate breaches, CATHARE being the scientific calculation tool used for the simulation of the accident.

63 Taking into account of dreaded physical phenomena such as contact between rods, bursting of cladding or relocation of fuel in exploded bloated areas.

As a result, ASN had asked EDF to study the feasibility of modifying its installations in order to be able to take a short-term position on the acceptability of the studies with regard to the reservations expressed in the context of the examination of the CATHSBI method.

For CPY type reactors, EDF has decided:

- to reduce the fuel pressure of the rods of the MOX fuel assemblies. Insofar as this change will not be effective until 2025, EDF will reduce, from phase A of the deployment of the review modifications, the authorized operating range of the reactors;
- to increase the accumulator fill pressure of the safety injection system as part of phase B of the roll-out of the review changes.

For the reactors at the Bugey nuclear power plant, EDF has also decided to reduce the fuel rod filling pressure: this modification will be effective in 2025.

The modifications adopted by EDF make it possible to limit the deformation of the cladding and the risks of occurrence of the phenomena feared for the behavior of the fuel. ASN loss of therefore to limit, in conclusion, considers that the modifications planned by EDF are sufficient to limit integrity of fuel assembly rods, and thus guarantee the capacity of the risk of fuel cooling in the event of a primary breach of intermediate size.

5.3.1.3.5 Fourth Category Steam Generator Tube Rupture (RTGV4)

With regard to the category 4 steam generator tube rupture accident (double-debited guillotine rupture of a steam generator tube combined with the blocking in the open position of a valve on this same steam generator), the study takes into account penalizing hypotheses in order to maximize the liquid discharges leaving the steam generator (which maximizes the radiological consequences).

It also aims to verify that the application of post-accident control procedures allows the cancellation of the leak (balancing of the primary and secondary pressures). The study carried out shows an overflow of the affected steam generator, significant liquid and vapor releases to the atmosphere, of the order of 340 tonnes and 120 tonnes respectively. Despite a material modification (increase in the discharge capacity of the turbine bypass unit to the atmosphere) and a change in the pipe planned by EDF, the liquid discharges are greater than in the study associated with the third periodic review: this results from the reduction of the anomalies affecting this study (modeling of the tank dome in the CATHARE software, safety injection flow rate). Furthermore,

The radiological consequences of this accident are discussed in paragraph 5.6.1.

5.3.1.3.6 Lateral deformation of fuel assemblies and deflection of their rods

The fuel assemblies deform laterally during their irradiation in a reactor. This deformation has an impact on the distribution of neutron power in the fuel assemblies, on the risk of a boiling crisis which must be prevented to guarantee the integrity of the fuel and on the functional behavior of the grids of the assemblies in an accident situation.

EDF estimated the amplitude of the deformations as well as their effect on power distribution. EDF concludes that the maximum linear power rod could be located at the assembly edge (peripheral rod), which is not the case in nominal geometry. EDF takes this impact into account when evaluating the uncertainty applied to the linear power of the hot rod.

The risk of a boiling crisis is assessed by a critical flux correlation. In nominal geometry, the channel carrying the minimum RFTC (Critical Flow Margin) value is usually located inside the assembly. Based on dedicated test results and scientific literature, EDF concludes that the critical flux correlation used to estimate the boiling crisis margin remains applicable to the periphery of deformed assemblies, by adding 'a correlative penalizing factor. ASN considers that the elements used by EDF are not sufficient to justify this conclusion.

Consequently, ASN considers it necessary for EDF to verify the applicability of the critical flux correlation used at the assembly periphery by means of specific tests. The test configurations to be carried out must be representative of the fuel assemblies introduced into the reactor.

At the end of the investigation, EDF undertook to carry out these tests, which is satisfactory. **However, ASN supervises their implementation through the prescription [Study-B] [48].**

Finally, ASN notes that EDF has undertaken to take into account the request expressed by ASN concerning the taking into account of the rod deflection penalty in the calculation of the uncertainty on the local linear power and the hot spot factor.

5.3.1.3.7 Mechanical behavior of assemblies

ASN asked EDF during the orientation phase of the review [6] to complete its safety studies by evaluating the neutron, thermohydraulic and mechanical impact of the deformation of the fuel assemblies on the verification of the safety criteria of the fuel assemblies. safety report studies.

EDF provided the justifications for the mechanical behavior of the fuel assemblies in the reactor core in normal, incidental and accidental situations during sizing studies. The most penalizing case, with respect to the buckling of the grids of the fuel assemblies, corresponds to the conventional case of cumulative effects (in terms of loading) of an earthquake and a loss of primary coolant accident (APRP).) of the fourth category. The absence of buckling of the fuel assembly grids makes it possible to simply guarantee compliance with safety requirements and in particular control of reactivity, by maintaining the integrity of the control rod drop channels.

Given the difficulties encountered in demonstrating the absence of buckling of the fuel assembly grids, EDF implemented a new methodology taking into account changes in the assumptions associated with the fourth review, in particular concerning the operating conditions of the reactor. (cycle extension) and the new “APRP” standard. This methodology gives rise to several reservations from ASN and requires additional justification on the assumptions used, as well as the performance of additional tests in order to validate certain assumptions used in the calculation models.

ASN notes that EDF has undertaken, with the expiry of June 30, 2023, to carry out tests allowing a re-evaluation of the non-buckling limit of assembly grids according to a protocol more representative than the current reference tests. available and to analyze the impact of this new limit on the conclusions of the studies.

ASN considers that EDF must provide a demonstration of the absence of buckling on the basis of a revised and validated method, integrating assumptions and rules adapted to the uncertainties and the limits of knowledge of the phenomena involved. exceeding the value ensuring the absence of buckling, EDF must define measures to ensure control of reactivity and core cooling in this situation.

These points are the subject of the ASN [Study-D] prescription [48].

In addition, during the orientation phase of the review [6], ASN asked EDF, in the event of non-compliance with the safety criteria associated with the design area, to identify any measures that could be implemented. implemented to remedy them and examine their feasibility and merit. During

the instruction, EDF has undertaken to assess, before the end of 2020, the effects of operation beyond the natural cycle times on the mechanical strength of the fuel assemblies in order to assess the effective impact of the extended cycle and to study the possibility of implementing other levers likely to limit the mechanical stresses of assemblies in accident conditions.

5.3.1.3.8 Transposition of the PCC operating conditions of the Flamanville EPR reactor

EDF assessed the EPR operating conditions for the 900 MWe reactors: these studies show that the safety criteria for the dimensioning range of the 900 MWe reactors are met for most of the PCCs of the Flamanville EPR reactor transposed to the reactors of 900 MWe. For the others, the studies carried out with the accident study rules of the complementary field, that is to say without aggravating and without cumulative MDTE, show that the criteria are respected.

The PCCs that do not comply with the safety criteria with the study rules for design operating conditions are as follows:

- the dilution of the borated water due to the rupture of a tube of the heat exchanger of the sealing circuit of the primary pumps, which EDF undertook, at the end of the investigation, to integrate into the conditions sizing operation (see paragraph 5.3.1.3.2);
- breaches on the primary circuit or on the RRA circuit in a shutdown state are studied as part of studies in the complementary field. They have led to the definition of additional provisions, in particular manual back-up means (namely the manual commissioning of the safety injection and the manual commissioning of a primary back-up). It should be noted that these same situations studied during the design of the EPR make it possible to define the thresholds for which a back-up system is automatically implemented. Taking these situations into account on 900 MWe reactors as design operating conditions with manual back-up means will not, in any case, make it possible to achieve the reliability associated with automatic means.

5.3.1.3.9 Transposition of deadlines before the first intervention of the operators of the Flamanville EPR reactor

EDF assessed the impact of an increase in operator time by retaining, for the sizing operating conditions, the time taken into account in the studies of the Flamanville EPR. ASN notes that the modifications made within the framework of the fourth periodic review enable the safety criteria to be met, with the exception of the uncontrolled boron dilution accident, for the reactors at the Bugey power plant. For this accident, the installation of additional clusters, planned by EDF, will improve control of reactivity (see paragraph 5.3.2.3).

5.3.2 Additional operating conditions

The historical dimensioning domain has been supplemented, as the safety reassessments progressed, by a so-called “complementary” domain for which the safety of the installation is verified on the basis of realistic methods.

5.3.2.1 Specific objectives of the review

The objective of studies in the complementary field is to verify that the so-called “complementary” measures implemented make it possible to reduce to an acceptable level the consequences of different triggering events, possibly more complex, than those taken into account in the operating conditions. sizing.

5.3.2.2 Summary of studies carried out for the reactor core

As part of the fourth periodic review of 900 MWe reactors, EDF updated the list of additional provisions as well as all the studies of additional operating conditions according to a new approach known as the “renovated complementary area”, comparable to that applied for the Flamanville EPR reactor.

This approach has evolved compared to the previous benchmark, in particular in terms of:

- use of realistic assumptions, ensuring that there is no cliff-edge effect when the physical parameters vary around the values selected;
- delay before the operator's first intervention, which is now similar to that retained for the sizing operating conditions (20 minutes in the control room, 25 or 35 minutes for actions carried out locally);
- global probabilistic reassembly, which is now supported by the benchmark probabilistic safety study.

5.3.2.3 ASN's position on achieving the objectives of the review

ASN underlines the extent of the work, carried out by EDF, which constitutes the resumption of all studies in the complementary field. At the end of its examination, ASN considers the list of additional provisions as defined and supplemented by the commitments made by EDF acceptable. ASN also considers the studies of additional operating conditions to be satisfactory on the whole, subject to the additional information that EDF has undertaken to provide.

ASN considers the use of the revised method to be acceptable in the context of the review. ASN emphasizes that EDF has generally declined the method by retaining penalizing hypotheses for the dominant parameters, which makes it possible to demonstrate compliance with the safety criteria with a high coverage rate.

However, ASN notes that EDF does not take into account the lateral deformations of the fuel assemblies in the context of studies in the complementary field. This physical phenomenon is retained by EDF only for the studies of the dimensioning field. ASN considers that the physical phenomenon of lateral deformation of the assemblies, which is a proven phenomenon in the reactors in operation, must be taken into account by EDF as an assumption for studies in the complementary field for the next reviews.

As part of the fourth periodic review of the 900 MWe reactors, EDF did not assess the impact of taking into account the delays before the first intervention of the operators selected for the EPR on studies in the complementary field. ASN considers that EDF must analyze this impact. The analysis to be carried out should make it possible to identify possible risks of cliff-edge effects. This point is the subject of a request from ASN [49].

Regarding the study of the total loss of the cold source of a reactor at the Bugey nuclear power plant (so-called “unit H1” situation), EDF only studied the total loss of the intermediate cooling circuit (RRI). , considering that this scenario covers scenarios of loss of the emergency raw water circuit (SEC) alone or followed by the loss of the RRI. ASN considers that the study of the total loss of the RRI does not constitute a study covering all the possible situations of total loss of the heat sink. Since the prescribed conduct differs according to the origin of the total loss of the heat sink, ASN considers that the achievement of the fallback state for all of the “unit H1” situations has not been demonstrated in such a way. envelope. This point is the subject of a request from ASN [49].

For the reactors at the Bugey nuclear power plant, ASN considers that EDF's demonstration of reactivity control has been satisfactorily provided for studies in the complementary field, except for the study of total loss. emergency power supplies (“H3” situation) due to a common cause failure of the 6.6 kV backed up electrical panels (so-called

“DCC-LH), the sub-criticality after the fall of the bundles (stopping margin) being lower on reactors using“ Cyclades ”fuel management than for reactors using“ MOX parity ”management. This is particularly linked to the limited number of control clusters (48 clusters) whereas, for “MOX parity” fuel management of CPY type reactors, the number of clusters is notably greater (61 clusters).

The establishment of additional clusters, planned by EDF, will improve the control of reactivity for the reactors of the Bugey nuclear power plant.

ASN therefore considers that EDF must study and implement, for the reactors at the Bugey nuclear power plant, material modifications to significantly improve control of reactivity.

At the end of the investigation, EDF undertook to carry out this modification, which is satisfactory. **However, given the challenges, ASN supervises its implementation with a prescription [48] ([Study-C]).**

With regard to the common cause failure study of 6.6 kV backed-up electrical panels (DCC-LH) of 900 MWe reactors, the operating procedure requires the operator to depressurize the primary circuit until the the discharge pressure of the safety injection accumulators has been reached. Before the complete emptying of the accumulators, at a primary pressure threshold dimensioned to prevent nitrogen [64] that they contain is injected into the primary circuit, the operator must isolate them. The accumulator insulation threshold used by EDF in the study takes into account the uncertainties linked to the pressure measurement. On the other hand, EDF did not justify the enveloping nature of the time required for the operator to carry out, upon reaching this threshold, the action to isolate the accumulators, and did not take into account the closing of the isolation valves. For these scenarios, ASN therefore considers that EDF must check that the accumulator isolation threshold used in the operating procedures prevents the risk of nitrogen injection into the primary circuit with a leak at the seals of the primary pump sets of less than 2 tonnes per pump and per hour, taking into account an envelope value of the operator's response time when the isolation threshold is reached and the isolation valve closing time, as well as the measurement uncertainty of the primary pressure. This point is the subject of a request from ASN [49].

Furthermore, with regard to “H3” situations affecting one or more reactors, the residual power of the reactor is removed by the steam generators. The water supply to the steam generators is provided by the turbopump of the Steam Generator Emergency Power System (ASG). In an "H3" situation, the loss of the electrical sources causes the ventilation of the turbopump room to stop, which leads to an increase in the temperature of this room, which may eventually jeopardize the operation of the turbine. the turbopump. EDF considers that this turbopump is capable of operating during the first hours without ventilation of the premises. However, EDF did not carry out thermal studies to justify this assertion and therefore did not demonstrate that the temperatures reached in these rooms remain below the admissible temperatures of the equipment necessary for the operation of the turbopump. This point is the subject of a prescription (see paragraph 4.1.2.4 relating to specific tests).

5.3.3 Specific supporting studies

5.3.3.1 Specific objectives of the review

In addition to studies of the design and additional operating conditions, specific supporting studies are carried out by EDF in order to assess the robustness of the installations in accident situations, taking into account physical phenomena not apprehended during design.

[64] Nitrogen has the effect of degrading the exchanges between the primary and secondary circuits.

As part of the fourth periodic review of the 900 MWe reactors, ASN asked EDF, by letter in reference [6], to study the risk of dilution inherent in the loss of primary coolant accident by implementing the rules for studying the design operating conditions. ASN also asked EDF to assess the consequences of the passage of low-boron water plugs in conditions surrounding the accident situations likely to be encountered in a reactor, in order to cover the current ignorance relating to the situations to be considered. [65].

5.3.3.2 Summary of studies carried out and planned modifications

As part of the fourth periodic review of the 900 MWe reactors, EDF carried out the following three specific supporting studies:

- studies relating to the risk of interaction between the fuel pellets and the cladding (IPG) for all of the planning management cycles as well as for certain "variable design cycles" [66]: the risk of cladding rupture by IPG in category 2 transients was not identified in the safety reports when the 900 MWe reactors were designed. It is now helping to define the technical operating specifications for these reactors to prevent the IPG risk;
- the primary breach accident corresponding to a doubly debated guillotine rupture of a piping in the primary circuit: this study aims to verify the robustness of the core coolability for breach sizes greater than those retained under design operating conditions;
- the primary breach accident vis-à-vis the risk of inherent dilution: during a transient accident involving loss of primary coolant, stopping the primary pumps followed by stopping the natural circulation (thermosiphon) can lead to the formation and accumulation in certain parts of the primary circuit of volumes of weakly borated water (called “water plugs”) by condensation of the steam in the tubes of the steam generators. However, accidental operating procedures require the initiation, during the transient, of cooling by the secondary circuit which may lead to the sending of these non-borated water plugs to the reactor core when natural circulation resumes in the reactor. the primary circuit, which is liable to induce a risk of an uncontrolled return to power.

All of these studies are carried out by considering realistic hypotheses.

5.3.3.3 ASN's position on achieving the objectives of the review

ASN considers the studies relating to the risk of sheath pellet interaction and the primary breach accident with a double-discussed main pipe failure to be satisfactory.

The inherent dilution studies carried out by EDF, using large volume water plugs and realistic assumptions for the neutron calculations, show the absence of unacceptable consequences on the fuel integrity of the 900 MWe reactors.

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[65] EDF used tests on the experimental PKL loop in order to assess in particular the volumes of non-borated water plugs injected into the core, the number of plugs sent simultaneously and the sending kinetics of these plugs. The PKL loop is an experimental device operated by Framatome in Germany. It represents on a scale reduced in volume and power and at scale 1 in height, the primary and secondary circuit of a German pressurized water reactor of the Konvoi type.

[66] Variable design cycles: production cycles that deviate significantly from the forecast management adopted at the stage of generic safety studies for fuel management. Variability is characterized by fluctuations in the number of new refill assemblies, the proportion of MOX and UO assemblies [2] new in recharge or cycle length. These fluctuations can appear on an ad hoc basis or repeatedly during successive campaigns.

5.3.4 Summary and requirements relating to reactor accident studies

EDF has carried out significant work on the resumption of all of its studies (sizing studies, studies in the complementary field and so-called specific supporting studies), by declining a set of new standards and by integrating the lessons of the previous instructions. In general, the modifications planned by EDF in the context of the review to limit the consequences of certain initiating events constitute improvements for the safety of the reactors.

ASN instructs EDF to ensure control of reactivity in certain situations (situations of homogeneous dilution of the primary circuit, loss of primary coolant accident given the risk of buckling of the fuel assembly grids as well as 'in the event of total loss of electrical power supplies) and, if necessary, to define additional provisions. In addition, ASN asks EDF to carry out critical flux tests to verify the applicability of the correlation used for the peripheral rods of deformed fuel assemblies.

The fourth periodic review was also an opportunity to reassess the probabilistic safety studies associated with events of internal origin. This probabilistic insight made it possible to identify additional modifications to be implemented, which will improve the level of safety.

The modifications resulting from the reassessed studies will make it possible to improve the management of incident and accident situations without core meltdown and, consequently, to improve the prevention of accidents with core melt. The results of these studies and the modifications planned by EDF, supplemented by ASN's requests, will make it possible to meet the objectives set for this review.

*

At the end of the examination, EDF undertook to carry out most of the necessary additions that the ASN examination revealed. ASN prescribes [48] the implementation of the major safety improvements planned by EDF as well as certain additional measures that it considers necessary to achieve the objectives of the review.

Dilution transients for the reactors of the Bugey nuclear power plant

[Study-A] By December 31, 2021 at the latest, the operator assesses, for the reactors at the Bugey nuclear power plant, the time required for the operator to carry out the first intervention to stop the dilution during the following transients:

- dilution by tube rupture of the exchanger of the sealing circuit of the primary pumps (CEPP) in the shutdown for intervention (API) and shutdown for recharging (APR) states;
- dilution by tube rupture of the non-regenerating exchanger (ENR) for the normal shutdown state “AN / RRA” with the primary pumps stopped.

In the event that this deadline is greater than the conventional deadline retained in the studies, the operator specifies this new deadline and the other study rules for the dimensioning field. Otherwise, at the latest issues for the new deadline to be taken into account. It checks that the safety criteria are met, taking into account December 31, 2022, the operator defines any changes to be implemented with regard to safety and the associated schedule.

Validity of the critical flux correlation in the presence of laterally deformed assemblies

[Study-B] By December 31, 2023 at the latest, the operator evaluates, through an experimental approach, the validity of the critical flux correlation used at the periphery of deformed assemblies. On the same date, it defines any changes to be implemented and the associated schedule.

No later than June 30, 2021, the operator shall send a detailed program of the test configurations to be carried out.

Sub-criticality in a situation of total loss of electrical power supplies due to a common cause failure of the LH electrical panels for the reactors of the Bugey nuclear power plant

[Study-C] I.– No later than December 31, 2022, the operator defines the modifications necessary to avoid a return to criticality in a situation of total loss of the electrical power supplies due to a common cause failure of the LH electrical panels for the reactors of the Bugey nuclear power plant.

II.– The operator implements the modifications mentioned in I.

Mechanical behavior of fuel assemblies

[Study-D] I.– No later than June 30, 2023, the licensee carries out tests to characterize the buckling limit of the fuel assembly grids.

On the same date, the operator evaluated the mechanical behavior of the assemblies in a situation of accident of loss of primary coolant of the fourth category cumulated with an earthquake occurring concomitantly on the basis of a validated method, integrating assumptions and rules. adapted to the uncertainties and the limits of knowledge of the phenomena involved.

II.– In the event that the value ensuring the absence of buckling is exceeded, the licensee defines the measures to be implemented to ensure control of the reactivity and cooling of the core in this situation and the associated schedule.

5.4 SECURITY REASSESSMENT OF THE FUEL STORAGE POOL

The situations that may affect the safety of fuel storage and handling can be divided into three main families:

- incidents, accidents or attacks affecting the cooling of the water in the fuel storage pool;
- incidents, accidents or attacks affecting the water inventory of the fuel storage pool;
- fuel assembly handling accidents.

5.4.1 Specific objectives of the review

EDF has adopted the safety objective of making the discovery of fuel assemblies in storage pools extremely unlikely during accidental emptying or loss of cooling.

ASN recalled [6] that *"Studies to reassess the safety of these swimming pools must be carried out with regard to the safety objectives applicable to new reactors and the possibility of extending the operating life of the reactors must be examined with regard to the" practical elimination "of the risk of fuel melting in the fuel building ".*

As regards the situations in the dimensioning domain, ASN in particular recalled [2] the request to assess the behavior of reactors for PCC operating conditions (" *Plant Condition Categories* ») Relevant to the design of the Flamanville EPR reactor, by applying the study rules for the dimensioning domain of reactors in operation. EDF presented an approach which only partially met this request as part of its periodic review orientation file [23]. ASN thus requested [6] " *to evaluate [...] the behavior of the 900 MWe reactors for the events and operator delays of the EPR reference system, by applying the rules of the studies of the design operating conditions* "And" *in the event of non-compliance with the safety criteria associated with the design domain, [...] analyze the reasons for exceeding these criteria, identify any measures that could be implemented to remedy them and examine their feasibility and their interest* ".

5.4.2 Summary of studies carried out by EDF

During the generic phase of the fourth periodic review of the 900 MWe reactors, EDF reassessed the safety of the fuel storage pools, in particular:

- prevention and control of incidents and accidents affecting fuel assemblies stored or handled;
- protection of the fuel storage pool cooling systems against internal attacks;
- the risks associated with handling spent fuel transport packaging.

As part of these studies, EDF valued the changes that will be implemented for the fourth periodic review. These include in particular:

- automatic shutdown of the pumps in the treatment and refrigeration system of fuel storage pools (PTR) and automatic isolation of the PTR suction line when a "very low" level is reached in the fuel storage pool;
- the installation of a non-return valve on the discharge line of the PTR circuit at an altimetry higher than the upper level of an assembly in handling, which brings redundancy and diversification to the siphon breaker;

- the installation of a new water injection circuit (SEG) belonging to the “hard core”, made up of flexible means and connections present in the building on the water injection lines of the PTR system. The SEG is supplied by the new ultimate water source (SEU system);

- an additional and diversified means of the PTR system, called "PTR bis", made up of existing fixed circuits and mobile means, conveyed by the nuclear rapid action force (FARN). The PTR bis system allows, in the event of loss of the PTR system (due to extreme aggression, loss of electrical sources, loss of the cold source, etc.), the resumption of cooling of the closed-circuit storage pool. .

5.4.2.1 Prevention and control of incidents and accidents affecting fuel assemblies stored or handled

To rule on the sufficiency of the nuclear safety demonstration with regard to the prevention and control of incidents and accidents affecting fuel storage pools, EDF studied:

- the risk of criticality during activities related to the operation of the fuel building;
- accidents involving loss of cooling or emptying of the storage pool included in the safety report under the additional field;
- the operating conditions relating to the storage pool resulting from the PCCs of the Flamanville EPR reactor, which study equipment failures necessary for the safety of the storage pool. EDF has defined the associated study rules, with regard to:

    - the classification of the systems used during the transient,
    - the definition and taking into account of the aggravating factor,
    - the methods of accumulation with a lack of external tension (MDTE),
    - the deadlines to be considered before the first intervention of the operators,
    - the requirements associated with the safe state.

Classification of the systems used during the transient

In accordance with the rules for sizing accident studies applied to the reactor, EDF recovers, for accidents affecting the fuel storage pool, equipment that falls under a safety classification [67], except for accidents with slow kinetics or in the long term phase of the accident. For these cases, EDF justifies the capacity of the system to guarantee its function under the conditions induced by the transient and accessibility to the premises.

Definition and consideration of the aggravating factor

EDF specifies in its file that " *the aggravating factor to be taken into account is a single active failure independent of the initiating event. In line with the rules adopted for the EPR reactor swimming pool, no passive failure is considered on the PTR [circuit] itself due to the specific nature of the cooling of the swimming pool water (low pressure in the circuit, monitoring in service, continuous operation)* ".

MDTE cumulation modalities

EDF uses the cumulative loss of external voltage (MDTE) for category 4 accidents. In this case, no aggravating factor is applied.

[67] The safety classification of a material defines requirements for design, manufacture, construction and monitoring in operation.

Deadlines to consider before the operators' first intervention

EDF has adopted the conventional deadlines for studies relating to accidents occurring on the reactor. In addition, for the safe positioning of assemblies during handling, EDF retains a period of 30 minutes, and in the event of loss of electrical power supplies, a period of two hours.

Requirements associated with the retained safe state

EDF defines the safe state as a state in which:

- control of reactivity is ensured;
- cooling of the assemblies is ensured. This can be ensured by boiling the water in the swimming pool and making a water make-up which makes it possible to maintain a water level such that the fuel assemblies are not uncovered.

In the event of boiling, an outlet of the fuel building is opened in order to reduce the pressure in the building lobby.
For some of the studies carried out for the transposition of PCCs for the Flamanville EPR reactor, EDF concludes that it would be necessary to introduce additional operating monitoring requirements for the new means of making up water to the swimming pool, as well as redundant isolation means to cancel certain leaks.

5.4.2.2 Protection of the cooling systems of the fuel storage pool against attacks of internal origin, excluding falling packaging

The attacks taken into account by EDF are fire, internal explosion, internal flooding, high energy piping failures (RTHE) and heavy load drops.

EDF has identified the damage potentially caused by each attack on the swimming pool cooling system, by examining:

- the measures making it possible to limit the risks of common cause failure on the equipment of the circuit ensuring the cooling of the swimming pool;
- the arrangements, in the event of loss of the swimming pool cooling system following an attack, to top up water in the swimming pool and restore the cooling of the assemblies (delays, available resources, etc.). In these situations, EDF uses the same definition of the safe state as for internal events.

EDF has adopted the same study rules for the swimming pool as for the study of the consequences of attacks on the boiler.

Fire risk

EDF has identified a risk of common cause failure of the two redundant pumps of the PTR system. Indeed, these pumps are installed side by side in a volume of fire safety [68] where their power cables run (and the control cables for the reactors of the Bugey nuclear power plant). This equipment can therefore be damaged by the same fire. EDF has planned to install a flame-resistant protective screen between the two pumps. EDF believes that this protective screen prevents the risk of attacking the power cables of the two tracks in the pump room for CPY type reactors. On the other hand, for the reactors of the Bugey nuclear power plant, this protective screen does not make it possible, given the configuration of the premises and the equipment, to protect the power cables and pump control cables against fire. EDF therefore plans to put in place a wrapping of these cables against fire.

[68] Fire volume: one or more rooms delimited by walls (physical separation) or borders (without physical separation) ensuring a separation between combustible materials and equipment, preventing the spread of the fire. EDF distinguishes between two types of safety fire volumes: the safety fire sector (delimited by a physical sector) and the safety fire zone (delimited according to distance criteria).

Explosion risk

EDF carried out an inventory with regard to the protection against internal explosion of the systems allowing the evacuation of the residual power and the maintenance of the water inventory of the fuel storage pools.

EDF considers that there is no risk of explosion in the fuel building since no circuit conveying flammable gas is present there.

EDF has carried out studies, in the event of an explosion occurring in adjacent buildings (BAN nuclear auxiliaries building and BL electrical building), which conclude that there is no damage to the civil engineering of the fuel building. During these studies, EDF identified a group of BAN premises in which an explosion is likely to lead to the loss of the PTR system cooling means. To compensate for the loss of the PTR system, EDF is upgrading the new SEG water injection circuit to evacuate the residual power by boiling and compensate for the evaporation rate.

Risk related to internal flooding and failure of high energy piping (RTHE)

EDF studied the risk of common cause failure of the PTR system in the event of flooding and identified several flooding or RTHE scenarios leading to a common mode of loss of the redundant channels of the swimming pool cooling system. In the event of a confirmed situation of loss of cooling of the fuel storage pool, the operating procedures provide for the realization of a manual water make-up to evacuate the residual power by boiling and to compensate the evaporation rate.

In addition, EDF also studied the consequences of a postulated leak in a pipe, including those of the cooling system connected to the swimming pool (the consequences are studied in terms of flooding on the equipment and the ability to manage the leak to avoid discovery of fuel assemblies):

- for "conventional" non-isolable leak scenarios[69], EDF uses the back-up to the swimming pool to maintain the water level. The make-up, used continuously, would feed the leak. EDF indicates that the water collected by the drainage systems up to a sump would be taken up by the dewatering pumps to the used effluent treatment system;
- for scenarios of a "conventional" isolable leak, EDF indicates that the back-up to the swimming pool systematically compensates for the leak, that the volume of water discharged through the breach does not affect the isolation means and that this volume remains confined in the lower levels of the fuel building without consequences for safety.

EDF concludes that the fuel assemblies stored in the swimming pool will always be kept under water.

Risk associated with falling loads

EDF studied the risks of collision and load drop in the fuel building.

Apart from handling the fuel packaging which is the subject of the following paragraph, EDF has verified that collisions or falling loads, handled by the auxiliary bridge and other handling means, do not present a risk for the vehicle. installation, or are covered by fuel handling accidents.

[69] The leaks studied in the context of design basis accidents by EDF relate only to conventional breaches of section eD / 4, where e is the thickness of the wall of the piping and D is the internal diameter of the piping.

5.4.2.3 Risks associated with handling fuel transport packaging

For 900 MWe reactors, transport packaging, weighing 110 tonnes or more, is handled by a heavy bridge over a height that can exceed 20 meters. This handling is carried out in a specific part of the fuel building, separate from the fuel assembly storage pool, which includes several areas: the loading pit, the handling hopper, the preparation pit (only for fuel reactors). CPY type) and the handling building (only for the reactors of the Bugey nuclear power plant).

The consequences of a fall of packaging can be of several natures:

- the loss of integrity of the storage pool by disturbing the structures and, consequently, the dewatering of the stored fuel. In order to limit these risks, energy damping devices (AED) of different types depending on the reactors are installed or will be soon;
- the risks associated with the phenomena likely to occur in the packaging (risk of criticality, dispersion of radionuclides, production of hydrogen by radiolysis of the water present in the packaging, heating of the used fuel assemblies and oxidation of the fuel rod cladding).

As part of the fourth periodic review of the 900 MWe reactors, EDF examined these two aspects in response to ASN SUR requests n ° 11 and n ° 12 [6].

Packaging drop into the loading pit

For the study of the resistance of the structures in the loading pits in the event of a fall of packaging, EDF concludes that there are no consequences of a fall of a packaging in a loading pit on the structural elements of the swimming pool. fuel storage for 900 MWe reactors.

Packaging chute in the handling hopper (Bugey and CPY type reactors) and in the preparation pit (CPY type reactors)

For the reactors of the Bugey nuclear power plant, EDF has justified the absence of any consequence of the fall of a packaging in the handling hopper on the structural elements of the fuel building for a fall of 21 meters in height in the presence of the device. energy absorber (DAE) on the level slab + 0.00 meters. For a fall from a height of 5.5 meters (height beyond which the AED is set up), EDF concludes that " *the ruin of the slab at 0.00 meters [...] is certain* »But that the condition of the raft does not call into question the integrity of the storage pool.

For the 900 MWe CPY type reactors, EDF specifies that the study of the fall of the packaging in the loading pit covers that of the fall in the handling hopper as well as that in the preparation pit, given the similarity of the shock-absorbing devices and the proximity of the loading pit to the storage pool.

Risks associated with the various phenomena likely to occur in the packaging following its fall

EDF studied the criticality risks associated with falling packaging and provided additional answers regarding the enveloping nature of the cases studied in terms of packaging configurations and fuel enrichment.

EDF has also studied the risks associated with the production of hydrogen by radiolysis of the water present in the packaging which can either be evacuated to the hall of the fuel building, or concentrate in the sky of the packaging, according to the capacity of the vent to evacuate the overpressure generated, and its possible damage following the fall. Only the risk of concentration in the overhead of the packaging is analyzed, EDF considering that the radiolysis flow rate is not high enough to reach the lower flammability limit (LII) in terms of hydrogen concentration in the hall of the fuel building.

In addition, EDF has assessed the risk of loss of integrity of the fuel rod cladding following their oxidation and considers that the time available is sufficient to manage this situation.

Lastly, EDF assessed the radiological consequences in the event of a package fall: these are lower than the benchmark values used for category 4 design basis accidents.

5.4.3 ASN's position on achieving the objectives of the review

5.4.3.1 General position

ASN underlines the work carried out by EDF in terms of safety studies and definition of additional measures defined with regard to the objectives adopted for the fourth periodic review of the 900 MWe reactors.

In fact, accidents involving loss of cooling and draining of the fuel assembly storage pool had not been studied at the design stage. They have since been partially introduced in the safety demonstration. In addition, the cooling systems of the fuel storage pools of French reactors did not benefit, from their design, from a physical separation of their two redundant safety channels. This design can therefore make them particularly vulnerable to attacks of internal origin which can lead to common cause failures of two redundant channels of the cooling circuits.

The fourth periodic review is the opportunity to propose a systematic approach to define the incidental or accidental initiators to be considered for the swimming pool, the safety requirements to be retained for incidental or accidental situations or attacks, as well as the study rules for study them.

5.4.3.2 Safety objectives and requirements associated with safe state

EDF has adopted as the safety objective of " *make the discovery of fuel assemblies in storage pools during accidental oil changes and loss of cooling extremely unlikely* ". ASN notes that the objective adopted by EDF does not fully meet the objective of the fourth review, recalled by ASN [6], namely that *"Studies to reassess the safety of these swimming pools must be carried out with regard to the safety objectives applicable to new reactors and the possibility of extending the operating life of the reactors must be examined with regard to the" practical elimination "of the risk of fuel melting in the fuel building ".* Indeed, the investigation highlighted situations likely to lead to a fuel melting in the fuel building, which are neither associated with a *accidental draining or loss of cooling.* EDF has undertaken to transmit the list of situations likely to lead to a fuel meltdown in the fuel building and to justify that these situations are:

- is extremely unlikely;
- either that the kinetics of the releases are compatible with the implementation of protective measures populations.

Accidents leading to significant but delayed releases are likely to have significant consequences for the environment and people. For these situations, it is advisable to favor an in-depth defense approach and to seek, as far as possible, measures to limit their consequences, in addition to measures to prevent them. EDF should therefore also study these situations. This point is the subject of a request from ASN [49].

In addition, ASN considers that the targeted safe state must correspond to a state for which the three fundamental safety functions (control of reactivity, evacuation of residual power, containment of radioactive substances) are guaranteed over the long term.

The safe state proposed by EDF cannot be considered as a durable state of the installation. Indeed :

- an unlimited source of water is needed to compensate for the boiling of the pool over time;
- the vapor atmosphere in the hall of the fuel building, in the event of lasting boiling in the the swimming pool, complicates any human intervention.

In addition, the need to open an outlet to evacuate the water vapor involves low but long-lasting discharges into the environment.

ASN considers that the safe state must eventually include the resumption of closed-loop cooling and the stopping of discharges. This means that the resumption of cooling must be guaranteed, even after the pool boils, and must be ensured by a closed circuit.

At the end of the investigation, EDF undertook to list the accidental situations (including those linked to attacks) for which the absence of boiling over time cannot be achieved and, for these situations, to make arrangements for post-accident management to achieve this safe state without boiling.

In view of the challenges, ASN regulates this subject with the prescription [PISC-C] [48].

5.4.3.3 Prevention and control of incidents and accidents affecting fuel assemblies stored or handled

In the current safety report for 900 MWe reactors, EDF does not retain, in the dimensioning field, any accident situation associated with the failure of equipment necessary for the safety of the storage pool.

Accidents involving loss of cooling and emptying of the storage pool are indeed presented in the safety report as part of studies in the complementary field. These studies lead in particular to defining the following provisions:

- manual commissioning of a back-up to the storage pool;
- automatic closing of the cooling circuit suction valve (PTR).

These studies are carried out without taking into account an aggravating factor.

As part of the review, in response to ASN's request, EDF studied the design operating conditions relating to the storage pool resulting from the operating conditions of the Flamanville EPR reactor, by considering equipment failures. necessary for the safety of the storage pool. In this context, EDF has defined the associated study rules.

Study rules

Concerning the study rules proposed by EDF for the transposition of the EPR operating conditions, ASN considers that:

- the valuation of classified equipment complies with the rules of the dimensioning field. Adapted in-service monitoring requirements must be defined according to the role of these systems in the safety demonstration and the specificities of the situations studied. The valuation of equipment which is not subject to a safety classification in the safety demonstration must be justified and remain exceptional. In addition, the valuation of mobile means is acceptable, provided that they comply with suitable design and manufacturing rules and are subject to periodic checks as well as operational monitoring requirements;

- the taking into account of the aggravating factor on active equipment is satisfactory; on the other hand, the failure to take into account an aggravating factor linked to a passive failure on the circuits connected to the fuel storage pool must be justified;
- the failure to take into account an aggravating factor for the cumulative situations of a triggering event in category 4 and the lack of external voltage (MDTE) within the framework of the fourth periodic review of the 900 MWe reactors is acceptable. On the other hand, ASN considers that the situations affecting the fuel storage pool, which may be induced by the failure, in the event of an earthquake, of equipment not classified as seismic, must be studied while simultaneously taking into account the effects induced by this earthquake, the MDTE and the most penalizing aggravation;
- safety requirements must be broken down into acceptance criteria for safety studies.

The study rules must incorporate the aforementioned expectations of ASN, which is the subject of a request [49]. In addition, ASN considers that EDF should include these study rules in the safety report.

This point is the subject of the ASN [PISC-B] prescription [48].

Triggering events to remember

Given the objective of practically eliminating the risk of fuel melting in the fuel building, ASN considers it necessary to include in a dedicated chapter of the safety report the following situations affecting the fuel storage pool , as well as the associated study rules:

- situations of partial or total loss of cooling of the water in the fuel storage pool;
- pipe rupture situations on an isolable section connected to the fuel storage pool.

ASN also considers that EDF must study the following situations, using the same study rules:

- situations of loss of cooling or draining of the reactor building pool when the two pools are in communication via the transfer tube, including when a fuel assembly is in the transfer tube;
- situations affecting the fuel building pool, which may be induced by the failure, in the event of an earthquake, of equipment not classified as seismic.

In the event that these studies lead to the definition of modifications that are not proportionate to the safety issues, EDF should justify its ability to manage these situations with less penalizing study rules.

These points are the subject of the ASN [PISC-B] prescription [48].

Other situations

Given the objective of practically eliminating the risk of fuel melting in the fuel building, ASN considers it necessary to check:

- the absence of cliff-edge effect for non-isolable breaches upstream of the second isolation unit and “breaks” in the transfer tube;
- the absence of cliff-edge effect by combining the lack of external voltage at the operating conditions;
- the absence of a cliff-edge effect if increased operating times are taken into account (values used for the Flamanville EPR reactor) for the operating conditions.

These points are the subject of requests from ASN [49].

During the investigation, additional accident situations, likely to lead to a loss of water inventory or to an absence of sufficient cooling of the fuel assemblies, were identified. EDF provided additional information on the risks associated with these situations. It's about :

- the situation of emptying the swimming pools by erasing a sealing tape; the examination of the probabilistic safety studies relating to the reactors of the Bugey nuclear power plant made it possible to identify a specific scenario that EDF undertook to study. ASN considers this commitment to be satisfactory and considers that EDF should draw lessons from it and define, if necessary, material or operating modifications;
- situations of prolonged incident blockage of a fuel assembly in the transfer tube. EDF has undertaken to send additional information to its study, which is satisfactory;
- situations of uncontrolled heating of a fuel assembly in a PT cell. ASN considers that the requirements to be applied when performing PT operations must be reinforced. This point is being investigated within the framework of the modification of the general operating rules for the fourth ten-yearly outage of the 900 MWe reactors;
- of an assembly overheating in the event of an object falling on the storage racks.

ASN considers that the modifications that EDF has planned or has undertaken to implement within the framework of the periodic review will significantly improve the safety of the storage and handling of fuel assemblies and contribute to reducing the risk of melting fuel assemblies stored in the swimming pool.

5.4.3.4 Protection of the fuel storage pool cooling systems against internal attacks, excluding falling packaging

Fire risk

The clarification provided by the probabilistic safety studies (see paragraph 5.7) confirms the importance of the modifications planned by EDF consisting of the installation of a flame-resistant protective screen between the two pumps of the cooling system of the swimming pools. fuel storage. In fact, this modification makes it possible to halve the risk of fuel assemblies being exposed in the storage pool in the event of a fire. EDF must specify the technical characteristics of this screen (dimensions, constituent material, fire resistance, precise location, etc.) as well as the resistance of the two pumps of the cooling system to the fumes given off by a fire. The screen will also have to be earthquake resistant with increased safety (SMS), to which EDF is committed.

In addition, the installation of a protection for the power cables of the pumps of the cooling system of the fuel storage pools in the room housing them is satisfactory.

Explosion risk

ASN considers that the elements presented by EDF, with regard to the protection against explosion of internal origin of the systems allowing the evacuation of the residual power and the maintenance of the water inventory of the storage pools of the fuel, will significantly improve control of the risks associated with this attack.

However, EDF upgrades the new SEG injection circuit in the event of loss of cooling of the PTR system following an internal explosion occurring in a group of premises in the nuclear auxiliaries building. ASN considers that appropriate in-service monitoring requirements must be defined in order to ensure high availability of the equipment making it possible to have ultimate water injection into the fuel storage pool. ASN also considers that EDF should revise its studies taking into account its requests made in the paragraph dedicated to these risks (paragraph 5.2.11).

Risk related to internal flooding and failure of high energy piping (RTHE)

The studies relating to the reactors at the Bugey nuclear power plant were submitted late and were not analyzed in the context of this report.

For CPY type reactors, ASN considers that the treatment of failure situations by common cause identified by EDF concerning the cooling of the swimming pool in the event of internal flooding or RTHE is generally acceptable. However, ASN points out that the compensation for a non-isolable leak and the evacuation of the residual power by boiling and making up water can only be acceptable on a temporary basis and considers that EDF must demonstrate its ability to isolate the leak and resume cooling of the closed-circuit fuel storage pool.

Regarding isolable leaks of conventional size leading to emptying of the fuel storage pool, ASN considers that, in the event of a leak in the room containing the isolation valve, isolation of the leak by maneuver in manual of this valve is not guaranteed due to the risk of spraying the operator and the water level in the room which could make the valve inoperable. In such a scenario, although the leak could be compensated for by back-up means, the flooding of the premises would continue. ASN therefore requests that EDF implement a reinforced check to detect the appearance of damage on this portion of piping. This point is the subject of a request from ASN [49].

ASN considers that the consequences of the floods induced by the initiators for emptying the swimming pools (initiators transposed from the EPR operating conditions) must be studied by retaining hypotheses of leaks greater than “conventional” leaks (by retaining hypotheses of leaks consistent with those taken into account to study the consequences on the discovery of fuel assemblies in swimming pools). During the investigation, EDF indicated, for floods induced by leaks of unconventional sizes [70] (namely with a section greater than eD / 4) downstream of the first isolation device, that the valued responses would not be called into question by the study of the consequences of the flooding on the equipment. ASN nonetheless considers that EDF's position is not satisfactory insofar as EDF limited its verification to the availability of back-up means at the swimming pool, without checking the availability of means making it possible to stop the emptying. In particular, the isolation valve of the swimming pool cooling system could be submerged by the flooding before its automatic closing by the signal of reaching a "very low level" of water in the swimming pool, which would not allow not isolate the leak.

At the end of the investigation, EDF undertook to carry out these studies, which is satisfactory.

Risk associated with falling loads

For handling loads other than handling fuel packaging, the verifications carried out by EDF and the commitments made are acceptable. In particular, EDF has undertaken to study the risks associated with the localized degradation of thermal exchanges in swimming pools, for example in the event of blockage of a cell containing a hot assembly following a drop in load.

[70] For the Flamanville EPR reactor, EDF retained in its studies a doubly debated breach in the pipes of the cooling system of the fuel storage pools (flood study induced by an accidental situation of emptying the pool).

5.4.3.5 Risks associated with handling fuel transport packaging

Disturbance of fuel storage pool structures

ASN considers that the principles of the method adopted to justify the structural resistance of the load-bearing elements of the fuel storage pool in the event of a package fall are acceptable.

Fall into the loading pit

For CPY type reactors, the study of the fall of a package in the loading pit does not take into account the presence of water in this pit, a situation however foreseen during operation.

A fall of packaging in the presence of water in the loading pit is likely to generate an overpressure on the sails participating in the support of the liner of the swimming pool. ASN therefore considers that the risk of damage liable to lead to the fuel pool in the building of the 900 MWe CPY reactors being emptied cannot be ruled out. This point is the subject of a request from ASN [49].

For the reactors at the Bugey nuclear power plant, EDF has undertaken to send additional information to check that there is no loss of seal in the liner at the bottom of the pit, which is satisfactory.

Fall into the handling hopper

For CPY type reactors, ASN considers that the case of a transport packaging falling into the handling hopper of the fuel building is covered by that of falling into the loading pit.

For the reactors at the Bugey nuclear power plant, ASN noted that the EDF study did not cover all the consequences of the packaging falling from heights of less than 5.5 m. During the investigation, EDF undertook to complete its study, which is satisfactory.

Risks related to phenomena that may occur in the dropped packaging

During the fourth periodic review of the 900 MWe reactors, EDF assessed the risks associated with the various phenomena likely to occur in the packaging following its fall.

EDF has produced a study on the criticality risk. In the event of a drop in the packaging for the reactors at the Bugey nuclear power plant, given the risks incurred due to the presence of non-borated water in the package, EDF has undertaken to implement the drying of the cavity. of the packaging before handling. ASN considers this commitment to be satisfactory.

EDF sent a study on the risk of hydrogen accumulation inside the packaging. This study considers that the vent in the packaging allows the hydrogen produced by radiolysis to be evacuated and that, therefore, the risk is prevented. ASN considers that additional information is necessary to ensure that there is no risk. This point is the subject of a request from ASN [49].

With regard to the radiological consequences associated with a drop in packaging, for CPY type reactors, EDF has undertaken to modify its specific rules of conduct relating to discharges of spent fuel by limiting the handling height of the packaging. without shock-absorbing device (when entering the means of transport). In addition, ASN considers that, for all the 900 MWe reactors, EDF must study the possibilities of improving the dynamic containment of the fuel building. This point is the subject of a request from ASN [49].

5.4.4 Summary and requirements relating to the safety of the fuel storage pool

Following the deployment of the modifications planned in the context of the fourth review, EDF will have an additional cooling system for the fuel storage pool (PTR bis), a water make-up system and an ultimate diverse water source. These means, which belong to the "hard core", are such as to greatly reduce the risk of the fuel being exposed and will, in most of the situations considered, make it possible to reach a final state after an accident without boiling the pool. They are major improvements to the review.

In addition, EDF has undertaken to include in the safety demonstration the accident situations considered for the sizing of the fuel storage pool for the Flamanville EPR reactor, with the exception of a limited number of situations. The resulting safety improvements will be a step forward for safety.

In addition, ASN instructs EDF to verify that, in the event of an accident, a safe state is reached, characterized by the absence of boiling of the fuel storage pool. EDF will have to make provisions to improve the prevention of situations for which such a state cannot be reached with the means selected in the safety demonstration, as well as post-accident management measures enabling such a state to be reached in the long term.

EDF has undertaken to analyze the accident scenarios affecting both the reactor and the fuel storage pool, which is satisfactory. Likewise, EDF has undertaken to complete the list of situations studied that may lead to a loss of water inventory or to an absence of sufficient cooling of the assemblies in the storage pool, in order to identify possible measures. to implement.

EDF has also reassessed the risks associated with fires, explosions and internal flooding occurring in the fuel building. These studies have led to the definition of material modifications to prevent the risk of loss by common mode of the means for injecting water into the swimming pool or for cooling. ASN also asks EDF to define operating provisions to prevent these risks.

EDF also studied the consequences of the fall of a general aviation aircraft on the fuel building. This situation does not lead to the uncovering of the assemblies in the fuel storage pool.

Finally, the fourth periodic review was an opportunity to shed a probabilistic light on events of internal origin, attacks associated with fires, explosions, internal floods, earthquakes and external floods. This clarification made it possible to identify additional modifications to be implemented, which will improve the level of safety.

The modifications resulting from all the studies provided or to come will complete the safety demonstration and will constitute major improvements in the safety of the fuel storage pools. The results of these studies and the modifications planned by EDF, supplemented by ASN's requests, will make it possible to meet the objectives set for this review.

*

At the end of the examination, EDF undertook to carry out most of the necessary additions that the ASN examination revealed. ASN prescribes [48] the implementation of the major safety improvements planned by EDF as well as certain additional measures that it considers necessary to achieve the objectives of the review.

Diversified back-up and cooling system for the fuel storage pool

[PISC-A] I.– The operator sets up a diversified cooling system for the fuel storage pool and an ultimate water make-up system for this pool, and monitors them during operation.

II.– The fixed parts of the provisions mentioned in I are important elements for the protection of interests for which the operator identifies the associated defined requirements.

III.– The means making it possible to ensure, in hard core situations, the diversified cooling functions of the fuel storage pool and the ultimate water make-up to this pool are part of the hard core and comply with the [ECS- 16] of the appendix to the aforementioned decisions of June 26, 2012 and [ECS-ND2] of the appendix to the aforementioned decisions of January 21, 2014.

Studies of accidents affecting the fuel storage pool

[PISC-B] I.– The licensee includes, in a dedicated chapter of the safety report, the study rules associated with the demonstration of the safety of the fuel storage pool as well as the incident and emergency situations. accident deductions.

This chapter includes the following situations:

- situations of partial or total loss of cooling of the water in the fuel storage pool;
- pipe rupture situations on an isolable section connected to the fuel storage pool.

He puts implement any necessary modifications.

II.– The operator defines before June 30, 2021 a schedule for carrying out studies of the situations following, retaining the rules mentioned in I:

- situations of loss of cooling or draining of the reactor building pool when the two pools are in communication via the transfer tube, including when a fuel assembly is in the transfer tube;
- situations affecting the fuel building pool, which may be induced by the failure, in the event of an earthquake, of equipment not classified as seismic.

At the end of these studies, it defines any changes to be implemented with regard to the challenges for safety and the associated schedule.

[PISC-C] The operator checks that, in the event of an attack, an incident or an accident, a safe state characterized by an absence of boiling of the fuel storage pool can be achieved. and maintained.

It identifies the situations for which such a state cannot be reached with the means valued in the safety demonstration. It defines and implements the measures necessary to improve the prevention of these situations and provides for post-accident management measures to ultimately achieve this safe state without boiling.

5.5 RE-ASSESSMENT OF HEART FUSION ACCIDENT STUDIES

5.5.1 Reassessment of the means of limiting the consequences of accidents with core meltdown

5.5.1.1 Specific objectives of the review

The improvement objectives adopted by EDF in the field of accidents with core meltdown, known as “severe accidents” (GA), concern the strengthening of the means of preventing core meltdown (presented in paragraph 5.3) and the strengthening of means of limiting its consequences. These reinforcements aim to limit the radiological consequences during a serious accident by making the risk of early and significant releases extremely improbable and by avoiding lasting effects in the environment.

To meet this objective and as part of the studies carried out following the accident at the Fukushima Daiichi nuclear power plant in 2011, EDF carried out a study of improvements allowing the removal of residual power from the core. without having to open the ventilation and filtration device of the reactor building containment. This absence of venting makes it possible to limit discharges outside the containment enclosure.

EDF has also initiated the study of new measures in order to prevent the risk of large or early releases into the environment and sought measures to limit the risk of the concrete of the base of the reactor building being pierced by corium (mixture of molten fuel and internal metal structures).

When examining the guidelines for the periodic review proposed by EDF [6], ASN underlined the importance of these improvements, which are necessary to meet the objective set and enable the level of reactor safety to be brought closer to 900 MWe of that targeted for the Flamanville EPR reactor.

Concerning the risk of perforation of the raft foundation, in its letter in reference [37], ASN asked EDF to " *propose criteria that must not be exceeded (eroded thickness, liner damage, etc.) in order to avoid any cliff-edge effect on the discharges observed. These criteria had to take into account, if necessary, the specificities observed on the different reactors (design of the containment or raft, repairs, condition of the concrete of the raft, presence or absence of liner, etc.)* ".

Finally, ASN asked EDF to study, as part of this review, on the one hand the possibilities of implementing dynamic water containment systems in order to avoid pollution, in a serious accident situation. groundwater, on the other hand the consequences of piercing the raft in the absence of such containment devices (see paragraph 5.5.2).

5.5.1.2 Summary of studies carried out by EDF and planned modifications

5.5.1.2.1 Measures planned by EDF to limit the risk of perforation of the raft of the reactor building in the event of a serious accident

The strategy planned by EDF within the framework of the fourth periodic review of the 900 MWe reactors to reduce the risk of perforation of the foundation raft consists of stabilizing the corium outside the vessel as follows:

1. pre-filling the sumps at the bottom of the containment chamber with water by the safety injection system (RIS) or water sprinkling in the containment (EAS) or, in the event of failure, by a new system, the ultimate containment residual heat removal device (EASu);
2. dry spreading of the corium in the reactor pit and in the internal core instrumentation room (RIC) adjacent to the reactor pit;

3. stabilization of the corium by injection of water at the surface of the corium, after spreading. The injection is carried out passively by gravity from the water present in the bottom of the enclosure before the opening of the tank;
4. evacuation of the residual power of the corium outside the enclosure by cooling the water using the EASu circuit, through its exchanger connected to the ultimate cold source (SFu).

The implementation of this strategy requires the carrying out of preliminary development works in the lower part of the reactor building, as well as the installation of new circuits (EASu, SFu).

If the reactor vessel is pierced after the core has melted, the corium falls into the vessel well of the reactor building. The concrete then decomposes under the effect of the heat transmitted by the corium: this phenomenon, called "corium-concrete interaction" (ICB), can lead to the opening of the raft. EDF adopted as a criterion, within the framework of the fourth periodic review of 900 MWe CPY type reactors, the objective of preserving the structural base of the containment by limiting the permissible erosion of the concrete to the thickness of the base of the structures. internal[71]. For the reactors at the Bugey nuclear power plant, the criterion adopted corresponds to a thickness of non-eroded concrete of at least two meters.

The thickness of the base of the internal structures and of the structural base of the enclosure as well as the composition of the concrete of the bases vary according to the reactors:

- the thickness of the base of the internal structures is of the order of 1 m for all 900 MWe nuclear reactors;
- the thickness of the structural raft of the enclosure is of the order of 3.5 m, with the exception of the reactors of the nuclear power plant of Bugey (1.5 m), Chinon (3 m) and Cruas (3 m);
- the concrete of the reactors of the nuclear power plant of Bugey, Gravelines are silico-limestone, those of the reactors of Tricastin and Cruas are siliceous, those of the reactors of Dampierre-en-Burly, Blayais, Saint-Laurent-des-Eaux and Chinon are very siliceous.

Sealing of the reactor pit and water detection in the corium spreading zones

In order to guarantee the dry spreading of the corium, a necessary condition for a complete and homogeneous spreading of it, EDF has planned the implementation of measures to avoid the presence of water in the spreading zone, an area made up of the tank well and adjacent RIC room. These arrangements also make it possible to prevent the risk of a steam explosion in the reactor pit. The presence of water in this area could result either from malfunctions when the reactor is in normal operation, or from the spraying of water into the enclosure during an accident. EDF has in particular planned:

- sealing devices for the access wells to the neutron measurement chambers (RPN), which do not prevent the depressurization of the reactor pit for accidents that require it;
- modifications to prevent the water contained in the sumps of the purges and vents (RPE) system from rising to the reactor pit and the RIC room. These modifications consist of the installation of taps or non-return valves at the level of the drains of the RPE system;
- on the reactors of the Bugey nuclear power plant, a sealing ring between the bottom of the swimming pool of the reactor building and the vessel.

In addition, EDF plans to use sensors located at the level of the isolation unit of the reactor pit drainage system and in the RIC room of CPY type reactors to detect the possible presence of water. However, EDF does not provide a sensor in the RIC room of the reactors of the Bugey nuclear power plant, insofar as the non-return valve allowing the evacuation of water potentially present in the RIC room is a passive device.

71 The lower part of the enclosures is made up of two rafts: the raft of the internal structures and the structural foundation of the enclosure. The first, around one meter thick, distributes the load descents of the walls of the internal structures, while the second, thicker and located under the first, ensures the structural strength of the enclosure.

Erosion of the side walls of the internal heart instrumentation room (RIC)

EDF's strategy provides for spreading the corium in the reactor pit and the RIC room. In order to demonstrate that the corium is maintained in the planned spreading zones, EDF has carried out calculations to assess the risks of lateral breakthrough of the walls of the internal core instrumentation room (RIC) by the corium, leading to its relocation outside of the core. planned sprawl areas. EDF concluded that the lateral drilling of the walls of the RIC room and the spreading of the corium in the area of the sumps at the bottom of the enclosure are excluded for the families of silica-limestone and siliceous concrete of the 900 MWe reactors, but not for the family of very siliceous concrete. However, EDF considers that the consequences of such a breakthrough are acceptable.

Removal of very siliceous concrete slabs

The stabilization of the corium and the thickness of the ablated concrete depend on the efficiency of the physical mechanisms for cooling the corium under water. This efficiency varies depending on the nature of the concrete constituting the rafts. EDF thus distinguishes three families of concrete: sand-lime concrete, siliceous concrete and finally very siliceous concrete. Corium-concrete interaction calculations (ICB) [72] underwater carried out by EDF show that the corium is stabilized for all concrete families at eroded concrete thicknesses of less than one meter and at times of less than 1.5 days. Also, for EDF, the criterion adopted in order to avoid any cliff-edge effect on the discharges is respected whatever the type of concrete of the rafts.

5.5.1.2.2 Provisions provided by EDF for the evacuation of residual power outside the enclosure without venting

EDF plans to install the EASu system to evacuate the residual power out of the containment in the event of a serious accident. This system injects the contents of the pool water treatment and cooling system (PTR) tank into the enclosure, then recirculates the water from the sumps, cooling it. Cooling is provided by an exchanger which is connected to the cold source by the nuclear rapid action force (FARN) which has a mobile pump and suitable connection pipes. EDF has retained two deadlines in its studies for the connection of the EASu to the mobile cold source by the nuclear rapid action force (FARN):

- 24 hours in the event of a serious accident situation resulting from an internal event at installation;
- 48 hours in the case of a "hard core situation" [73], representative of a situation of aggression extreme of external origin.

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[72] Phenomenology of corium cooling under water:

In the first moments following the flooding of the corium, the induced quenching makes it possible to solidify part of the corium and to initiate the formation of a corium crust on the surface. The cooling mechanism is based on two mechanisms observed experimentally:

- the ejection of corium through the crust by the decomposition gases of the concrete which makes it possible to solidify liquid corium in the form of debris;
- the imbibition of water in the corium crust which allows, depending on the conditions (concrete content in the corium, convective flow of the corium upwards), to promote the growth of the thickness of the crust by cracking and penetration of water and therefore extract energy. The ejection of corium by the gases occurs in the case of concrete containing a large fraction of CO_2 (sand-lime concrete). For a very siliceous concrete (very little CO_2), this phenomenon contributes little to cooling. This phenomenon also depends on the speed of ablation which decreases with time.

Water imbibition does not depend on the type of concrete. The rate of corium solidification depends on the heat flux extracted by the water entering the permeable crust. This flux decreases sharply when the mass fraction of concrete in the crust increases. The value of the flux is not known for large mass fractions in concrete, for lack of experimental data.

[73] The following situations, as well as the situations resulting from their accumulations, are called “hard core situations”:

- the total loss of power supplies not belonging to the "hard core";
- the total loss of the cold source not belonging to the "hard core";
- the external aggressions retained for the "hard core";
- situations resulting from the state of the installation, the site and its environment after one or more external attacks selected for the "hard core".

The pressure and temperature conditions in the enclosure depend on the supply of borated water before connecting the SFu to the EASu system as well as the medium-term reliability of the cooling function.

Serious accident occurring after an internal event

The reference scenario adopted by EDF for internal events is a four-inch breach occurring in the hot branch with the failure to switch the backup systems to recirculation and the commissioning of the EASu pump and the EASu / SFu exchanger. 24 hours after the start of the accident. EDF concludes that the commissioning by the nuclear rapid action force (FARN) of the EASu / SFu exchanger from 24 hours makes it possible to meet the pressure criteria in the containment, so as not to have to vent the enclosure, and the temperature of the water in the sumps, so as not to interfere with the correct operation of the EASu system.

For EDF, achieving the objective of cooling the corium spread on the raft, without opening the venting device, requires the injection into the enclosure at the start of the accident of a corresponding volume of borated water. the volume contained in the tank of the swimming pool water treatment and cooling system (PTR), the operation of the EASu in recirculation and the connection to the ultimate cold source.

Serious accident resulting from a "hard core situation"

The reference scenario adopted by EDF in the event of the occurrence of an extreme stress of external origin corresponds to the total loss of cold sources and electrical sources. Cooling by the steam generators, via the “hard core” steam generator backup power system (ASG-ND), is assumed to be operational over a period of 48 hours, then lost after that. The EASu / SFu exchanger is put into service by the FARN 48 hours after the initiator. EDF concludes that the commissioning of the EASu / SFu exchanger from 48 hours makes it possible to meet the pressure criteria in the enclosure and the water temperature in the sumps, by operating the ASG-ND for at least 12 hours on the CPY type reactors and for at least 24 hours on the reactors of the Bugey nuclear power plant.

EDF plans to deploy ASG-ND during phase B of the modifications associated with the fourth periodic review of the 900 MWe reactors.

Quality of the mechanical equipment of the EASu system

In its design note for the EASu system, EDF indicates that the entire EASu injection circuit was designed according to level 2 of the RCC-M code, with the exception of the EASu pump, which is not an item of equipment. under nuclear pressure. EDF also indicates that the equipment of the fixed part of the cooling circuit of the EASu arrangement was designed in accordance with level 3 of the RCC-M code.

Availability of EASu in the event of internal flooding likely to occur in the fuel building

EDF considered the overflow of the fuel storage pool, the condensates generated by the boiling of the pool water in the event of a loss of cooling accident, as well as the leaks caused by the original extreme attacks. external, especially an earthquake.

EDF has defined a provision making it possible to redirect the water condensates from the fuel storage pool to this same pool.

EDF considered the other sources of flooding for the qualification of the EASu equipment.

5.5.1.2.3 Measures planned by EDF to reduce discharges in the event of venting of the containment enclosure

The containment ventilation and filtration device, used as part of the so-called “U5” ultimate procedure and by extension called “U5 device”, has the following functions in the event of a serious accident:

- avoid the containment failure that could result from an increase in its internal pressure beyond its design pressure, by opening a vent to the atmosphere;
- to limit radioactive discharges and to limit the radiological consequences of the discharges by filtering the fluid passing through the vent line before it is released into the environment.

The EASu device must make it possible to manage serious accident situations without requiring ventilation of the enclosure. However, EDF has planned, as part of the fourth periodic review, two additional control options to remedy a failure of this means of removing residual power outside the enclosure:

- the restarting of an alternative emergency system, most probably the low pressure pump of the safety injection system (RIS-BP) coupled to the sprinkler system and recirculation of the sprinkler water in the enclosure (EAS), which makes it possible to evacuate the residual power outside the enclosure without having to open the ventilation and filtration device of the enclosure;

- in the event of failure of this solution, recourse to a charge pump, operating by direct injection from the PTR tank replenished with water, coupled to an opening of the ventilation and filtration device.

Situations *long-term loss of EASu*

EDF had undertaken to examine, in terms of robustness, the possibilities of dealing with a failure of the EASu system pump in the long term. EDF has provided for the principle of an additional arrangement which will allow water to be made up in the bottom of the containment by mobile means for a sufficient period of time to keep the spread corium flooded in the reactor pit and the RIC room, in the event of failure of the EASu in the medium or long term.

Resistance of the U5 device to earthquake

The U5 device was not dimensioned for the earthquake when it was designed. At the end of the meeting of the standing group of experts for reactors on July 7, 2016, ASN asked EDF to give an opinion, for each of the sites, on the capacity of the ventilation and filtration system of the reactor. 'atmosphere of the containment to perform its function following an increased safety earthquake (SMS), or even a "hard core earthquake" (SND).

EDF plans to reinforce the U5 system for the historically probable maximum earthquake (SMHV). EDF specified that it could not comment on the safety increased earthquake resistance (SMS) of the parts of the U5 device located outside the enclosure, with the exception of the filter, the supports of which should be reinforced. EDF also indicated that ensuring that the U5 device withstands a “hard core earthquake” (SND) would require significant modifications in the design of the line (for example, a different location of the sand filter).

Reduction of discharges by filtration of the U5 device

The short-term radiological consequences associated with the use of the U5 ventilation and filtration device are, in large part, linked to the releases of gaseous species containing radioactive iodine. As the sand filter of the current U5 device is not an effective trap for these species, ASN considered at the end of the meeting of the standing group of experts for reactors on July 7, 2016 that the possibilities for improvement filtration of gaseous iodine species had to be re-examined with a view to reducing the radiological consequences of a core melt accident. ASN therefore asked EDF to specify the conditions of use of the ventilation and filtration device of the containment enclosures and to assess the associated discharges,

Given the installation of the EASu system, EDF did not send a study on improving the efficiency of U5 filtration or on the implementation of new filters.

5.5.1.2.4 Instrumentation associated with accident management

Instrumentation of the water level in the bottom of the enclosure

Following the meeting of the standing group of experts for nuclear reactors on July 7, 2016, ASN asked EDF to provide qualified instrumentation for severe accidents [37], making it possible to assess the water level in the bottom of the enclosure and its evolution and to transmit a description of this instrumentation.

EDF indicated that the sizing of the EASu and of the corium spreading device did not require a level measurement in the sumps of the reactor building since, in order to return and to cool the corium, the injection of borated water corresponding to the volume of the pool water treatment and cooling system (PTR) tank is sufficient. EDF has however planned to set up such instrumentation.

5.5.1.3 ASN's position on achieving the objectives of the review

5.5.1.3.1 Limitation of the risk of piercing the raft of the reactor building in the event of a serious accident

In general, ASN considers that the measures intended to promote dry spreading of the corium in the reactor pit and the adjacent RIC room, then its stabilization under water, constitute safety improvements making it possible to significantly reduce the risk of drilling. of the raft.

Sealing of the reactor pit and water detection in the corium spreading zones

ASN considers that the sealing devices presented by EDF make it possible to guarantee dry spreading of the corium with a sufficient level of confidence.

ASN notes in particular EDF's commitment to change, during each reactor shutdown, the seals present in the access wells to the RPN neutron chambers as well as, for the power plant reactors. nuclear power plant at Bugey, at the level of the sealing ring.

Furthermore, the detection of water in the reactor vessel wells, as well as in the RIC room of CPY type reactors, based on existing sensors is satisfactory. However, these sensors must be considered as important elements for protection (EIP).

For the RIC room of the reactors of the Bugey nuclear power plant, the control of the dry spreading of the corium in this room is based on a non-return valve, installed on the drain of the RPE system, which has the function of evacuating the water present in the room and prevent water from rising from the sumps of the reactor building. During normal operation of the reactor, there is no monitoring of the water level in this room. In the event of a valve malfunction, a quantity of water could thus be present in the RIC room, without the control team being informed, and would be liable to call into question the strategy of dry spreading of the corium. Also, in view of the importance of this valve for controlling the dry spreading of the corium, ASN considers it necessary that it be subject to enhanced surveillance during operation. This point is the subject of a request from ASN [49].

Erosion of the side walls of the internal heart instrumentation room (RIC)

EDF considers that the lateral drilling of the walls of the RIC room and the spreading of the corium in the area of the sumps at the bottom of the enclosure are excluded for the families of silica-limestone and siliceous concrete of the 900 MWe reactors and are possible for the family of very siliceous concrete.

ASN considers that, in the thickness of the non-eroded concrete of the walls of the RIC room, a cracking front could appear, which would compromise the sealing of the wall with respect to the corium, whatever the type of concrete. . The relocation of the corium outside the spreading zones cannot therefore be ruled out for the 900 MWe reactors and would be liable to induce risks not considered by EDF. ASN therefore considers that the thickness of these walls at their base is not sufficient.

This point is the subject of the ASN [AG-A] prescription [48].

Removal of very siliceous concrete slabs

The criterion proposed by EDF to guard against piercing the raft is acceptable.

The interaction simulations between corium and concrete (ICB) carried out by IRSN give very different results from those of EDF with regard to the eroded thickness in the case of very siliceous concretes. Thus, for the 900 MWe reactors, they show that the corium would be stabilized only after about 30 days and at an ablated thickness of about three meters, which does not allow the criterion adopted by EDF to be respected.

The complexity of the physical phenomena governing corium stabilization is still the subject of significant research work. The small number of representative tests available and the dispersive nature of the physical phenomena involved do not allow a conclusion, when the concrete of the base is very siliceous, as to the respect of the criterion proposed by EDF, namely to preserve the structural base of the enclosure by limiting the permissible erosion of the concrete to the thickness of the base of the internal structures.

ASN notes that EDF is involved in the "ROSAU" (Reduction Of Severe Accident Uncertainties) international research and development program of the Nuclear Energy Agency, which relates in particular to the behavior of the interaction between corium and concrete representative of the rafters of the containment. EDF will also carry out specific additional tests on the behavior of very siliceous concrete in French reactors before the end of 2022. Pending the conclusions of these research programs, ASN asks EDF to prepare the activities and work required for thickening very siliceous concrete slabs, in order to have the means to implement them from 2025.

This point is the subject of the ASN [AG-A] prescription [48].

Finally, taking into account the specific features of the rafts of the reactors of the Bugey nuclear power plant (alveolar structure), the specific risks of radiological releases, likely to arise in the event of interactions between these slabs and the corium will be the subject of an investigation particular.

5.5.1.3.2 Evacuation of residual power outside the enclosure without venting

Serious accident resulting from an internal event

EDF's evaluations show the effectiveness of the EASu and the good cooling of the corium spread on the raft foundation, following the injection into the enclosure of a volume of borated water corresponding to the tank of the cooling system. swimming pool water treatment and cooling (PTR).

The models carried out by IRSN as part of the examination show, for their part, that the design pressure of the containment is reached before 24 hours for all types of concrete in the raft. This 24 hour period corresponds to the time required for the installation of the ultimate heat sink by the nuclear rapid action force.

The IRSN's evaluations also show that the replenishment of the PTR tank engaged at the start of the serious accident, followed by the injection, 12 hours after the triggering event, of a sufficient volume of water from this tank by the EASu pump would make it possible not to reach, during the first 24 hours following the triggering event, the design pressure of the enclosure.

ASN therefore considers that the injection of an additional volume of borated water into the reactor building is likely to significantly reduce the risk of pressure build-up in the containment which would lead to the opening of the device. ventilation of the building.

This point is the subject of the ASN [AG-B] prescription [48].

In addition, the level 2 probabilistic study carried out by EDF shows that the risk of the raft breaking through is largely attributable to the failure of the EASu before 24 hours, which is likely to prevent the injection of all water from the PTR tank to the containment sumps. ASN considers that EDF must have the means to inject borated water in the short term, in addition to

that from the cover of the swimming pool water treatment and cooling system (PTR), in the reactor building during an accident with fuel melting.

Serious accident following a "hard core situation"

ASN notes that the EASu provision will only be able to limit the consequences of a serious accident caused by an extreme attack of external origin on the 900 MWe reactors, only after the deployment of the modification relating to the power supply. back-up for the “hard core” steam generators (ASG-ND), planned by EDF during phase B of the deployment of the modifications associated with the periodic review of the 900 MWe reactors.

Quality of construction of the mechanical equipment of the EASu arrangement

At the end of the meeting of the standing group of experts for nuclear reactors on July 7, 2016, ASN informed EDF that the requirements for the design, production and in-service monitoring of EASu system equipment had to be particularly high.

As the EASu pump is not a nuclear pressure equipment (ESPN), EDF had not planned to design and manufacture them according to the requirements of level 2 of the RCC-M code. However, the EASu system is used both for the prevention of serious accidents and for the limitation of the consequences of a serious accident. Thus, a malfunction of one of the equipment of this system could lead to faulty two levels of defense in depth. Following the instruction, EDF undertook to design and manufacture these pumps according to the provisions of level 2 of the RCC-M.

For the pumps already manufactured, EDF has verified that the design provisions it has used comply with the requirements of level 2 of the RCC-M code and will prove their level of manufacturing quality.

Availability of EASu in the event of internal flooding likely to occur in the fuel building

ASN considers that the provision presented by EDF on the occasion of the fourth periodic review of 900 MWe reactors, which makes it possible to redirect the water boiling condensates of the fuel building swimming pool (BK) to this same swimming pool, is satisfactory.

EDF is committed to providing the qualification elements for EASu equipment, taking into account the risks of flooding associated with other potential sources.

Reinjection to the reactor building (BR)

In the event of leaks, effluents are likely to flow onto the floor, located at the back of the fuel building (BK), on which components of the EASu system will be installed. The RIS and EAS circuits may in particular be required to operate in recirculation mode in a serious accident situation. EDF estimates that any leaks from the RIS and EAS systems in the premises of the fuel building would be detected by the level measurement instrumentation of the sumps in these premises. This instrumentation is the subject of a dedicated paragraph (paragraph 5.5.1.2.4 on instrumentation).

EDF also plans to collect leaks from the mechanical seals of the EASu system pump and the rods of three taps. These leaks will be collected in tanks. However, leaks from other components of the EASu system, such as flanges for example, are possible. Such leaks could jeopardize the functioning of the EASu in the short, medium or long term.

The presence of this highly contaminated water in the fuel building would generate high doses on the equipment of the EASu, RIS and EAS systems as well as difficulties in accessing the premises. The availability and reliability of these systems would be reduced. In addition, this contaminated water can be a source of activity discharges outside the fuel building, which is not watertight.

The early reinjection of effluents present at the bottom of the fuel building into the reactor building would limit the impact of radiological environmental conditions in the fuel building on the EASu, RIS and EAS systems, and limit activity releases outside the building and also to limit the loss of water inventory from the sumps in the reactor building.

EDF has provided a means of reinjecting external leaks into the reactor building, implemented under the so-called “U2” ultimate procedure, as soon as the pressure in the enclosure is below 2.4 bar. This pressure corresponds to the pump capacity of the nuclear purges, vents and exhales (RPE) system ensuring reinjection. However, this reinjection system is not qualified in the conditions of a serious accident and the pressure in the enclosure in a serious accident situation could be greater than 2.4 bar. EDF completed the device with an additional pump capable of reinjecting the leaks with a pressure in the enclosure equal to the design pressure.

This point is the subject of the ASN [AG-B] prescription [48].

5.5.1.3.3 Reduction of discharges by the ventilation and filtration device of the enclosure

The one-year mission duration of the EASu arrangement is difficult to guarantee, due to the high probability of failure of the EASu pump and the non-repairable and non-substitutable nature of the pump and the exchanger. ASN therefore considers that, even if alternative emergency means could be deployed, use of the U5 device to compensate for an EASu failure must always be taken into account in the safety demonstration. As such, the U5 system must continue to be part of the equipment required in a severe accident following the fourth periodic review of the 900 MWe reactors and be considered an important element for the protection of the interests mentioned in article L. 593-1 of the Environment Code, to which EDF made a commitment at the end of the investigation.

EASu long-term loss situations

EDF studied, following the meeting of the standing group of experts for reactors on March 27 and 28 2019, the feasibility of an additional arrangement which would allow water to be made up in the bottom of the enclosure by mobile means for a period sufficient to limit the erosion of the raft, in the event of failure of the EASu to medium or long term, and is committed to implementing it.

Given the non-repairable and non-substitutable nature of the EASu system pump, its long-term mission duration and the health consequences of a breach in the raft foundation, ASN considers that the installation of this means is necessary. necessary.

ASN supervises EDF's commitment through the prescription [AG-B] [48].

Resistance of the U5 device to earthquake

EDF is committed to demonstrating the ability of the U5 device to perform its functions in the event of an increased safety earthquake (SMS).

In view of the stakes, ASN supervises this action by prescription [AG-C] [48].

Reduction of emissions by U5 filtration

EDF did not send a study on improving the efficiency of U5 filtration or on the implementation of new containment ventilation filters. However, recent research work carried out by IRSN has demonstrated the good filtration capacities of silver zeolites for organic iodides under severe accident conditions. ASN considers that improvement in the efficiency of the filtration of the discharges by the containment venting device must be sought, in order to remedy any failure of the EASu system.

ASN notes that EDF has undertaken to continue its research and development efforts and to propose, if necessary, by December 2024, a program for the deployment of a modification following industrialization studies. .

5.5.1.3.4 Instrumentation associated with accident management

Instrumentation allowing the detection of the breakthrough of the tank

ASN considers that the new control strategy established by EDF for the management of tank top-ups in a severe accident situation is satisfactory, subject to the proper implementation of the passive corium flooding strategy.

EDF's tank top-up management strategy incorporates water injection actions, respecting a time limit after the tank has been pierced. However, the instrumentation making it possible to detect this vessel breakthrough does not appear in the list of instrumentation required in severe accidents for 900 MWe reactors, even though it is identified in the similar lists for 1300 MWe reactors and 1450 MWe. At the end of the investigation, EDF confirmed that a temperature measurement chain in the reactor pit will be added to the list of instrumentation required in a severe accident as part of the fourth periodic review of the 900 MWe reactors.

Instrumentation to detect corium spreading

In order to strengthen the monitoring of the condition of the installation in the event of a serious accident and to facilitate the operation of the “hard core” pump of the EASu system, EDF has undertaken to analyze the feasibility of deploying instrumentation that will allow detecting the spread of corium over the entire surface of the room in which the internal heart instrumentation (RIC) is located, as well as integrating the feedback of this information for severe accident driving. ASN considers that this commitment by EDF is satisfactory and that the operating recommendations in the severe accident intervention guides (GIAG) must be explicit for all situations.

Instrumentation of the water level in the bottom of the enclosure

ASN considers that instrumentation of the level in the sumps of the reactor building making it possible to assess the water level in the bottom of the containment and its evolution in a severe accident situation is likely to make the management of the reactor more reliable. 'a serious accident. Indeed, this information would make it possible to decide to inject water into the enclosure if necessary and therefore to maintain a sufficient water level in the sumps without risk of flooding the suction of the ventilation and filtration device U5. . At the end of the investigation, EDF undertook to put this instrumentation in place, which is satisfactory.

Sump level measurement instrumentation in the fuel building to detect leaks on the RIS and EAS circuits

In the event of leaks, effluents are likely to flow onto the floor, located at the back of the fuel building (BK), on which components of the EASu system will be installed. The RIS and EAS circuits may be required to operate in recirculation mode in a serious accident situation. EDF estimates that any leaks from the RIS and EAS systems in the premises of the fuel building would be detected by the level measurement instrumentation of the sumps in these premises. As part of the fourth periodic review of 900 MWe reactors, this instrumentation is checked for its operational character under severe accident conditions. ASN considers that such instrumentation must be considered by EDF as necessary in a severe accident,

5.5.2 Contaminated water management

Numerous studies have focused on possible devices to limit the contamination of the water in the environment, in the event of a contaminated water leak after an accident that led to the core meltdown.

5.5.2.1 Specific objectives of the review

Following the accident at the Fukushima Daiichi nuclear power plant, ASN had ordered EDF [3] to transmit: " *before December 31, 2012, [...] a feasibility study with a view to setting up, or renovating, technical devices, of the geotechnical enclosure type or of equivalent effect, aimed at preventing the transfer of radioactive contamination to groundwater and surface water in the event of a serious accident leading to the corium breaking through the tank* ". EDF submitted its study on December 20, 2012.

The principle of geotechnical enclosures consists of pumping the water present in the polluted zone, in order to lower the level of the water table in this zone (about one meter). This lowering of the water level forces the water flows to move from the "outer" water table towards the polluted area, thus preventing the pollution from spreading. In order to limit the quantities of water to be pumped and then to be treated, it is generally necessary to place in the ground, between the polluted area and the environment, a wall called a "geotechnical enclosure", sufficiently waterproof and of depth to a relatively impermeable layer of soil. Finally, the pumped water must be stored and then treated, before it can, if necessary, be discharged, after monitoring, into the environment.

In its letter of 20 April 2016 relating to the guidelines for the fourth periodic review of 900 MWe reactors [6], ASN stated that, " *in view of the complex nature of the phenomena studied, ASN may have to consider installing technical devices, such as a geotechnical enclosure, to avoid contamination of the groundwater in the event of a serious accident leading to the piercing of the building base. of the reactor* ". In a letter of 29 June 2016, ASN informed EDF of the additional information expected following examination of the information sent in December 2012. In particular, ASN asked:

- to continue the discussions initiated on the dynamic containment systems for contaminated water by sending ASN more detailed feasibility studies than those already transmitted, taking into account the specificities of each site and proposing a deployment schedule for the modifications studied;
- send to ASN, by distinguishing each site, a first summary assessment of the consequences of piercing the raft foundation following a serious accident, in the absence of any specific device aimed at limiting the contamination. This study was to identify, for each site, the aquifers, populations, geographical areas, agricultural crops and industries that would then be affected and provide an initial assessment of the consequences of such pollution.

ASN also underlined that such devices could make it possible to manage the situations caused by the flow of radioactive fluid outside the reactor building, during a serious accident, by means of escape routes other than piercing the raft. of this building.

5.5.2.2 Summary of studies carried out and modifications identified

EDF has studied the technical feasibility of systems aimed at preventing radioactive contamination in groundwater up to surface water in the event of a breach in the raft, following an accident that led to the core meltdown. The devices studied combine, for 900 MWe reactors:

- provisions permanently installed on the sites, namely:
  - a so-called "offshore" geotechnical enclosure (located on the outskirts of nuclear buildings),
  - a pumping device (consisting of two pumping wells, one of which is an emergency),
  - "buffer" storage tanks for pumped water;
- provisions forwarded and put in place by the nuclear rapid action force (FARN), in a post-accident situation, namely:
  - a mobile treatment station,
  - a mobile installation for the discharge of treated water, conditioning and temporary storage of solid waste.

EDF considers that the benefit in terms of safety of such devices is not justified with regard to the costs they would entail, given the uncertainties as to their effectiveness, of the management on the site of effluents in very large quantities and therefore of '' a floor area for the installation of tanks and the treatment unit potentially greater than that available in the currently defined perimeters of basic nuclear installations.

During the investigation, EDF did not send any information on the summary assessment of the consequences of drilling the raft in a serious accident situation, considering that research actions were necessary on the retention of radionuclides in soils before such a study can be carried out.

5.5.2.3 ASN's position on achieving the objectives of the review

IRSN carried out a summary assessment of the consequences of piercing the raft in a serious accident situation for river sites, without any specific device aimed at limiting contamination. For most sites, a few months after the opening of the raft, the concentrations of radionuclides in the river may exceed, by a factor of around 1000, the reference provided by the decree of January 11, 2007 relating to the limits and quality references for water intended for human consumption (which corresponds to an indicative dose of 0.1 mSv / year).

This summary assessment also shows that in a serious accident situation, even in the absence of piercing of the raft foundation, a leak of the order of one cubic meter [74] of contaminated water coming from the bottom of the reactor building, can lead to reaching in rivers, in one to three months, the reference levels for water intended for human consumption.

At the end of the investigation, EDF undertook to implement means to reduce the risk of environmental water contamination after an accident leading to core meltdown, using a successive lines of defense approach, in :

- limiting the risk of contaminated water leaks outside the reactor building. This line of defense is based on the measures planned to limit the risk of perforation of the raft of the reactor building mentioned in the previous paragraphs, as well as on the design rules of the EASu system making it possible to limit the risk of leaks in the fuel building;

- limiting the risk of leaks to the ground in the event of a leak of highly contaminated water in the combustible building; this line of defense is based on the devices for collecting leaks at different points of the EASu system, collecting effluents reaching the sumps of the fuel building (with strengthening of the tightness of these sumps), then reinjection of the effluents collected in these sumps. sumps to the reactor building;
- limiting the extent and duration of water contamination in the environment in the event of contaminated water leaking outside buildings. This line of defense could be based on means of reducing the contamination of the water present in the reactor building or on devices making it possible to limit the migration of radioactive elements, through the soil and underground water, towards the environment. .

ASN underlines the ambitious nature of EDF's commitment. VS **Bearing in mind the challenges, ASN oversees these commitments with the prescription [AG-D] [48].**

[74] For flows in rivers lower than the average annual flow, this value can be reduced to a few hundred liters of contaminated water leaking outside buildings.

5.5.3 Summary and prescriptions relating to accident studies with core melt

The improvement objectives adopted for the field of accidents with core meltdown concern the reinforcement of the means of limiting its consequences. The latter aim in particular to limit the radiological consequences during a serious accident, by making the risk of a major early release extremely unlikely and by avoiding lasting effects in the environment.

To meet this objective, EDF has defined improvements in order to:

- to evacuate the residual heat, without it being necessary to open the ventilation and filtration device of the containment enclosure of the reactor building. This absence of venting makes it possible to limit discharges outside the containment enclosure;
- to limit the risk of corium piercing the concrete of the base of the reactor building.

EDF made a commitment at the end of the instruction to set up systems for detecting and reinjecting the effluent present in the fuel building into the reactor building. EDF also plans to implement means to deal with an eventual loss of the so-called “ultimate” device for removing residual power from the containment, in a post-accident situation.

In order to further reduce the risk of discharges, ASN prescribes that EDF must have the means to inject an additional volume of borated water into the reactor building in the short term.

In order to reduce the releases of iodine in the gaseous phase from the contaminated water present in the containment of the reactor building during a serious accident as well as in the fuel building in the event of recirculation of this water, EDF is committed to putting specific measures in place.

ASN asks EDF to implement measures to limit the leaks of contaminated water outside the reactor building and the fuel building in the event of an accident leading to core meltdown, and to have the necessary resources allowing to reduce the contamination of the water present in the reactor building after an accident which led to the core meltdown. For each site, EDF must also, in order to limit the extent and duration of the contamination in the event of a contaminated water leak outside the buildings, study the means of limiting the dissemination outside the site of radioactive substances, by soil and groundwater.

The fourth periodic review was also an opportunity to reassess the probabilistic safety studies making it possible to assess the risk of releases into the environment in the event of an accident leading to core meltdown. This probabilistic insight made it possible to identify additional modifications to be implemented, which will improve the level of safety.

ASN underlines the very important work carried out by EDF on limiting the consequences of accidents with core meltdown and the very ambitious nature of the associated modification program. This program will allow major advances in terms of safety and meet the objectives set for this review.

*

At the end of the examination, EDF undertook to carry out most of the necessary additions that the ASN examination revealed. ASN prescribes [48] the implementation of the major safety improvements planned by EDF as well as certain additional measures that it considers necessary to achieve the objectives of the review.

Corium stabilization device

[AG-A] I.– The operator implements the technical devices for keeping the reactor pit dry, for spreading the corium on the bottom of the reactor pit and the adjacent room and for passive reflooding of the corium by the water, provided in response to the prescription [ECS-ND16] of the appendix to the decisions of January 21, 2014 referred to above, aimed at preventing the raft from piercing in the event of partial or total core meltdown.

II.– The operator:

1. send, no later than December 31, 2022, to the Nuclear Safety Authority a detailed draft allowing the thickening of the base of the reactor buildings whose concrete is very siliceous from 2025. This draft includes a radiation protection optimization study for workers;
2. transmits, no later than June 30, 2023, to the Nuclear Safety Authority the conclusions of its program for studying the behavior of slabs in an accident situation with core meltdown based on tests. On the same date, it took a position on the need to thicken the base of the reactor buildings, the concrete of which is very siliceous;
3. thickens the rafts requiring it.

III.– The operator reinforces the walls between the internal core instrumentation room (RIC) and the sump area at the bottom of the reactor building containment enclosure to prevent any risk caused by their piercing by the corium.

Evacuation of the residual heat outside the containment without venting

[AG-B] I.– The operator implements the ultimate device for removing residual power from the containment (EASu) and has the ultimate cold source (SFu), provided for in response to the third paragraph of III of the prescription [ECS-ND1] of the appendix to the aforementioned decisions of January 21, 2014, allowing the evacuation of the residual power outside the containment without opening the ventilation and filtration device.

II.– The operator:

1. defines, no later than December 31, 2022, the means for injecting in the short term into the reactor building a volume of borated water complementary to that contained in the tank of the water treatment and cooling system swimming pools (PTR) in order to ensure the evacuation of the residual heat from the containment during an accident with fuel melting. At the same time, it justifies the feasibility of injecting this volume of additional borated water, taking into account the requirements associated with the means selected and the borated water capacities available;
2. implements any necessary modifications.

III.– The licensee implements the means to deal with an eventual loss of the ultimate device for evacuating the residual power from the containment (EASu), in a post-accident situation.

IV.– The operator installs the necessary means to ensure the detection, collection and reinjection to the reactor building of any leaks from the ultimate device for removing residual power from the containment (EASu), including in a serious accident situation.

[AG-C] I.– The operator protects, with regard to internal attacks, the components of the “wide range” measurement chain of the containment pressure located in the main electrical rooms safety track B.

II.– The operator reinforces the ventilation and filtration system of the containment so that it remains operational after an increased safety earthquake (SMS).

Contaminated water management

[AG-D] I.– In order to reduce the risk of groundwater contamination after an accident leading to core meltdown, the operator implements the means to limit the leaks of contaminated water outside the building reactor and fuel building.

II.– The operator has the necessary means to reduce the contamination of the water present in the reactor building after an accident leading to the core meltdown and ensures that they are operational on site.

III.– In order to limit the extent and duration of water contamination in the environment in the event of contaminated water leaking outside buildings after an accident leading to core meltdown, the operator is studying the means of limit the dissemination of radioactive substances, through the soil and groundwater, outside the site.

It defines the possible measures to be implemented with regard to the challenges for safety and the associated schedule.

5.6 REASSESSMENT OF THE RADIOLOGICAL CONSEQUENCES OF ACCIDENTS

5.6.1 Assessment of the radiological consequences of accidents without core meltdown

5.6.1.1 Specific objectives of the review

EDF indicated in its orientation file for the fourth periodic review of 900 MWe reactors [23] that the approach it has set itself aims in particular to tend towards the absence of the need to implement safety measures. protection of the population in the short term for all design basis accidents in the safety report. This objective consists, during the so-called “short-term” phase of the accident, in remembering the absence of any need for shelter, evacuation of populations and administration of stable iodine.

Article D. 1333-84 of the Public Health Code sets benchmark dose values for the implementation of measures to protect the population in a radiological emergency:

- an effective dose of 10 mSv for sheltering; an
- effective dose of 50 mSv for evacuation;
- a thyroid equivalent dose of 50 mSv for administration of stable iodine.

ASN has considered [6] following the analysis of this guidance file that the general safety objective should also cover the limitation as far as reasonably possible of the consequences radiation in the short, medium and long terms, and this for all the accidents in the safety report.

With regard to the radiological consequences of the accident linked to the rupture of a tube of a generator, Category 4 steam (RTGV4), ASN, in the same letter, asked EDF to study ensuring that the modifications allowing the consequences of this accident to be significantly reduced so as to the cliff-edge solution that will ultimately be adopted is as robust as possible, in particular with regard to effect induced by the risk of water overflowing from the affected steam generator.

5.6.1.2 Summary of studies carried out and planned modifications

5.6.1.2.1 Dose limits considered

EDF has thus set itself the short-term objective of respecting the following values at 500 meters from the installation:

- for second category operating conditions, EDF checks the overall limit of 1 mSv / year for members of the public relating to normal operation of the installation;
- for third category operating conditions, EDF retains an effective dose of less than 10 mSv;
- for category 4 operating conditions, EDF retains an effective dose of less than 50 mSv.

The objective retained for the long term corresponds to an effective dose lower than one Sievert. This dose represents the effects of an accidental transient integrated over the life of an individual, which leads to consider the following four exposure routes: exposure to the radioactive plume, inhalation of the plume, exposure to deposits and ingestion of contaminated food.

Moreover, to meet the objective of " *tend towards the lack of implementation of measures to protect the population (sheltering, evacuation, administration of stable iodine [...]) for all design basis accidents, in the short term* », EDF studied realistic exposure scenarios, taking into account the real distance from

first dwellings [75]. The estimated doses for accidents of the third and fourth categories in the short term (24 hours and 7 days) are compared with the following values at the first homes:

- effective dose: 10 mSv;
- equivalent dose to the thyroid: 50 mSv.

For the "medium-term" phase, EDF has defined an intermediate objective of an effective dose over one year of less than 20 mSv beyond 2 km.

5.6.1.2.2 Results obtained

Concerning second category incidents, the doses evaluated by EDF at the level of the first dwellings are much lower than 1 mSv: the highest effective dose, ingestion included, is that which would be caused by the opening of a steam pipe valve. .

Concerning third-category accidents, the doses evaluated by EDF at 500 meters in the short term meet the objectives set and those at the level of the first dwellings do not require the implementation of means to protect the population.

Concerning the fourth category accidents, the accidents leading to the highest doses are the loss of primary refrigerant accident (APRP4) and the rupture of a steam generator tube (RTGV4). These accidents are detailed below.

Category 4 primary refrigerant loss accident (APRP4)

EDF indicates that the objectives in terms of radiological consequences expressed in terms of effective dose limits at 500 meters are respected for the accident involving the loss of category 4 primary coolant.

In addition, the objectives aiming to tend towards the absence of implementation of measures to protect the population in the short term and of an effective dose over one year of less than 20 mSv beyond 2 km are "generally respected". Indeed, EDF notes that the recommended benchmark value for the 7-day iodine intake has been exceeded for the reactors at the Bugey nuclear power plant.

Cumulative Steam Generator Tube Rupture Accident with a Category Four Stuck Open Valve (RTGV4)

The assessments of the radiological consequences of the fourth category accident of rupture of a cumulative steam generator tube with a valve stuck in the open position take into account the lowering, from 150 GBq / t to 100 GBq / t, of the threshold shutdown in iodine equivalent 131 (Eq.131I) in power transient of the radiochemical specifications of the water in the primary circuit.

EDF concludes that it has met its objectives in terms of radiological consequences expressed in terms of effective dose limits at 500 m for the RTGV4 accident.

However, the objectives aiming to tend towards the absence of implementation of measures to protect the population in the short term are not respected: the calculated doses would indeed require sheltering and the administration of stable iodine. . The effective dose over one year of less than 20 mSv beyond 2 km is respected.

EDF considers that it has fulfilled its objective of continuous improvement, due to the reduction in the radiological consequences of this accident.

At the end of the investigation, EDF undertook to further lower, for the last quarter of 2021, the stop threshold in iodine-131 equivalent in power transient of the radiochemical specifications of the water in the

[75] The first dwellings, except for the Bugey site, are more than 500 m away from the installations.

primary circuit at 80 GBq / t, on all of its reactors and to modify the control of the RTGV4 (safety injection control) in order to reduce the radiological consequences.

Complementary domain accidents

Concerning accidents in the complementary field, their radiological consequences are evaluated either on the basis of specific studies, or on the basis of arguments aimed at showing that they are covered by those of certain accidents in the dimensioning field.

The accident in the complementary area with the most significant radiological consequences is the accident of total failure of the safety injection and the spraying of the containment following a breach in the primary circuit, in terms of power and in the “AN / GV” or “AN / RRA” shutdown states. The radiological consequences of this accident are lower than those of the accident in the category 4 primary coolant loss dimensioning domain.

5.6.1.3 ASN's position on achieving the objectives of the review

ASN notes that the radiological consequences in categories 2 and 3 meet the objectives set and do not require measures to protect the population.

With regard to category 4, the rupture of a steam generator tube is the most at stake (RTGV).

Fourth Category Steam Generator Tube Rupture Accident (HSR 4)

The dose limit targets set by EDF at 500 meters for the fourth periodic review of 900 MWe reactors have been met.

However, the RTGV4 is the only accident which shows, on the basis of the hypotheses adopted, the need to implement means of protection of the population at the level of the first dwellings.

For technological reasons, the 900 MWe reactors stand out unfavorably in terms of the quantity of water released in RTGV4 and therefore of the radiological consequences associated with this accident compared to other EDF reactors. In its position on the guidelines for the fourth periodic review of 900 MWe reactors [6], ASN asked EDF to “ *study modifications to significantly reduce the radiological consequences of a RTGV accident so as to guarantee that the solution that will be finally adopted is as robust as possible, in particular with regard to the cliff-edge effect induced by the possibilities of overflow of the affected GV* ".

EDF adopted a material modification (increase in the discharge capacity of the turbine bypass unit to the atmosphere) in order to reduce the mass of water from the primary circuit discharged into the atmosphere during this accident on the 900 reactors. MWe (paragraph 5.3.1.3.5). At the end of the investigation, EDF proposed a lowering of the stop threshold in iodine equivalent 131 in power transient of the radiochemical specifications of the water in the primary circuit to 80 GBq / t as well as a modification of the pipe. RTGV4, which significantly reduces radiological discharges.

These points are the subject of the ASN [CR-A] prescription [48].

ASN notes that these modifications will limit the radiological consequences of the accidents studied in the safety report. This will significantly reduce the occurrence of situations leading to population protection measures. EDF will have to continue its efforts to reduce the radiological consequences of the steam generator tube rupture accident, which leads to the most significant radiological consequences.

Complementary domain accidents

ASN notes that the radiological consequences of accidents in the complementary field assessed by EDF for CPY type reactors comply with the objectives that EDF has set for itself in terms of dose limits and do not require the implementation of protection measures. population. For reactors

at the Bugey nuclear power plant, the values obtained are still below the values obtained for the category 4 primary coolant loss accident.

Overall reduction of radiological consequences

ASN notes that, in accordance with its request in reference [6], to limit as far as reasonably possible the radiological consequences of design basis accidents in the short, medium and long term, EDF used in its studies an approach aimed at identifying the main contributors to rejection and considered ways to reduce them.

5.6.2 Assessment of the radiological consequences of accidents linked to attacks

5.6.2.1 Specific objectives of the review

The assessment of the radiological consequences of attacks makes it possible to assess the facility's ability to fulfill its function of containing radioactive substances in the event of an attack.

The objective of the studies is to verify the acceptability of the radiological consequences of attacks of internal or external origin, having regard to the dose limits defined by EDF during the generic phase of the review and by comparing them with the dose limits defined for the Working conditions. In addition, beyond these limitation objectives, ASN asked EDF, (SUR request n ° 13 [6]), to justify that the radiological impact of accidents, in particular linked to attacks, is as low as reasonably possible.

5.6.2.2 Summary of studies carried out and planned modifications

5.6.2.2.1 Radiological consequences of attacks other than fire

The approach adopted by EDF to assess the radiological consequences consists of:

- identify, among the scenarios of attacks of internal or external origin that could induce radiological consequences, enveloping scenarios. Attacks for which there is no risk of radiological consequences due to the precautions taken when sizing buildings and systems are excluded;
- assess the radiological consequences of these envelope scenarios;
- assess the probability of occurrence of these scenarios when the radiological consequences are greater than 0.5 mSv[76] medium term (one year);
- compare the radiological consequences of these short-term scenarios (seven days) with the dose limits associated with the operating conditions of the dimensioning and complementary fields.

The medium-term doses calculated by EDF to assess the consequences of attacks other than fire are all less than 0.5 mSv with the exception of that calculated for the attack by projectiles generated by the wind on the Bugey site. estimated at 2.3 mSv.

For this last scenario, EDF estimates a frequency of occurrence corresponding to that of design basis accidents of the third category (between 10^{-2} and 10^{-4} per year and per reactor), and a short-term dose of less than 0.3 mSv. This value is lower than the dose limit objective in terms of radiological consequences for this category of accidents (10 mSv), which EDF considers acceptable.

[76] This dose limit corresponds to half of that provided for the annual exposure of the public to ionizing radiation in application of article R. 1333-11 of the public health code.

5.6.2.2.2 Radiological consequences of the fire

For the radiological consequences of fires, EDF uses a different method from that adopted for other attacks. EDF has thus developed a study of the risk associated with fire, which takes into account eight radionuclides and which determines, on the basis of models carried out using software, various short-term doses (an "inhalation" dose , a “plume” dose and a “depot” dose) for an adult located 500 meters away. This study concludes with a very low total dose, lower than the microsievert.

5.6.2.3 ASN's position on achieving the objectives of the review

ASN emphasizes the value of evaluations of the radiological consequences of attacks in order to assess the ability of the 900 MWe reactors to perform their function of confinement of radioactive substances.

ASN's comments on certain assumptions made for these assessments are not such as to call into question the achievement of the objectives set for this review.

With regard to fires, EDF plans to update its assessments of the radiological consequences when submitting the review conclusion report. Indeed, the evaluations presented at this stage do not completely meet the objectives set by the BNI order [1], in particular because the doses must be determined in the short, medium and long terms, for the different age groups and by considering all routes of exposure.

5.6.3 Assessment of the radiological consequences of core melt accidents

5.6.3.1 Specific objectives of the review

The reinforcements planned by EDF aim to limit releases in the event of a serious accident, make the risk of early and significant releases extremely unlikely and avoid lasting effects in the environment.

5.6.3.2 Summary of studies carried out and planned modifications

EDF assessed the radiological consequences associated with an accident with core meltdown without opening the U5 device. They are determined from a source term, evaluated on the basis of hypotheses on the release rates, the release kinetics of the various radionuclides, the leakage rates of the reactor building and of the peripheral buildings.

EDF concludes that the doses received by the population, assessed with the implementation of the EASu provision, show that it is not necessary to implement measures to protect evacuation populations beyond five kilometers and of stable iodine intake beyond ten kilometers.

The effective doses, excluding ingestion, calculated seven days and one year after the accident are less than 20 mSv at a distance of three kilometers from the discharge, downwind of the damaged reactor.

5.6.3.3 ASN's position on achieving the objectives of the review

The results of the radiological consequences confirm that the implementation of the EASu arrangement without opening the U5 device provides a significant safety gain with regard to discharges outside the installation, making it possible to limit the doses received by the population outside of the installation. beyond 24 hours.

Coverage area

The assessments of the radiological consequences of severe accidents presented in the safety report correspond to situations of limited releases, associated with situations of core meltdown without opening the U5 device, knowing that releases with opening of the U5 device are significantly higher.

The level 2 probabilistic safety study shows that the proportion of filtered late releases, with opening of the U5 device, constitutes approximately 18% of the total frequency of releases.

As the discharges occurring following severe accident situations with opening of the U5 device are not negligible, both in terms of their frequency and their intensity, EDF has undertaken to present the radiological consequences in a severe accident situation with and without opening the U5 system in the safety report for 900 MWe reactors at the end of phase B of deployment of the modifications associated with the fourth periodic review.

Amount of different chemical forms of iodine

For certain severe accident scenarios, with the implementation of the EASu provision without opening the U5 device, the quantities of the various chemical forms of iodine present in the containment and which can be mobilized for releases into the atmosphere of containment system differ significantly between EDF's and IRSN's assessments. ASN considers that the assessment presented by EDF underestimates the quantities of iodine that can be mobilized in the atmosphere of the containment and in the atmosphere of the fuel building. As a result, ASN considers that EDF must seek and put in place measures to significantly reduce, in the event of a serious accident,

This point is the subject of the ASN [CR-B] prescription [48].

5.6.4 Summary and prescriptions relating to the radiological consequences of accidents

The modifications planned by EDF will make it possible to limit the radiological consequences of the accidents studied in the safety report. This will significantly reduce the occurrence of situations with the implementation of population protection measures.

In particular, EDF has planned to carry out modifications in order to limit the quantity of radioactive liquid water discharged into the environment in the event of a tube rupture accident of a fourth category steam generator (RTGV4). This accident has the most significant radiological consequences and EDF must continue its efforts to further reduce them.

ASN considers that the measures provided for by EDF, supplemented by the responses to the prescriptions formulated by ASN, will enable the objectives of the review to be achieved by limiting the radiological consequences of accidents without core meltdown, including in the event of an attack , which will significantly reduce the occurrence of situations with the implementation of population protection measures, as well as significantly reducing releases into the environment during accidents leading to core meltdown .

*

At the end of the examination, EDF undertook to carry out most of the necessary additions that the ASN examination revealed. ASN prescribes [48] the implementation of the major safety improvements planned by EDF as well as certain additional measures that it considers necessary to achieve the objectives of the review.

Reduction of the radiological consequences of the tube rupture accident of a fourth category steam generator

[CR-A] I.– No later than June 30, 2022, the licensee lowers the equivalent iodine limit authorized in power transients by the radiochemical specifications of the water in the primary circuit.

II.– The operator is implementing the modifications that he has planned to reduce the radiological consequences of the accident involving the rupture of a fourth category steam generator tube:

1. the modification aimed at increasing the discharge capacity of the turbine bypass unit to atmosphere in order to increase the cooling rate of the primary circuit and to reach the fallback state more quickly;
2. the modification of the high pressure safety injection line for this accident.

Reduction of gas phase iodine releases from contaminated water

[CR-B] The operator is implementing measures to significantly reduce, during a serious accident, the releases of iodine in the gaseous phase from the contaminated water present in the containment of the reactor building as well as in the fuel building in case of recirculation of this water.

5.7 RE-EVALUATION OF PROBABILISTIC SAFETY STUDIES

Probabilistic safety studies (EPS) shed additional light on the demonstration of deterministic safety. They help to assess the safety of reactors by quantifying the frequency of scenarios leading, for so-called “level 1” PSAs, to core meltdown and, for so-called “level 2” PSAs, to significant radioactive releases. These studies make it possible, in particular, to identify the importance of certain equipment, the risks associated with certain families of events and the need for modifications. They provide elements of assessment to decide on the relevance of the implementation of additional measures aimed at limiting the risk of core meltdown or discharges. They also make it possible to update the list of so-called “additional” provisions (see paragraph 5.3.2).

As part of the fourth periodic review of 900 MWe reactors, EDF updated its level 1 PSAs, in particular by improving the modeling of the support systems necessary for the operation of equipment important to safety, such as, for example, the ventilation systems which provide thermal conditioning of the premises.

Since the previous review, EDF has greatly extended the scope of its probabilistic studies and some of them were developed for the first time as part of the fourth periodic review of 900 MWe reactors. This is the case for probabilistic studies relating to the explosion of internal origin, to the flood of external origin (EPS level 1), to the fire, to the flood of internal origin and to the earthquake (EPS levels 1 and 2). EDF also presented for this review probabilistic analyzes relating to so-called long-term scenarios, as well as to the dependencies between two reactors on the same site, in situations where they would be affected by the same initiator.

The results and lessons learned from the level 1 and 2 PSAs carried out for the reactors at the Bugey nuclear power plant are, in general, similar to those obtained for the 900 MWe CPY type reactors. They lead to the same positions and requests from ASN.

5.7.1 PSE level 1

5.7.1.1 Specific objectives of the review

The objectives defined in the guidelines for the review [23] relate to:

- extending the scope of the study to the risks associated with the fuel storage pool, with the aim of making the discovery of the fuel assemblies extremely improbable;
- the development of level 1 and 2 PSAs associated with risks linked to attacks of internal (fire, explosion, flood) and external (earthquake, flood) origin;
- carrying out a specific analysis of loss scenarios for long-term electrical sources.

For level 1 PSE, the following objectives are retained:

- aim for an overall frequency of core meltdown, including attacks, less than a few 10^{-5} per year and per reactor;
- return the discovery of fuel assemblies in swimming pools, during an emptying accidental or loss of cooling, extremely unlikely.

5.7.1.2 Summary of studies carried out and modifications identified

5.7.1.2.1 Level 1 EPS associated with internal events affecting the reactor

Level 1 EPS associated with internal events[77] affecting the reactor conclude a risk of core meltdown of 3.3.10-6 per year and per reactor for CPY type reactors and 5.0.10-6 for the reactors of the Bugey nuclear power plant.

These values take into account the modifications identified by EDF, during the performance of these EPS, as necessary (such as, for example, the modification of the electrical supply of the fans of the electrical rooms in order to ensure their supply in the event of a fault. 'an electrical panel) and modifications associated with the re-examination deployed in phase A (such as, for example, the resupply of the "hard core" equipment by the ultimate backup diesel). Taking these modifications into account allows a 28% reduction in the risk of core meltdown compared to the condition taken into account at the start of the review (status corresponding to the third periodic review of the 900 MWe reactors).

The level 1 PSA highlights the importance of the electrical systems of 900 MWe reactors, the failures of which carry more than 45% of the risk of core meltdown for internal events.

5.7.1.2.2 Level 1 PSAs associated with internal events affecting the fuel storage pool

EDF carried out PSAs relating to internal events aimed at assessing the risks of uncovering fuel assemblies stored in the swimming pool for scenarios of accidental emptying of the swimming pool and loss of cooling.

These studies do not include the modifications associated with the storage pool carried out as part of the fourth periodic review of the 900 MWe reactors. They also do not incorporate most of the modifications resulting from the additional safety assessments, in particular the modifications associated with the installation of a new cooling system (PTR bis), of the ultimate water make-up and of diesel fuel. ultimate help.

These studies conclude, for CPY type reactors or the Bugey nuclear power plant, at a risk of fuel assemblies being exposed:

- 5.3.10-8 per year and per reactor, for scenarios of loss of cooling of the storage pool;
- 3,7.10-9 per year and per reactor, for assemblies being handled for scenarios of accidental emptying of the storage pool;
- 1,2.10-9 per year and per reactor, for assemblies stored for accidental emptying scenarios of the storage pool.

During the appraisal, EDF upgraded certain additional existing provisions, which enabled it to reduce the risk of uncovering assemblies stored or being handled in the storage pool at 1.3.10-8 per year and per reactor.

EDF concludes that these results are in line with the objective of making the discovery of fuel assemblies stored in swimming pools extremely unlikely, even without valuing all the measures decided in the context of the review, including the PTR bis provision.

5.7.1.2.3 Level 1 PSE associated with assault

In accordance with the guidelines of the review, EDF has greatly extended the scope of its probabilistic studies. Thus, certain level 1 EPS were developed by EDF for the first time for operating reactors: an EPS relating to the risk of internal explosion, a complete EPS

[77] Events caused by a failure of a component of the installation or human error.

relating to the risk of earthquakes, as well as probabilistic analyzes relating to the risks of flooding of external origin.

The probabilities of core meltdown and discovery of fuel assemblies in the storage pool obtained in the level 1 PSAs associated with the attacks must be considered as indicative, since they are, for most of the attacks, of a first exercise.

With the exception of the earthquake and the flood of external origin, the level 1 EPS associated with the attacks lead to core melting frequencies of the order of a few 10^{-6} per year and per reactor, taking into account the implementation of the modifications identified during the performance of these EPS or planned for the deployment of the "hard core". In addition, the level 1 EPS associated with attacks lead to frequencies of discovery of fuel assemblies in the storage pool of the order of a few 10^{-8} per year and per reactor.

For the flooding of external origin, the study of which was carried out at this stage for the sites of Tricastin, Bugey, Gravelines and Saint-Laurent-des-Eaux, the values obtained are, for the risk of melting of the heart, between 10^{-6} and 10^{-5} per year and per reactor and are negligible for the risk of exposed fuel assemblies in the storage pool.

For the earthquake, the study of which was carried out at this stage only for the Tricastin and Bugey sites, the values obtained are, for the risk of core meltdown, of the order of 10^{-5} per year and per reactor. However, the risk of core meltdown corresponding to seismic acceleration levels less than or equal to the “hard core earthquake” represents only 15% of the overall risk, which shows the robustness of the installation for these earthquake levels. For the risk of uncovering the fuel assemblies in the storage pool, the values obtained are of the order of a few 10^{-6} per year and per reactor; for the swimming pool, the risk associated with earthquakes at levels lower than the “hard core earthquake” represents only 3% of the overall risk.

The performance of the EPS relating to attacks led EDF to identify additional modification needs, including in particular: the installation of hydrogen detectors in the battery charging rooms, the reliability of certain measures adopted in the event of an attack (for example, modification of the control-command of the pressurizer valves in order to avoid sending an untimely opening order in the event of fire, protection by wrapping of several cables necessary for the control of the turbopump of the system. emergency power supply to the steam generator, reinforcement of the fuel oil tarpaulins for the emergency generator sets of each reactor with regard to the earthquake, installation of floor drains in certain rooms of the electrical panels).

Finally, for certain attacks, EDF has made use of the “hard core” provisions in order to achieve the objectives associated with the fourth periodic review.

5.7.1.3 ASN's position on achieving the objectives of the review

At the end of its examination, and the consultation of the permanent group of experts for nuclear reactors (GPR), ASN gives a positive assessment of the methodological and scope changes made by EDF to the PSAs as part of the fourth periodic review. 900 MWe reactors.

The probabilities, for internal events, of core meltdown and discovery of fuel assemblies are acceptable in view of the safety objective set for this periodic review [6]. These EPS show that, from a probabilistic point of view, the risks associated with the reactor and the fuel storage pool are acceptable, taking into account the modifications that will be implemented.

ASN points out that a deviation from conformity affects the isolation device for the return line of seals no. 1 of the primary pumps. This discrepancy calls into question the objective of making a scenario that could lead to the core meltdown with a containment bypass extremely unlikely. ASN asked EDF [32] to process it within the time limits provided for in ASN guide no. 21 [87].

ASN notes that the PSAs relating to the reactor and the fuel storage pool, developed by EDF separately, do not make it possible to assess the impact, on the risks thus assessed, of the dependencies existing between certain means used to manage accidents, on the one hand for the reactor, on the other hand for the fuel storage pool. EDF has undertaken, at the end of phase B of the deployment of the modifications associated with the fourth review, to analyze the accident scenarios affecting both the reactor and the swimming pool, taking into account their impact on the equipment and human actions recovered, which is satisfactory. Likewise, EDF has undertaken to complete the list of situations likely to lead to a risk of fuel melting in the swimming pool,

Concerning the level 1 PSAs relating to the attacks carried out for the first time by EDF, ASN considers that they constitute a significant advance for safety. The implementation of the modifications planned by EDF following these EPS will improve the safety of the installations.

ASN also considers that, for certain EPS relating to attacks, further studies are necessary from EDF. These points are developed in the paragraphs dedicated to these attacks.

5.7.2 PSE level 2

5.7.2.1 Specific objectives of the review

Level 2 EPS are used in addition to level 1 EPS and aim, in the event of a sequence leading to core meltdown, to assess the risk of releases into the environment by bypass of containment or by releases filtered afterwards. decompression of the enclosure. The purpose of these studies is to identify the sequences leading to the most significant releases in order to reduce the frequency of these sequences or to deploy measures to limit these releases.

Level 2 PSAs are also used to verify the objective of making the risks of early releases extremely improbable, that is to say not allowing the implementation of population protection measures, and significant.

5.7.2.2 Summary of studies carried out

The level 2 EPS presented by EDF covers all of the internal initiating events affecting the reactor and leading to core meltdown and the internal initiators affecting the storage pool and leading to the discovery of the fuel assemblies.

For each of the sequences leading to the core meltdown, including following attacks linked to a fire, internal flooding and an earthquake, EDF assessed the risk of radioactive releases into the environment. EDF has classified the different types of discharges into seven categories, according to their consequences on the environment:

- releases in the form of gases and aerosols into the air:
    - R1 - significant early releases: all the scenarios leading to a clear rupture or a bypass of the enclosure before 24 hours,
    - R2 - significant late releases: all the scenarios leading to a containment rupture after 24 hours following its slow pressurization (due to the failure of the opening of the ultimate venting device of the enclosure called the filter U5),
    - R3 - filtered late rejections: all scenarios with implementation of the U5 filter,
    - R4 - limited discharges: all the scenarios for which confinement (enclosure, raft) is maintained,
    - RD - limited releases of an order of magnitude similar to design basis accidents (scenarios without core meltdown);

- releases by soil:
    - RP - pierced foundation raft: all the scenarios leading to the opening of the vessel through the molten core (corium) then to the opening of the final foundation raft,
    - IR - integrated raft: all the scenarios leading to the maintenance of the core in the tank or its spreading out on the raft and its cooling maintained by the ultimate device for evacuating the residual power from the containment (EASu).

The sequences leading to the discovery of the fuel assemblies in the storage pool are directly associated with type R1 and RP releases.

The results presented below for the level 2 PSA carried out by EDF for internal events are representative of 900 MWe CPY type reactors, after deployment of the modifications in phase A. However, these studies do not take into account driving and material modifications defined at the end of the serious accident investigation. The level 2 PSAs associated with internal events lead to the results presented in Figure 1.

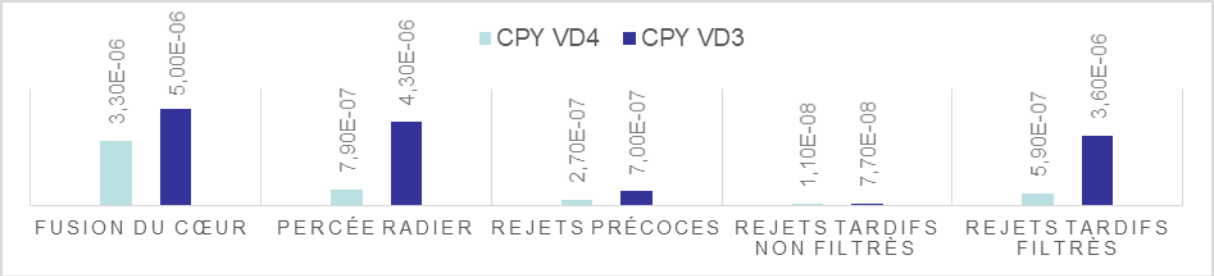

Figure 1: Risk of releases into the environment following an internal event (EDF assessments)

The values obtained for the reactors at the Bugey nuclear power plant are similar.

The level 2 EPS associated with attacks of internal origin lead to the results presented in Figure 2.

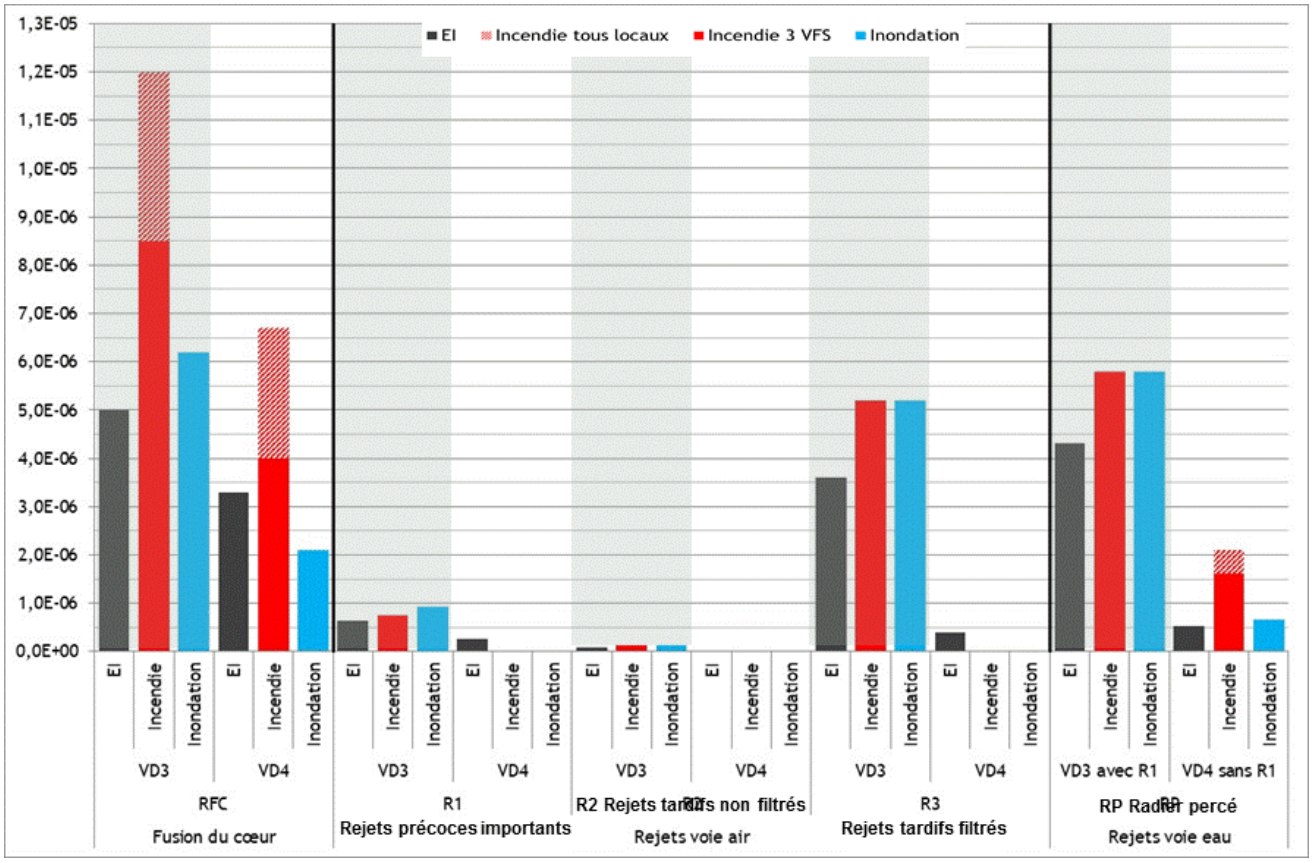

Figure 2: Risk of releases into the environment in the event of internal damage (EDF assessments)

EDF concludes that these results are in line with the objectives selected for the review. The level 2 EPS did not lead EDF to adopt additional modifications.

EDF transmitted, in the course of 2020, an assessment of the frequencies in the event of fire or flooding of internal origin, significant early overhead discharges and a new assessment of the risk of opening the raft (with valuation of an operating modification) . In the end, the values obtained are:

- for the fire, 2,8.10-7 per year and per reactor for “R1” and 7,0.10- discharges7 per year and per reactor for “RP” releases; for the flood, 1.1.10-7 per year and per reactor for “R1” and 2.4.10-
- discharges7 per year and per reactor for “RP” releases.

5.7.2.3 ASN's position on achieving the objectives of the review

At the end of its investigation and the consultation of the permanent group of experts for nuclear reactors (GPR), ASN gives a positive assessment of the results of the level 2 PSAs presented by EDF for the fourth periodic review of the 900 reactors. MWe. These EPS show the significant contribution of the material and conduct modifications planned during the review in the reduction of the risks of releases into the environment, such as for example the reduction of more than 60% of the frequencies of early and significant releases associated with internal events. .

ASN notes that the risk of the raft breakthrough still remains relatively high despite the deployment of the modifications. A significant part of this risk results from the failures of the EASu system, which has the task of cooling the corium when it is spread on the raft of the reactor building, after an accident with core meltdown and vessel breakthrough. Modifications contributing to limiting the risk of failure of this function are detailed in the paragraph relating to severe accidents (see paragraph 5.5).

ASN has also made requests for changes to the methodology or scope of level 2 PSAs, which must be taken into account in the context of future periodic reviews.

The level 2 PSAs relating to fire and internal flooding highlight the need for new measures, in particular to reduce the risk of the raft breaking through. EDF has undertaken to carry out one of the necessary modifications and ASN has prescribed one modification relating to the protection of the “wide range” measurement chain of the containment pressure [49]. This point is detailed in the paragraphs relating to assaults.

5.8 PROVISIONS AFTER THE FUKUSHIMA DAIICHI NUCLEAR POWER PLANT ACCIDENT

5.8.1 Context reminder

5.8.1.1 Decisions taken following additional safety assessments

Following the accident at the Fukushima Daiichi nuclear power plant, ASN adopted a set of decisions dated 5 May 2011 asking the operators of major nuclear installations to carry out additional safety assessments. The conclusions of these assessments were the subject of an ASN position on January 3, 2012, as well as a review by European peers, in April 2012, as part of the European stress tests. On the basis of the opinion of the permanent expert groups and the conclusions of the European stress tests, ASN took a set of decisions dated June 26, 2012 asking EDF to put in place:

- a set of corrective actions or improvements, in particular the acquisition of additional means of communication and radiological protection, the installation of additional instrumentation, the taking into account of risks of internal or external damage to the extended manner and the strengthening of the consideration of emergency situations;

- a nuclear rapid action force (FARN) making it possible, on the basis of mobile resources outside the site, to intervene on a nuclear site in a pre-accident or accident situation;
- a "hard core" of material and organizational measures aimed, in the event of extreme aggression of external origin, at:
    - prevent an accident with fuel melting or limit its progression,
    - limit massive radioactive releases,
    - allow the operator to carry out the missions incumbent on him in the management of an emergency situation.

ASN supplemented its requests with a set of decisions dated January 21, 2014 aimed at specifying certain design provisions for the "hard core", in particular, the definition and justification of the levels of extreme natural attacks of external origin. to remember for the "hard core".

In general, ASN's requests are also part of a process of continuous improvement of safety with regard to the objectives set for third-generation reactors, and aim, in addition, to cope with very dangerous situations. - beyond the situations hitherto retained for this type of installation.

These requests relate to measures to prevent and limit the consequences of an accident that could affect several installations. These additional measures consist of fixed means and mobile means provided for all the installations on a site.

Given the nature of the requests, the operator must carry out studies on the design, construction and installation of new equipment which require, on the one hand, deadlines and, on the other hand, planning. for their optimal installation on each of the reactors. In fact, insofar as this important work takes place on operating nuclear sites, it is also necessary to ensure that their performance does not degrade the safety of nuclear power plants.

Deployment of the "hard core" on all 900 MWe reactors is governed by the ASN [ND-C] prescription [48].

5.8.1.2 Improvements implemented by EDF upstream of the fourth periodic review of the 900 MWe reactors

In 2015, EDF completed the implementation of temporary or mobile measures aimed at strengthening the management of situations of total loss of the heat sink or loss of electrical power supplies. In particular, connection means have been installed so that, in the event of a crisis, it is possible to connect mobile means to provide water. In addition, the nuclear rapid action force (FARN), which is one of the main means of crisis management, has been set up. Since 1 er January 2016, the FARN teams have the capacity to intervene simultaneously on all the reactors of a site in less than 24 hours [78] (up to six reactors in the case of the Gravelines site).

EDF has also initiated the implementation of certain definitive means of design and robust organization vis-à-vis extreme attacks aimed at dealing with situations of total loss of the cold source or loss of electrical power supplies to beyond the safety standards in force and accidents with core meltdown. The most important measures are:

- the installation of a high-power emergency diesel requiring the construction of a dedicated building. All 32 diesels of ultimate help for the 900 MWe reactors have been put into service by EDF;
- the establishment of an ultimate water source. EDF has initiated the installation of these water sources and expects work to be completed at the end of 2021, except for the sites of Bugey, Blayais, Chinon, Gravelines, Saint-Laurent-des-Eaux and Dampierre-en -Burly for which EDF is aiming for full completion of works in 2022. For these latter sites, EDF plans to deploy transitional means by the end of 2021 to supplement the water sources;
- the construction on each site of a local crisis center capable of withstanding extreme attacks of external origin (functionally autonomous in a crisis situation). EDF commissioned the local crisis center at the Flamanville site in 2020. For sites with 900 MWe reactors, EDF expects work to be completed between 2022 and 2024.

5.8.1.3 Measures planned by EDF as part of the fourth periodic review of 900 MWe reactors

The provisions presented in the previous paragraph will be completed for the 900 MWe reactors during their fourth periodic review by the implementation of the "hard core".

The most important measures are:

- the addition of a new booster pump to the primary circuit, called “EASu pump”;
- the implementation of an ultimate cooling arrangement for the containment, called “EASu”;
- the completion of the fixed circuits of the emergency water supply to the steam generators;
- the installation of a water make-up circuit for the fuel storage pools and a pool cooling circuit which is partly based on mobile means;
- the establishment of an ultimate instrumentation and control system and the final instrumentation of the "hard core";
- the implementation of measures aimed at stabilizing the corium on the raft foundation, in the event of an accident with core meltdown and vessel breakthrough.

[78] In the event of extreme aggression, EDF retains in its studies deadlines exceeding 24 hours for carrying out certain actions in a very degraded situation, such as connecting the exchanger of the new EASu system to the cold water source (known as the source ultimate cold).

ASN has adopted a position in paragraph 5.2 on the types of attack to be used for checking the strength of the "hard core", in paragraph 5.4 on the arrangements for cooling the fuel storage pool and in paragraph 5.5 on the measures planned by EDF concerning the ultimate cooling of the containment and the stabilization of the corium on the raft in the event of an accident with core meltdown in a “hard core situation”.

The “hard core situations” are made up of the following situations, as well as situations resulting from their accumulations:

- the total loss of power supplies not belonging to the "hard core"; the total
- loss of the cold source not belonging to the "hard core"; the external
- aggressions retained for the "hard core";
- situations resulting from the state of the installation, the site and its environment after one or more external attacks selected for the "hard core".

This chapter supplements these ASN positions. It successively addresses the solutions adopted by EDF concerning:

- means for injecting borated water into the primary circuit;
- the arrangements made to ensure heat removal by the steam generators;
- ultimate control and electrical distribution of the "hard core";
- the ability of teams to manage extreme situations.

5.8.2 Means for injecting borated water into the primary circuit

5.8.2.1 Specific safety objectives set for the injection of borated water

Following additional safety assessments, ASN asked EDF to put in place a “hard core” of measures to manage extreme situations [5]. The strategy envisaged by EDF is based on:

- the complete fall of the control rods in the reactor core, which makes it possible to stop the chain reaction;
- rapid cooling of the main primary circuit and its depressurization by opening a discharge line from the pressurizer, to allow the injection of borated water by the accumulators of the safety injection system RIS then by the EASu pump.

The information transmitted by EDF did not allow us to demonstrate the complete fall of the control clusters following a “hard core earthquake”. Given the complexity of the phenomena involved, ASN asked EDF to carry out studies to provide a reasonable assurance of control of reactivity in “hard core situations” (A4 request from [65]) . ASN thus asked EDF:

- to propose a reasonably enveloping configuration corresponding to the absence of fall of one or more control clusters in the same zone of the heart, including the blocking outside the heart of the most anti-reactive cluster;
- to present the management strategy making it possible to demonstrate the sub-criticality of the core in this configuration by identifying, if applicable, any modifications associated with this strategy and the associated deployment schedule. For these studies, ASN asked EDF not to evaluate the temporary decrease in the reactivity of the core due to the increase in the xenon concentration.[79], such valuation constraining the operator's time limits for action.

[79] The xenon isotope 135 has a very strong neutron absorption capacity. After the automatic shutdown of the reactor, the xenon concentration initially increases, which is a favorable effect for controlling the reactivity.

Finally, to improve control of reactivity, ASN asked EDF to study the possibilities of injecting borated water in “hard core situations” while the pressure in the primary circuit is high, thus allowing to ensure a supply of anti-reactivity from the start of the transient and to compensate for the effects of a possible blocking of clusters.

5.8.2.2 Summary of studies carried out and modifications planned by EDF

In response to ASN's requests, EDF adopted as the reasonably envelope configuration of cluster blocking the case corresponding to all the inserted clusters, except the most anti-reactive cluster blocked outside the core and two adjacent clusters blocked at the top of the constriction. For this configuration, EDF has valued the anti-reactivity provided by the increase in the concentration of xenon in the core. With this favorable hypothesis, the results obtained by EDF show that the maintenance of the sub-criticality of the core cannot be guaranteed, for the reactors of the Bugey nuclear power plant, throughout the “hard core pipeline”, and that therefore, there would be a return to a low power level. EDF considers that the secondary circuit is able to evacuate this return to power following a resumption of the chain reaction:

In the event that the anti-reactivity provided by the increase in the concentration of xenon in the core is not valued, the results obtained by EDF show that the maintenance of the sub-criticality of the core cannot be guaranteed, that this is for the reactors of the Bugey nuclear power plant, or for the CPY type reactors throughout the "hard core pipeline".

For the Bugey reactors, EDF has decided to add several shutdown clusters, which will provide additional anti-reactivity, however, not covering the needs to maintain the sub-criticality of the core throughout the "hard core pipeline. », In the cluster blocking configuration studied.

Finally, EDF studied various possible modifications to the 900 MWe reactors in order to inject boron into the primary circuit at high pressure in a “hard core situation” and decided to integrate, in the “hard core” of each reactor of 900 MWe, an injection back-up at the joints of the motor-driven pumps of the primary circuit allowing boron to be injected at the start of the "hard-core pipe".

5.8.2.3 ASN's position on achieving the objectives of the review

At the end of the investigation, ASN considers the cluster blocking configuration adopted by EDF in its study to be acceptable: blocking of the most anti-reactive cluster outside the core and of two adjacent clusters at the top of the constriction.

ASN considers that EDF's “hard core line” must not lead to a return to power for this cluster blocking configuration. In addition, ASN considers that valuing the increase in anti-reactivity temporarily provided by xenon restricts the operator's response times too much, whereas, in very degraded situations such as “hard core situations” , on the contrary, a certain adaptability must be sought.

EDF has decided to modify its facilities in order to be able to inject boron into the core at the start of the “hard core pipe”, when the primary circuit is still at high pressure. This modification will make it possible to ensure “hard-core driving” without reverting to power and without enhancing the increase in anti-reactivity provided temporarily by the xenon, which is satisfactory. It will also improve the management of certain situations in the complementary domain.

In view of the stakes, ASN supervises the deployment of this modification by prescription [ND-B] [48].

5.8.3 Heat removal by steam generators

During normal reactor operation, the feed water flow regulation circuit (ARE) extracts, via the steam generators, the heat from the water in the primary circuit, producing steam which is then transmitted to the turbine. . The water that feeds the steam generators comes from the condensation of this steam, after it has passed through the turbine.

In an accident situation, the emergency water supply circuit for the steam generators (ASG) allows water to be injected into the steam generators, thanks to pumps which draw water from a tank called "ASG tank" . These are two motor pumps, electrically backed up by the diesels, each providing the necessary "half-flow", as well as a "full-flow" turbopump driven by a steam turbine supplied directly by the steam coming out of the pumps. steam generators.

5.8.3.1 Specific safety objectives

The prescription [ECS-ND1] of the ASN decisions of January 21, 2014 provides that " *for the cooling of the core and the evacuation of the residual power out of the containment of the reactor building when the primary circuit is pressurizable, the hard core allows control strategies favoring cooling by the secondary circuits while maintaining integrity of the main primary circuit* ".

In addition, the prescription [ECS-1] of the ASN decisions of June 26, 2012 provides that, for the "hard core", " *the operator sets up independent and diversified systems, structures and components (SSC) in relation to existing SSCs in order to limit common mode risks* " and " *the operator justifies the use of non-diversified or existing SSCs, if applicable* ".

For the emergency water supply to steam generators (ASG) in a “hard core situation”, EDF decided in 2018 to modify and strengthen the existing ASG system, rather than setting up an independent and diversified system in relation to to existing equipment. In April 2019, ASN asked EDF on this subject to: “[...] *to justify [...] that the lack of diversification of the emergency water supply to the steam generators is acceptable from the point of view of the reliability of this function in each situation where it is valued* "And present" *the analysis of the risks associated with the absence of geographical separation between the different equipment performing this function "[65].*

5.8.3.2 Summary of studies carried out and modifications planned by EDF

EDF has programmed, in phase B of the deployment of the modifications resulting from the review, a modification entitled “ASG hard core”. The purpose of this modification is to allow the residual power to be evacuated by the secondary circuit in situations of total loss of the cold source and total loss of electrical power supplies, following extreme attacks of external origin. To do this, EDF plans to:

- to reinforce the ASG tarpaulin in order to make it robust against “hard core earthquakes”;
- to set up an ultimate back-up valve, allowing, among other things, to replenish the ASG tank by the ultimate water source;
- to create a new automatic start signal for ASG independent of existing signals, representative of the degradation of the water inventory of steam generators, integrated into the "hard core" instrumentation and control system;
- set up a high-voltage source inverter to allow the emergency diesel power-driven pump to supply the emergency water to the steam generators (ASG) on track B automatically, by means of the emergency diesel;
- to replace certain components of the ASG track B motor pump (rotor shaft, pump / motor coupling and suction flange) and to equip this pump with a self-lubricated bearing system;

- to set up an electrical supply, by the emergency diesel, of a ventilator blower (channel B) of the DVG thermal conditioning system for the room housing the ASG motor pumps.

EDF further indicates that " *In general, the existing equipment upgraded and the modifications made to the installation will be robust to extreme natural aggressions: "hard core" earthquake, flooding and related phenomena (wind, lightning, hail, tornado) and their induced effects on installation* ".

In order to justify its choice to use an existing ASG motor pump for the "hard core", EDF presented assessments of the impact that the addition of a diversified ASG motor pump with its dedicated cover would have had on the frequency core melt for CPY type reactors. EDF concludes that the addition of a new motor pump would have led to a reduction of around 15% in the frequency of core melt associated with internal events and of around 10% in the frequency of core melt associated with fires in internal origin. EDF presented similar information concerning the impact that the addition of a diversified ASG motor pump would have had on the core melt frequency for the reactors at the Bugey nuclear power plant.

5.8.3.3 ASN's position on achieving the objectives of the review

Taking into account the information provided by EDF during the examination, ASN considers that the ASG "hard core" modification should provide sufficient diversification of the means making it possible to ensure the cooling function by the steam generators in emergency situations. total loss of the cold source and total loss of electrical power supplies, following extreme attacks of external origin, compared to currently existing means.

ASN nonetheless considers that EDF will have to demonstrate that the new components introduced during the modification relating to the "hard core" ASG, in particular the new components introduced on the ASG motor pump on channel B and the new source changeover switch at high tension, do not undermine the current ASG. EDF is committed to providing this demonstration before July 2021.

ASN underlines the importance of the modification relating to the "hard core" ASG in order to allow the residual power to be removed by the secondary circuit in situations of total loss of the cold source and total loss of the electrical power supplies. , following extreme attacks of external origin. Furthermore, this modification is also essential to make it possible to manage the consequences of a core meltdown in a "hard core situation", before the connection of the EASu mobile cold source by the FARN (see paragraph 5.5). EDF will therefore have to deploy this modification during the fourth periodic review of the 900 MWe reactors, taking into account the request mentioned above.

Given the stakes, the deployment of the "hard core" ASG is the subject of the prescription [ND-A] [48].

5.8.4 Ultimate instrumentation and control and electrical distribution

5.8.4.1 Specific safety objectives

The principles of design and use of electrical distribution and "hard core" instrumentation and control must make it possible to meet the safety requirements mentioned in the ASN decisions:

- " *for this hard core, the operator sets up independent and diversified [systems, structures and components] compared to existing [systems, structures and components] in order to limit common mode risks. The operator justifies the use of undiversified or existing [systems, structures and components], if applicable.* »(III of the prescription [ECS-1] [3]);

- " *the hard core comprises an instrumentation and control system and an electrical distribution that are as independent as possible of the means existing on the date when the additional safety assessments imposed by the aforementioned decision of 5 May 2011 were initiated, except in cases where this independence is a source of lower reliability of the hard core* "(Prescription [ECS-ND4] [5]).

The design of the instrumentation and control system and the “hard core” electrical supply must make it possible both to control and supply the new “hard core” actuators and sensors, but also the “hard core” actuators and sensors. hard core ”existing, currently controlled and supplied by an existing instrumentation and control system and electrical sources.

5.8.4.2 Summary of studies carried out and modifications planned by EDF

Control-command of the "hard core"

The "hard core" instrumentation and control system includes a part that interacts with the existing equipment of the installation, based on the use of conventional technology based on relaying, and a digital PLC dedicated to diesel control and monitoring. of ultimate help.

To prevent the risk of failure by common mode on the two existing instrumentation and control channels and the “hard core” instrumentation and control, EDF has planned to carry out the monitoring and control of the existing “hard core” actuators using, part, the existing instrumentation and control of these actuators if it is robust to extreme aggressions and their induced effects. This choice makes it possible to limit the complexity of the design.

EDF considers that the relaying technologies retained for most of the “hard core” instrumentation and control, which are particularly simple, do not call for any need for technological diversification and are used, in France and abroad, without making any changes. subject of such a provision. In addition, the digital automaton, which controls the ultimate backup diesel, is technologically diversified compared to the existing instrumentation and control, produced in relay technology.

Electrical distribution of the "hard core"

The existing equipment belonging to the "hard core" must be able to be supplied by the existing electrical distribution for situations that can be managed without the "hard core" and by the electrical distribution of the "hard core" in "hard core situation".

EDF has chosen to supply the new equipment with high voltage from the “hard core” from a new switchboard supplied by emergency diesel, present in the same building as the latter. The existing ASG-ND pump is also powered by emergency diesel, in a “hard core situation”.

For “hard core” equipment supplied with low voltage, it is not possible to have a dedicated electrical distribution with regard to the number of actuators to be powered and the size of the electrical rooms. As a result, EDF has used for the “hard core” existing electrical distribution equipment belonging to track A or to track B, supplied by emergency diesel.

5.8.4.3 ASN's position on achieving safety objectives

Control-command of the "hard core"

The principle adopted by EDF of carrying out the monitoring and control of the "hard core" of the existing actuators of the "hard core" by using the existing instrumentation and control of these actuators, if it is robust to extreme aggressions and their induced effects, favors reliability and preserves the space needed to add new equipment. Powering the instrumentation and control of the "hard core" by switching the electrical sources upstream of the instrumentation and control system avoids having different polarities coexist in the instrumentation and control cabinets, which limits the risk of failure by common mode of the equipment. different electrical sources.

Consequently, ASN considers that the principles adopted by EDF are acceptable. In addition, the technologies and design rules adopted by EDF make it possible to carry out the control-command functions of the "hard core" in a manner consistent with the existing control-command in terms of design, use and maintenance.

Electrical distribution of the "hard core"

The addition of the "hard core" must not jeopardize the safety of reactors for situations that can be managed without the "hard core". Also, the existing electrical distributions (of tracks A and B) and those of the “hard core” must be such that an electrical fault cannot propagate from one to the other or make them unavailable at the same time.

Concerning the independence between the “hard core” and existing electrical distributions, ASN notes that:

- for the new EASu pump, this independence is guaranteed. The requirements of ASN [ECS-1.III] and [ECS-ND4] are therefore respected. Indeed, this new pump is supplied by a new dedicated high voltage electrical panel;
- for existing actuators supplied with low voltage, this independence is not possible. EDF has chosen a solution (installation of an inverter) enabling the existing “hard core” equipment to be supplied, depending on the situation, by the existing distribution or by the “hard core” distribution;
- for the ASG-ND pump (existing) supplied with high voltage, EDF plans to add a high voltage inverter.

For the inverters, EDF has undertaken, on the one hand to check their capacity to ensure the isolation of the electrical distributions, on the other hand to carry out selectivity studies to verify their robustness to with regard to reports of electrical faults.

On the other hand, the introduction of inverters reduces, in principle, the reliability of the electrical not part of the "hard core". Indeed, their failure is likely to make it impossible to specify that these distribution and the electrical supply to the actuators from one or the other of the two electrical inverters are designed on the basis of proven equipment currently used on inverters are as reliable as sources. EDF has some of its reactors with very favorable feedback, which makes it possible to possible. In addition, these inverters have been the subject of “hard core” adaptation studies. The guarantee that these by the original designers, with the aim of meeting the new design requirements reliability of this “hard core” equipment must be assessed, taking into account the point that is the of feedback from the rectifiers and inverters used. currently on some of your reactors. This subject of an ASN request [49].

Finally, ASN underlines the importance of checking the robustness of the instrumentation and control electrical distribution to extreme aggressions. Indeed, during the accident of the nuclear power plant of system and of the Fukushima Daiichi, some actuators could not be re-supplied, despite the existence of electrical sources, because the electrical distribution was partially flooded.

5.8.5 Team capacity to manage extreme situations

5.8.5.1 Specific safety objectives set

Following the additional safety assessments carried out in 2011, EDF had to define (I and II of the prescription [ECS-35] of the decisions [3]) the human actions required as well as the skills necessary for the management of extreme situations and to verify that these actions were feasible, taking into account the conditions of intervention likely to be encountered. The operator also had to put in place (I to III of the prescription [ECS-36] of the decisions [3]) specialized teams capable of intervening to take over the shift teams and implement intervention means. emergency in less than 24 hours, with the start of on-site operations within 12 hours of their mobilization. Finally,

5.8.5.2 Summary of studies carried out and measures planned by EDF

EDF presented the provisions defined in terms of organization and emergency resources to ensure the teams' ability to carry out the actions required in the event of an extreme situation, as well as the measures taken to have specialized teams capable of intervening on Site (s.

To master extreme situations[80], EDF has set up a new organization of the management team known as the “extreme situation” team, as well as a nuclear rapid action force (FARN) operational within 24 hours, which is based on the national crisis organization. . The “extreme situation” team includes, in addition to the management team, permanently present on site, an operator called “unit pilot operator”, who acts as supervisor in extreme situations.

EDF has sized the “extreme situation” team, taking into account the actions required in incident and accident control, the tests carried out on simulators as well as the intervention time measurements of the teams in the field under intervention conditions. degraded. The operator postulates that the “extreme situation” team can be isolated for 24 hours on the site and that, during this period, the national crisis organization replaces the local crisis organization. Beyond these 24 hours, the nuclear rapid action force (FARN) is able to intervene on the site. Its mission is to intervene in the fields of control, maintenance and logistics on a nuclear site which would experience an accident affecting one or more of its reactors following a "hard core situation".

To assess the ability of the “extreme situation” team to cope with various extreme situations, EDF has since 2014 been conducting field tests for the operating teams on a full-scale simulator.[81] from the control room. The exercise scenarios include cases of progressive degradation of the installation, as well as unforeseen elements.

[80] Extreme situations are characterized by a high degree of uncertainty, organizational upheaval, loss of reference points and degraded intervention conditions due to the material consequences of attacks of external origin.

[81] A full scale simulator is a simulator that offers a very high level of realism. It is endowed with a great capacity of calculation which allows it to be very reactive with behaviors faithful to those of the central reference. It also allows the simulation of individual actions and groups of operators.

EDF has also developed a so-called “operability” approach for driving in extreme situations. It aims to provide reasonable assurance in the capacity of the teams to carry out, within the required deadlines and taking into account the extreme aggressions considered and the difficulties of progress which could result from it, the local actions necessary for the "hard core" management. It may be, for example, operations of hydraulic linings of the EASu or linings of “hard core” electrical cabinets. EDF retains as a field of analysis the configurations corresponding to installations on which the entire “hard core” is deployed (namely in phase B of the deployment of the modifications resulting from the review) and studies its capacity to implement the planned operation. in "hard core situation".

For the management of teams who have to face extreme situations, EDF has transposed the tactical reasoning method (MRT) used by the armed forces and civil security. This method provides a framework for decision-making and action which simultaneously leaves room for initiative, while integrating a mechanism for comparing the solutions envisaged.

Finally, EDF integrates all of these provisions into a model known as the “situational resilience model (MRS)”. This model was initially built from different theories relating to human and organizational reliability as part of the study of incident and accident driving on a simulator. It makes it possible to functionally describe the overall socio-technical system and its components (groups of actors), as well as to define the different functions to be fulfilled within the framework of the management of a situation in real time (for example, reconfigurations in real time). roles and responsibilities, prioritization of actions, cooperation between actors). It thus makes it possible to model, understand and assess the robustness of the system and the resilience of the organization,

5.8.5.3 ASN's position on achieving the objectives of the review

ASN assessed the efficient and robust nature of the organization and the emergency resources put in place or planned by EDF in the event of an accident affecting all or part of the installations on the same site in an extreme situation.

ASN first assessed the acceptability, with regard to safety and radiation protection, of the method used by EDF to size the “extreme situation” team. ASN considers that the method adopted, which includes simulator evaluations, is satisfactory in principle. However, the overall validation of the adequacy of the organization put in place (including the contribution of the procedures and tools put in place such as operability and MRT) can only be carried out after the completion of the deployment of all the “hard core” provisions provided for in the fourth periodic review of 900 MWe reactors. This involves in particular checking that the “hard core” equipment required by the new rules of conduct is accessible and can be operated in degraded situations by field agents. In addition, the operational nature of the organization put in place must be tested in the field with integrated teams (field agents, control room and crisis organization). EDF plans to carry out such tests in 2021.

ASN assessed [67] the measures put in place by EDF in terms of training and preparing FARN team members to intervene in a particularly stressful environment. ASN considers that these arrangements are satisfactory on the whole, but reiterates the importance, for the FARN, of the frequency of training and exercises involving the chain of command, as well as experience feedback systems.

5.8.6 Summary and prescriptions relating to the measures planned after the accident at the Fukushima nuclear power plant

EDF plans to deploy, during the fourth periodic review of 900 MWe reactors, the “hard core” defined after additional safety assessments carried out following the accident at the Fukushima Daiichi nuclear power plant. In particular, EDF provides robust resources for extreme situations in order to:

- prevent an accident with fuel melting or limit its progression: in particular, it involves diversifying and strengthening a channel in the water supply system for the steam generators, setting up a means for supplying water the supply tank for this system, to inject water into the storage pool and to have new means to cool the storage pool;
- to ensure the maintenance of the sub-criticality of the core in extreme situations: this involves having a means of injecting borated water at high pressure;
- to limit large-scale radioactive discharges: this concerns in particular the means implemented in the event of a core meltdown (new device, called "ultimate", for removing residual power from the containment, means prevention of perforation of the raft ...).

The electrical supply to this equipment is provided by the ultimate emergency diesels (DUS) already present on all the 900 MWe reactors and by an instrumentation and control system resistant to extreme situations.

These measures will make it possible to limit the risk of core meltdown in the event of extreme situations, limit the consequences of a serious accident and reduce the risk of the fuel assemblies stored in the swimming pool uncovering. They will constitute major advances for safety.

*

At the end of the examination, EDF undertook to carry out most of the necessary additions that the ASN examination revealed. ASN prescribes [48] the implementation of the major safety improvements planned by EDF as well as certain additional measures that it considers necessary to achieve the objectives of the review.

Emergency water supply for steam generators forming part of the hard core

[ND-A] The operator implements the modification of the emergency water supply to the steam generators, provided for in response to the second paragraph of III of the prescription [ECS-ND1] of the appendix to the decisions of 21 January 2014 referred to above, allowing residual power to be evacuated via the secondary circuit in hard core situations.

Back-up means of injection at the joints of the primary pump units

[ND-B] The operator is implementing a backup injection system at the joints of the primary pump units in order to be able to inject borated water when the primary circuit is at high pressure in hard core situations.

This means is part of the hard core.

Deployment of the hard core

[ND-C] Without prejudice to the provisions of this decision and the aforementioned decisions of January 21, 2014, the operator implements all of the other hard core provisions.

5.9 REASSESSMENT OF THE SAFETY OF BUILDINGS OF PACKAGING AND WASTE TREATMENT AUXILIARIES (BAC / BANG)

Although the nuclear fuel present in the reactor or in the fuel storage pool is the main issue in controlling the risk of radiological accidents in nuclear power plants, accidents involving the radioactive waste and effluents stored or being processed on the site are also likely to lead to releases of radioactive substances.

5.9.1 Specific objectives of the review

ASN asked EDF, during the orientation phase of the periodic review (SUR request n ° 20 [6]), to re-examine the control of the risks of accidents of a radiological nature that could occur in the annex conditioning buildings. of waste (BAC)[82]. More specifically, this request related to the inclusion of the following elements in the updated safety reports for the fourth periodic review:

- a description of the facilities and all the operations that may take place there;
- description of the radioactive substances present (inventory specifying the physical and radiological characteristics of the substances and estimate of the maximum quantity that may be present);
- the list, justified on the basis of the operations carried out in these buildings, of the incident and accident scenarios selected within the framework of the prudent deterministic approach provided for in article 3.2 of the BNI order [1];
- the provisions for the prevention and detection of incident and accident situations associated with these triggering events;
- the provisions for limiting the consequences of these incident and accident situations;
- the safety requirements to be applied to these provisions, taking into account the safety objectives selected;
- assessment of the radiological consequences of incident and accident situations, with regard to the reference scenario (s) corresponding to the source terms and envelopes.

5.9.2 Summary of studies carried out and planned modifications

In response to ASN's request, EDF sent a safety study relating to ancillary waste conditioning buildings and an update of the safety report.

The safety study analyzes:

- “internal events” likely to occur in ancillary waste conditioning buildings (incidents and accidents);
- the sufficiency of the measures taken with regard to attacks (in particular fire, earthquake, industrial risk, internal explosion, internal or external flooding, meteorological conditions, lightning, collisions and falling loads).

For these situations, EDF retains as a safety objective the absence of measures to protect the population. For the short-term phase, the radiological consequences must be lower than the level of intervention adopted by the public authorities for the shelter of the populations , i.e. 10 mSv.

82 For the Bugey nuclear power plant, this building is called the general nuclear auxiliaries building (BANG).

The most penalizing scenario corresponds to the fire and leads to a value less than 1 mSv at 500 m. EDF concludes that the measures taken at design and during operation are sufficient to guarantee a satisfactory level of safety.

EDF also underlines the positive impact of the implementation of the operating reference system for the management of radioactive waste as part of the implementation of the ASN decision relating to the study on waste management [22] . This contributes to the respect of the safety objectives, in particular by reducing the source terms (control of the inventory of stored radioactive materials, improvement of radiological cleanliness) and to the control of the heat load in the building (reduction of the risk of 'fire).

5.9.3 ASN's position on achieving the objectives of the review

ASN considers that these studies constitute a step forward for the safety demonstration. In particular, ASN notes the numerous changes made to the safety studies relating to the annex buildings for conditioning 900 MWe reactors in response to the requests it made during the guidelines for the periodic review and considers in particular satisfactory the responses provided by EDF on the radiological inventories, the identification of operations presenting radiological or non-radiological risks, the study of certain incident or accident scenarios and the assessment of the radiological consequences.

However, given the source term present in this building, ASN considers that EDF must review its safety objectives for this building, by proposing more ambitious objectives.

In addition, ASN considers that the list of scenarios to be considered must be completed. In addition, the EDF study is based solely on the acceptability of the radiological consequences of the envelope accident (the fire). ASN considers that EDF should seek possible improvements in the prevention or limitation measures for the consequences for the various possible scenarios. This list of scenarios to be considered must also be completed.

These points are the subject of requests from ASN [49].

5.10 CAPACITY OF OPERATORS TO CARRY OUT DRIVING ACTIONS IN AN ACCIDENTAL SITUATION, SERIOUS ACCIDENT OR AGGRESSIVE SITUATION

5.10.1 Specific objectives of the review

Following the third periodic review of the 1300 MWe reactors [38], ASN considered that it was " *essential for EDF to verify that the actions planned to limit the consequences of an accident can be carried out, in compliance with the requirements set by labor and public health codes* ". ASN also considered that " *EDF's approach must be supplemented during the next reviews in order to justify the possibility of carrying out the planned actions (locally) by workers when this intervention has been taken into account to limit the radiological consequences of certain accidents such as that they have been evaluated. EDF will also have to justify the availability of the means allowing the intervention in the conditions of environment and access (radiological, thermal, toxic, anoxia, opening of doors, valves,...) of the agents. "*

5.10.2 Summary of studies carried out

The accessibility analyzes carried out by EDF consist of verifying that stressful situations, accidents in the dimensioning field, accidents in the complementary field and serious accidents do not generate any change in the radiological or thermal environment likely to compromise the implementation, in the short term (ie during the first twenty-four hours), of the local actions necessary for the management of the situation in question.

The approach implemented for the fourth periodic review of the 900 MWe reactors is similar to that implemented for the third periodic review of the 1300 MWe reactors. The scope of the situations analyzed was extended to the operating conditions of the complementary domain and to attacks.

Accessibility analyzes follow a common general approach comprising four main stages:

- the selection of accidents in the dimensioning area and in the complementary area, as well as serious accidents and attacks, likely to have an effect on accessibility conditions;
- identification of the actions required locally for these different situations; the study
- of the consequences, in terms of accessibility, for the selected situations; the
- conclusion on the feasibility of local actions for these situations.

In the event of an accident in the dimensioning or complementary domain, EDF only studies the radiological and thermal environmental conditions of the room in which actions must be carried out, and not the conditions for accessing this room and for carrying out the expected actions. . For attacks, EDF identifies the particular environmental conditions generated by the attack likely to make the premises in which actions are necessary inaccessible (in particular smoke or fire for a fire and projectiles generated by strong winds).

EDF has set itself two objectives, verified separately:

- for radiological conditions, a dose target associated with "benchmark values" per action, namely 20 mSv for attacks, incidents and accidents in the dimensioning domain and in the complementary domain and 100 mSv for severe accidents. The doses evaluated through theoretical studies (associated with the various actions to be carried out and their implementation methods) are compared with these benchmark values, in order to verify that the dosimetry does not compromise the ability to carry out these actions;
- for thermal conditions, EDF examines whether the situation analyzed is likely to change the ambient conditions in the room in question.

Following all the checks carried out, EDF concludes that only the radiological and thermal environments of the operating building (BW) in the event of a loss of primary coolant (APRP) accident with a lack of external voltage (MDTE)) and the malfunction of the emergency diesel engine generator set on track A do not allow us to conclude that the premises are accessible. For this situation, EDF plans to implement a modification allowing to re-supply the components necessary to carry out the action of "IS line A line in simultaneous injection", from the electrical building (BL) in an environment allowing its accessibility.

5.10.3 ASN's position on achieving the objectives of the review

ASN notes that the approach adopted by EDF aims only to justify the ability of the operators to remain in the room for the planned duration of the mission, but does not allow the ability of the operators to go to the site and carry out the tasks to be checked. local actions within the required deadlines. For example, in the event of internal flooding, EDF does not justify the operators' ability to access the premises in which they must carry out the interventions.

ASN considers that demonstrating the ability of operators to carry out actions locally requires:

- the demonstration that operators can get to the premises in the time required; the
- demonstration of the habitability of the premises in which the actions must be carried out;
- the demonstration of the effective ability of operators to carry out the required control actions locally (for example, accessibility of control and command units, ability to carry out actions in the event of wearing personal protective equipment, availability of the tools, etc.).

EDF must complete its demonstration concerning the ability to travel to the premises and carry out the actions required for operation, in particular by integrating the accessibility of the control and command units, the ability to carry out actions in the event of port of personal protective equipment (PPE), the availability of tools and the time required for access.

At the end of the investigation, EDF undertook to complete its demonstration, which is satisfactory. **However, given the stakes, ASN supervises this action by prescription [FOH-B] [48].**

Furthermore, the requests formulated in the letter in reference [66], in particular relating to the assumptions used to calculate the dose and the duration of exposure, must apply to the studies which will be carried out. In addition, the accessibility analysis planned by EDF does not include the definition of provisions aimed at optimizing exposure, insofar as it is limited to the comparison of the dosimetry associated with the performance of actions with reference levels. .

These points are the subject of a request from ASN [49].

5.10.4 Summary and prescription relating to the operators' ability to carry out driving actions in an accident, serious accident or aggression situation

EDF has verified that the particular environmental conditions likely to be generated in an accident situation are acceptable in the premises in which actions must be carried out. It has undertaken to complete its demonstration concerning the ability to travel to these premises and to carry out, within the deadlines, the actions required in an accident situation.

These analyzes will make it possible to take into account the ability of operators to carry out the planned actions and meet the objectives of the review.

*

At the end of the examination, EDF undertook to carry out most of the necessary additions that the ASN examination revealed. ASN has prescribed [48] the implementation of the major safety improvements planned by EDF.

Ability of operators to carry out actions on the premises

[FOH-B] The operator checks the effective capacity of the operators to access the premises and to carry out the control actions required therein in the demonstration of nuclear safety in the event of an accident, serious accident or attack (for example , accessibility of control and command units, ability to carry out actions in the event of wearing personal protective equipment, availability of tools, time required for access).

The operator defines any changes to be implemented and the associated schedule.

6 ASN'S POSITION ON THE REVIEW OF NON-RADIOLOGICAL RISKS AND THE DISADVANTAGES OF THE NORMAL OPERATION OF THE INSTALLATIONS

6.1 REASSESSMENT OF NON-RADIOLOGICAL RISKS

6.1.1 Specific objectives of the review

Article L. 593-18 of the Environment Code provides that the review must make it possible to update the risk assessment, including non-radiological risks.

ASN therefore requested [6] " *to include in the safety report the study of incidents and accidents that may have non-radiological consequences and to integrate, in the conformity examination, checks related to the prevention of pollution as required by Title IV of the decision in reference [82].* "

6.1.2 Summary of studies carried out

EDF has transmitted a two-step process for taking into account non-radiological risks:

- the first aims to assess the situation of the installations with regard to the rules applicable to them;
- the second aims to assess the risks and their acceptability vis-à-vis the interests to be protected. If, at first glance, sufficiently probable or serious accident scenarios can affect the interests to be protected, the operator must provide for the implementation of risk control measures so as to reduce as much as possible the probability of occurrence of the accident. these or their severity.

EDF has included a description of its non-radiological risk assessment approach in the section of the generic safety report for all 900 MWe reactors.

The application of this approach for each of the sites will be provided in the section of the safety report specific to each site, which will be sent when the report concluding the periodic review is submitted. As all nuclear power plants fall under the “high threshold” classification of Directive 2012/18 / EU of 4 July 2012 known as “Seveso 3”, this approach will also take the place of a review of non-radiological risks provided for by II of article 4.3. .2 of the BNI order [1].

6.1.3 ASN's position on achieving the objectives of the review

ASN considers that the first step in the process of taking non-radiological risks into account, which aims to assess the situation of the installations with regard to the rules applicable to them, contains shortcomings in terms of the scope of the checks carried out and the procedures control implemented.

This point is the subject of the ASN [INC-A] prescription [48].

While the methodology presented by the licensee for assessing non-radiological risks is broadly based on the methodology used for assessing industrial risks in facilities classified for environmental protection, EDF has made adaptations to the reference methodology. The first checks carried out led ASN to issue reservations on the application of this adapted methodology [15].

ASN will be particularly vigilant in assessing and updating the non-radiological risks presented in the report concluding the periodic review specific to each of the reactors.

The checks carried out by ASN also showed that the assessment of the impact of non-radiological risks on the equipment and activities contributing to reactor safety is not presented in the safety reports. Thus, the demonstration of the ability to restore and maintain the reactors in a safe state, after a non-radiological accident on another part of the installation, is not formally provided by EDF. EDF has undertaken to transmit a work program to identify any additions to be made. ASN will check the relevance and implementation of this work program.

6.2 RE-EVALUATION OF DISADVANTAGES PRESENTED BY NORMAL OPERATION

6.2.1 Specific objectives of the review

Article L. 593-18 of the Environment Code provides that the periodic review must make it possible to update the assessment of the inconveniences of the installation caused by its normal or degraded operation.

The disadvantages presented by the installations correspond to the potential impacts of water withdrawals, effluent discharges as well as nuisances constituted by noise and vibrations, the flight of dust, odors and the dispersion of pathogenic microorganisms.

In addition, the management of waste arising from the normal operation of the operation is attached to this part of the review.

6.2.2 Summary of studies carried out

EDF has transmitted a two-step process to take into account the drawbacks:

- the first stage aims to assess the situation of the installations with regard to the rules applicable to them;
- the second step aims to update the assessment of the drawbacks that the installation presents, based on the provisions introduced by the BNI order [1] and the ASN decision of July 16, 2013 [16].

This approach was updated in 2018 to incorporate ASN requests ([17], [18], [19]). The application of this approach will be presented in the report concluding the periodic review of each reactor.

6.2.3 ASN's position on achieving the objectives of the review

ASN considers that the approach transmitted by EDF contains shortcomings in relation to the elements prescribed by the regulations, in particular:

- the verification of the conformity of the installations does not explicitly integrate all the regulatory texts to be considered, in particular the applicable European regulations (such as the CLP regulations[83] 101], biocide [102] and REACH[84] 103]);
- the equipment and material control program is limited to checking the effective performance of routine maintenance and control operations for a reduced number of equipment. No systematic checks are planned in the field.

83 CLP: Classification, Labeling and Packaging.
84 REACH: Registration, Evaluation, Authorization and restriction of Chemicals.

Given the number of materials and equipment used during current operation, it is necessary to target the control of the equipment to be carried out during the review. However, the criteria retained by EDF appear too restrictive, excluding, for example, *a priori,* equipment contributing to the treatment of effluents or to the monitoring of the environment. In addition, a periodic review is expected to provide additional analysis and controls compared to current operations, in particular the assessment of the relevance of current operations, in particular with regard to the best available techniques and the results of controls. equipment in the field.

This point is the subject of the ASN [INC-A] prescription [48].

In addition, EDF incorporates in the second step of its approach the responses to the requirements of the BNI order [1] and the ASN decision of July 16, 2013 [82] which require the production of studies and analyzes. , in particular an analysis of the chemical and radiological state of the environment, noise measurements or even positioning of the operator's practices in relation to the best available techniques. With the exception of the issue of noise measurement campaigns, for which reserves have been identified by ASN [20], the methodological elements presented in the EDF program do not call for any particular comment.

While EDF recalls in its orientation file dedicated to drawbacks [21] the principles implemented to regulate withdrawals and discharges from its installation, it does not provide for a review of the impact study of the installations. However, the impact study of a site currently consists of several documents, in particular partial updates following successive modifications to the operating conditions of the equipment or even the evolution of applicable ASN prescriptions. during installation. ASN considers that a review of the impact study cannot be ruled out *a priori* periodic review, especially since it participates in " *the assessment of the risks or disadvantages that the installation presents for the interests mentioned in article L. 593-1* "Requested by article L. 593-18 of the environment code. EDF has, however, defined a process of "updating" making it possible to lead, every ten years, to a global impact study covering all the changes in the installation, its operating conditions and changes in its environment.

ASN considers that EDF must consolidate the site impact study in light of the requirements of articles R. 122-5 and R. 593-17 of the environment code, which constitute the best practice in the matter.

With regard to waste management, this impact study should integrate the elements currently presented in the study on waste provided for by the ASN decision [22]. It will thus have to justify, on the basis of the best available techniques, the measures adopted for the management of the waste produced or to be produced, in particular to prevent and reduce the production and the harmfulness of the waste at source, and to ensure their traceability.

These points are the subject of the ASN [INC-B] prescription [48].

6.3 SUMMARY AND PRESCRIPTIONS RELATING TO NON-RADIOLOGICAL RISKS AND DISADVANTAGES PRESENTED BY NORMAL OPERATION

The disadvantages presented by the normal operation of the installations are specific to each site. The generic phase of the review made it possible to define the actions that will be implemented for each of the reactors to review the control of the drawbacks. EDF has thus defined the scope of the checks to be carried out and the studies to be carried out, for example on the chemical and radiological state of the environment.

ASN prescribes additional information on the checks to be carried out, in particular on equipment and structures allowing effluent treatment and waste conditioning. It also calls for the consolidation of impact studies in the form currently provided for by the environment code and the identification of improvements allowing the reduction of environmental impacts.

ASN also prescribes additional information on the checks to be carried out with regard to non-radiological risks.

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At the end of the examination, EDF undertook to carry out most of the necessary additions that the ASN examination revealed. ASN prescribed [48] the implementation of the major improvements planned by EDF as well as certain additional measures that it considers necessary to achieve the objectives of the review.

Compliance of installations

[INC-A] I.– No later than June 30, 2021, the licensee sends the nuclear safety authority the compliance control program for its facilities that it will implement during the periodic review of each reactor. vis-à-vis the disadvantages presented by normal operation and non-radiological risks.

This compliance is assessed with regard to the regulations of December 18, 2006, December 16, 2008 and May 22, 2012 referred to above, the provisions relating to the inconveniences presented by normal operation and non-radiological risks of the aforementioned order of February 7, 2012, the decisions of July 16, 2013, April 21, 2015, December 6, 2016, March 23, 2017 and April 6, 2017 referred to above and individual decisions applicable to water withdrawal and consumption, effluent discharge and environmental monitoring.

The operator justifies the scope of the equipment selected in this control program. The scope includes in particular the civil engineering works and the equipment necessary to control the drawbacks presented by installations in normal operation and non-radiological risks, in particular the important elements for the protection allowing the treatment of effluents and the conditioning of the waste. waste.

This inspection program includes on-site inspections of civil engineering works and equipment and the re-examination of the relevance of current inspection and maintenance operations with regard to their objectives and the corresponding best available techniques.

II.– The licensee sends the Nuclear Safety Authority a state of compliance of its installation with regard to the results of the checks mentioned in I and the measures it has defined to remedy any discrepancies observed.

Installation impact studies

[INC-B] I.– The operator consolidates the updates of the impact study carried out up to this date in the form provided for by articles R. 122-5 and R. 593-17 of the code of the environment. In this context, it ensures:

- to take account of changes in the state of knowledge, in particular as regards the assessment of the impacts of discharges from installations and changes in the site's environment;
- describe the impact of installations on the climate and the vulnerability of installations to climate change, in particular with regard to thermal discharges, the management of liquid discharges and the use of water resources.

It can base its study on existing data and analyzes when these are still relevant, in particular when it has assessed certain impacts on the environment during recent modifications.

In the absence of any significant change identified, the operator can repeat the existing elements on knowledge of the environment that must appear in the description of the relevant aspects of the state of the environment.

II.– The licensee specifies the improvements contributing to the reduction of the impacts of its installations on the environment that it foresees with regard to the conclusions of the impact study mentioned in I and the best available techniques, as well as the timetable associated implementation.

III.– No later than December 31, 2023, the licensee submits a study presenting the cumulative impact on the Rhône and on the Loire of the nuclear power plants located on these rivers.

7 ASN'S POSITION ON ORGANIZATIONAL AND HUMAN FACTORS

Organizational and Human Factors (HOF) refer to factors that influence human performance, such as skills, work environment, job characteristics, and organization [1]. The study of these factors mobilizes knowledge and methods from the human and social sciences in order to understand socio-technical systems in their real functioning [26] with the aim of preventing, detecting and managing undesirable situations.

7.1 SPECIFIC OBJECTIVES OF THE REVIEW

In its orientation file of January 2014 relating to the fourth periodic review of 900 MWe reactors [23], EDF provided for a study on " *improving operating conditions in terms of HOFs* ". More specifically, this study was to analyze experience feedback to identify areas requiring improvement with a view to reactor operation beyond the fourth periodic review. EDF specified that the objectives pursued consisted of the identification, in other words of the operator, of recurring operating difficulties which could in particular lead to significant errors and incidents and of a cross-examination "design - operation" of these difficulties in order to define the appropriate response. .

In its letter of 20 April 2016 relating to the guidelines for the fourth periodic review of 900 MWe reactors [6], ASN also indicated that, given *"The extent of the work of modifications envisaged within the framework of these fourth ten-yearly outages, [which] induce [...] significant changes for the people and organizations in place on the nuclear sites* ", EDF was to provide additional information regarding the control of" *the effect of the cumulative impacts of the modifications of the "VD4-900" project on the operational activities concerned and the risk of errors which could prove to be harmful to safety. ".* In particular, ASN requested information relating to EDF's "socio-organizational and human" design approach (SOH approach) and the related organizational process (methods and tools for taking into account cumulative effects, skills required, sharing of analysis results).

7.2 SUMMARY OF STUDIES CARRIED OUT AND IDENTIFIED MODIFICATIONS

7.2.1 Improvement of operating conditions

The EDF study, sent in 2013, on " *improving operating conditions in terms of HOFs* "Integrates the" *feedback from operators and operating events* ". It mentions, without listing or justifying them, the existence of 100 levers for improvement which led to 56 subjects requiring further study and then to 26 requests for improvement. EDF specifies that the requests for improvement fall into three categories (improvement of man-machine interfaces in the control room, improvement of interfaces between businesses and reduction of " *disruptions for teams "*) And that they will be studied within the framework of the EDF project associated with the fourth periodic review. EDF has not planned to send an additional study.

7.2.2 Taking into account the organizational and human dimensions in the design of the modifications

At the request of ASN [6], EDF provided information relating to the approach implemented for the study of human and organizational factors on the project for the fourth periodic review of the 900 MWe reactors. In particular, EDF transmitted information relating to the management of the so-called "socio-organizational and human" (SOH) approach associated with the design of the modifications, in particular the taking into

account of the unit and cumulative effects of modifications on human activities. EDF also communicated in its responses the measures planned to make stakeholders (study pilots, designers, etc.) aware of the “SOH” approach and to put in place support from specialists in organizational and human factors.

7.3 ASN'S POSITION ON ACHIEVING THE REVIEW OBJECTIVES

7.3.1 Improvement of operating conditions

ASN considers that the information transmitted is insufficient to meet the objectives that EDF has set for itself.

For ASN, determining the improvements to be made to “ *FOH operating conditions* ”Involves an assessment of risk control during operation. This control of operational risks results from the capacity of socio-technical systems to cope with the diversity of real situations, on the one hand by taking into account their own functioning, on the other hand by promoting their adaptability. The analysis of socio-technical systems requires an evaluation of the actual operating activities, such as for example the activities of operating the reactor in a normal, incidental or accident situation, the maintenance activities of the equipment or those contributing to the control of conformity.

The evaluation of these activities must in particular cover all of their relevant characteristics (such as, for example, the use of subcontracting, integration into a project structure or even co-activities), as well as on the measures implemented to control risks (for example, those relating to the acquisition and maintenance of skills, the supervision of service providers and human-machine interactions).

ASN therefore considers that, in order to improve the control of operating activities, EDF must define a study program enabling it to assess the capacity of its socio-technical systems to cope with the diversity of real life situations. operation and, where appropriate, identify avenues for improvement. In this context, EDF must integrate the many standardization approaches (standardization of organizations, procedures, tools, human behavior) that it has developed and developed in order to take advantage of the standardized nature of its reactors. This program should also include, among the operating activities studied, those contributing to the control of compliance and its maintenance over time, in particular the detection and treatment of deviations.

At the end of the investigation, EDF undertook to carry out these studies, which is satisfactory. **However, in view of the challenges, ASN supervises their implementation through the specification [FOH-A] [48].**

7.3.2 Taking into account the organizational and human dimensions in the design of the modifications

Given the specific context of the reorganization of EDF's engineering departments and the creation, within EDF, of a new entity called the “design authority”, ASN assessed, with the support of the IRSN, the organization put in place by EDF for the design, construction and operation of the modifications planned as part of the periodic review.

At the end of this assessment, ASN considers that EDF has defined and deployed organizational measures to improve the taking into account of the specific features of the sites, the preparation of operational documentation, the planning of design activities and performance, and capitalization of lessons learned from experience feedback from the fourth periodic review of reactors

of 900 MWe. However, ASN considers that these systems, which are based on a multiplication of entities and organizational interfaces and on a movement of centralization and pooling of players and resources, lead to an increase in the complexity of EDF's organization. .

Inspections carried out by ASN to assess the actual functioning of this organization ([27], [28], [29], [30], [31]) reveal a set of points of weakness which appear to be linked to this organizational complexity. :

- taking into account the specific features of sites in the design process, which is still too late, does not allow design assumptions to be called into question when necessary;
- a reduction in the ability of plant personnel to recover from errors in operational documentation associated with modifications;
- an analysis of operating experience feedback carried out at the scale of each modification without overall capitalization of the lessons learned from the deployment of all the modifications on the Tricastin site on which the first ten-year inspection was carried out.

ASN therefore considers that EDF should in particular study the effects of the increased complexity of its organization on the efficiency of its process for designing and carrying out modifications to its installations. It will have to assess the suitability of the organizational arrangements adopted during the deployment of modifications to the installations as they are carried out on the sites. This point is the subject of a request from ASN [49]. In addition, EDF will have to ensure that these modifications are adopted by the operators, in particular through appropriate training actions.

7.4 SUMMARY AND PRESCRIPTION RELATING TO ORGANIZATIONAL AND HUMAN FACTORS

Given the scope of the changes planned in the context of the review, EDF has put in place specific organizational measures to improve the design and implementation activities of the changes, the preparation of operational documentation and the capitalization of lessons learned from the feedback.

EDF has also undertaken to analyze the organization put in place at its nuclear power plants and the possible improvements to strengthen its capacity to cope with the diversity of actual operating situations. In particular, it will study the activities contributing to the control of compliance.

These analyzes will improve the consideration of organizational and human factors and meet the objectives of the review.

*

At the end of the examination, EDF undertook to carry out most of the necessary additions that the ASN examination revealed. ASN supervises [48], through a prescription, the analysis of the organization put in place at the nuclear power plants and possible improvements to strengthen the capacity to cope with the diversity of actual operating situations.

Reassessment of organizations, procedures, tools and human behavior

[FOH-A] By December 31, 2024 at the latest, the licensee assesses the capacity of the complex socio-technical systems that constitute its nuclear power plants to cope with the diversity of actual operating situations.

To do this, the licensee sends the Nuclear Safety Authority, no later than December 31, 2021, a study program that includes the impact of the approaches to standardize organizations, procedures, tools and human behavior. This program includes, among the operating activities studied, those contributing to the control of compliance and its maintenance over time, in particular the detection and treatment of deviations.

8 CONCLUSION ON THE CONTINUED OPERATION OF THE REACTORS 900 MWE AT THE END OF THE GENERIC PHASE OF THE FOURTH PERIODIC REVIEW

In conclusion, ASN underlines the particularly ambitious objectives of the fourth periodic review of the 900 MWe reactors and the very substantial work carried out by EDF within the framework of the generic phase. It also underlines the extent of the modifications planned by EDF, the implementation of which will constitute very significant improvements in safety.

At the end of the examination, ASN prescribes the completion of the major safety improvements planned by EDF as well as certain additional measures that it considers necessary to achieve the objectives of the review.

The provisions provided for at the generic stage of the review, as well as those which will be defined in the context of studies specific to each site, must be applied to each reactor with a view to continuing its operation. ASN asks EDF to carry out most of the safety improvements before submitting the review conclusion report, and in practice during the ten-yearly outage of each reactor. The other improvements must be made no later than five years after the submission of this report. This period is extended to six years for the seven reactors, the ten-year inspection of which is prior to 2022.

This phasing is linked to the scope of the work on each reactor, which will also be carried out simultaneously on several 900 MWe reactors. It takes into account the capacity of the industrial fabric to achieve them with the expected level of quality, as well as the necessary associated training for operators to take ownership of these changes.

ASN asks EDF to report annually on the progress of the actions to be carried out, the lessons it has drawn from the implementation on the sites of the provisions resulting from the periodic review, as well as its industrial capacity and that of external stakeholders to carry out the modifications to the installations on time. It also asks, in the event of a risk of non-compliance with deadlines, to specify the additional measures implemented to remedy the shortcomings observed. ASN requests that these elements be made public.

ASN considers that the measures planned by EDF, supplemented by the responses to the requirements formulated by ASN, will enable the objectives of the review to be achieved and the level of safety of the 900 MWe reactors to be brought closer to that of the third-generation reactors. generation, especially :

- by verifying, over a wide scope, the compliance of reactors with their reference system;
- by improving the consideration of attacks of internal or external origin. Reactors will thus be able to cope with more severe attacks than those previously used and will be robust to the failure of active equipment and the most important passive equipment;
- by limiting the radiological consequences of accidents without core meltdown, including in the event of an attack, which will significantly reduce the occurrence of situations with the implementation of population protection measures;
- by taking into account new accident situations for swimming pools, in particular those considered for the EPR reactor at Flamanville, and by improving the measures provided for managing accident or stress situations affecting the storage swimming pool;
- by reducing the risk of an accident with core meltdown and by limiting the consequences of this type of accident, in particular by limiting the situations that would require venting the containment and by reducing the risk of the breakthrough of the bottom of this enclosure by the corium. These provisions will thus make it possible to significantly reduce discharges into the environment during this type of accident.

At the end of the generic review phase, ASN considers that these safety improvements open the prospect of continued operation of the 900 MWe reactors for the ten years following their fourth periodic review.

9 REFERENCES

[1] Order of 7 February 2012 as amended setting the general rules relating to basic nuclear installations

[2] Letter from ASN referenced CODEP-DCN-2013-013464 of June 28, 2013: Generic program proposed by EDF for the continued operation of reactors in operation beyond their fourth periodic safety review

[3] ASN decisions n ° 2012-DC-274 to n ° 2012-DC-292 of June 26, 2012 relating to the conclusions of the additional safety assessments

[4] ASN letter referenced DEP-DCN-0116-2008 of 18 March 2008: Pressurized water nuclear reactors (PWR) in operation - Safeguard circuits - Recirculation function

[5] ASN decisions n ° 2014-DC-0394 to n ° 2014-DC-0412 of January 21, 2014 setting requirements for EDF in view of the examination of the file presented by the licensee in accordance with the requirement (ECS-1) ASN decisions n ° 2012-DC-274 to n ° 2012-DC-292 of June 26, 2012

[6] ASN letter referenced CODEP-DCN-2016-007286 of 20 April 2016: Generic guidelines for the periodic review associated with the fourth ten-yearly outages of EDF 900 MWe reactors (VD4-900)

[7] Letter from ASN referenced CODEP-DCN-2014-010622 of 10 March 2014: Guidelines for the periodic safety review associated with the fourth ten-yearly outages of 900 MWe reactors

[8] Letter from ASN referenced CODEP-DCN-2021-007672 of February 26, 2021: Verification of the conformity of the 900 MWe reactors for their fourth periodic review (RP4,900)

[9] Letter from ASN referenced CODEP-LYO-2019-026756 of 20 June 2019: Procedures for verifying compliance and implementing hybrid modifications

[10] Letter from ASN referenced CODEP-LYO-2020-002833 of January 13, 2020: Modalities of the verification of compliance for the 4e ten-year inspection of Bugey 2 and implementation of hybrid modifications

[11] Letter from ASN referenced CODEP-DCN-2021-007629 of 12 February 2021: Sampling of equipment on the reactors of the Fessenheim nuclear power plant

[12] ASN letter referenced CODEP-LYO-2019-033529 of July 24, 2019: BNI n ° 87 and n ° 88 Management of deviations

[13] Letter from ASN referenced CODEP-LYO-2020-002250 of 9 January 2020: BNI n ° 78 Management differences

[14] ASN letter referenced CODEP-DCN-2014-014235 of June 4, 2014: Containment of reactor building and peripheral buildings

[15] ASN letter referenced CODEP-DCN-2019-001769 of April 17, 2019: Prevention of pollution and pollution control

[16] ASN decision n ° 2013-DC-0360 of the Nuclear Safety Authority of July 16, 2013 basic relating to the control of nuisances and the impact on health and the environment of nuclear installations

[17] Letter from ASN referenced CODEP-DEU-2017-010461 of 7 April 2017: Review periodical for basic nuclear installations - “Disadvantages” section

[18] ASN letter referenced CODEP-DCN-2017-010474 of 5 July 2017: Periodic review - orientation file for the “disadvantages of the periodic review of EDF BNIs” section

[19] ASN letter referenced CODEP-DCN-2019-000490 of 7 June 2019: Choice of reference installations for the application of the ASN “environment” decision for EDF reactors in operation

[20] ASN letter referenced CODEP-DCN-2017-049428 of 7 December 2017: Periodic review - Carrying out noise measurement campaigns

[21] Letter from EDF referenced D4008101180067 of February 9, 2018: Update of the orientation file for the periodic review of drawbacks

[22] Decision n ° 2015-DC-0508 of the Nuclear Safety Authority of April 21, 2015 relating to the study on waste management and the assessment of waste produced in basic nuclear installations

[23] EDF note referenced EMESN130349 Ind. C: January 2014 guidance file relating to the fourth periodic reviews of 900 MWe reactors

[24] ASN letter referenced DEP-DCN-N ° 360-2007 of July 25, 2007: earthquake of July 16, 2007 that affected the Kashiwazaki-Kariwa nuclear power plant

[25] Consultation on improving the safety of the 900 MWe reactors of the French nuclear fleet as part of their fourth periodic review - Report of the guarantors - June 11, 2019

[26] INERIS report referenced DP-FOH-1418284253 of December 10, 2014: Industrial safety: How to integrate Organizational and Human Factors in the prevention of technological risks?

[27] Letter from ASN referenced CODEP-BDX-2019-002537

[28] Letter from ASN referenced CODEP-BDX-2019-0024

[29] ASN letter referenced CODEP-CHA-2019-033610 of 1er August 2019: Operational rigor - Safety management - Control of the compliance of installations and operating standards with the demonstration of nuclear safety

[30] ASN letter referenced CODEP-CAE-2018-0044669

[31] Letter from ASN referenced CODEP-CHA-2019-012548 of March 28, 2019: Modification, material and documentary compliance

[32] Letter from ASN referenced CODEP-DCN-2020-007982 dated January 28, 2020: 900 MWe nuclear power reactors - EDF - Reopening of the return line of joints n ° 1 of the GMPP in situation H3 with loss of the IJPP

[33] Letter from the DGSNR referenced DEP-SD2-500-2005 of 21 October 2005: Risks associated with severe accidents in PWRs in operation - Safety review during the third ten-yearly outages of 900 MWe reactors

[34] Letter from ASN referenced CODEP-DCN-2013-038780 of 25 November 2013: ASN requests following the severe accident GP and EPS2 in the context of the third periodic safety review of the 1300 MWe reactors

[35] ASN letter referenced CODEP-DCN-2018-018786 of 22 November 2018: Examination of level 1 (EPS1) and 2 (EPS2) probabilistic safety studies for 1450 MWe reactors with a view to their second periodic review

[36] Decision n ° 2009-DC-0153 of the Nuclear Safety Authority of August 18, 2009 relating to the levels of intervention in a radiological emergency situation

[37] ASN letter referenced CODEP-DCN-2017-014451 of July 19, 2017: Control of severe accidents: post-Fukushima “hard core” and reactor operating time

[38] ASN letter referenced CODEP-DCN-2014-020043 dated 16 July 2014: Electronuclear reactors - EDF - 1300 MWe stage - Safety review associated with the third ten-yearly reactor inspection (VD3 1300) - Radiological consequences of accidents (excluding RTGV and severe accidents) associated with the periodic safety review of the reactors of the 1300 MWe reactors carried out during their third ten-yearly outage

[39] Letter from ASN referenced CODEP-DCN-2019-032720 of July 19, 2019: List of deliverables expected by ASN for its position on the generic phase

[40] Order of 20 November 2009 approving decision n ° 2009-DC-0153 of the Nuclear Safety Authority of 18 August 2009 relating to levels of intervention in a radiological emergency situation

[41] Publication 60 “1990 Recommendations of the International Commission on Radiological Protection” adopted by the Commission in November 1990

[42] Council Regulation (Euratom) No 2218/89 of July 18, 1989 amending Regulation (Euratom) No 3954/87 fixing the maximum permissible levels of radioactive contamination for food and feed after a nuclear accident or in any other radiological emergency

[43] Decree No. 2002-460 of April 4, 2002 on the general protection of people against the dangers of ionizing radiation

[44] ASN letter referenced CODEP-DCN-2019-047431 of 14 November 2019: Fourth periodic review of 900 MWe reactors - Additional information to be provided by EDF with a view to the ASN's position statement on the conditions for continuing the operation of 900 MWe reactors after their fourth periodic review

[45] ASN letter referenced CODEP-DCN-2021-007693 of February 26, 2021: Control of aging and obsolescence in the context of the fourth periodic reviews

[46] Order November 10, 1999 relating to the supervision of the operation of the main primary circuit and the main secondary circuits of pressurized water nuclear reactors

[47] Report WENRA - Safety reference levels for existing reactors - 24th September 2014

[48] Decision n ° 2021-DC-0706 of the Nuclear Safety Authority of February 23, 2021 setting for the company Électricité de France (EDF) the requirements applicable to reactors of nuclear power plants in Blayais (BNI n ° 86 and n ° 110), du Bugey (INB n ° 78 and n ° 89), Chinon (INB n ° 107 and n ° 132), Cruas (INB n ° 111 and n ° 112), Dampierre-en-Burly (INB n ° 84 and No. 85), Gravelines (INB No. 96, No. 97 and No. 122), Saint-Laurent-des-Eaux (INB No. 100) and Tricastin (INB No. 87 and No. 88) in view of the findings of the generic phase of their fourth periodic review

[49] ASN letter referenced CODEP-DCN-2021-007988 of 4 March 2021: ASN position on the generic phase of the fourth periodic review

[50] ASN letter referenced CODEP-DCN-2018-045418 of September 28, 2018: Response note to the objectives of the fourth periodic review of 900 MWe reactors

[51] Letter from ASN referenced CODEP-DEP-2018-058304 of February 28, 2019: Keeping the core zone of the 900 MWe reactor vessels in service for the 10-year period following their fourth ten-yearly outage

[52] ASN letter referenced CODEP-DEP-2019-046852 dated 3 January 2020: Keeping the core zone of the 900 MWe reactor vessels in service for the 10-year period following their fourth ten-yearly outage

[53] ASN letter referenced CODEP-DEP-2020-045660 of 7 December 2020: Keeping the core zone of the 900 MWe reactor vessels in service for the period of 10 years following their fourth ten-yearly outage

[54] ASN letter referenced CODEP-DEP-2019-025552 of 19 July 2019: Aging and service life of the molded elbows of the main primary circuit of 900 MWe reactors

[55] Letter from ASN referenced CODEP-DEP-2019-053770 dated January 28, 2020: Update of regulatory reference files in the context of continued operation beyond the fourth ten-yearly outages of 900 MWe reactors

[56] ASN letter referenced CODEP-DCN-2020-032576 of August 4, 2020: Compliance of emergency generators - Feedback from the summer 2019 heat wave

[57] ASN letter referenced CODEP-DCN-2011-023760 of 20 May 2011: Safety review corresponding to the third ten-yearly outages - Seismic movements to be taken into account for the safety of nuclear installations in application of RFS 2001-01

[58] Letter from ASN referenced CODEP-DCN-2021-001430 dated 3 March 2021: 900 MWe reactors - Controlling reactivity during the accident where a third category steam generator tube ruptured

[59] ASN letter referenced CODEP-DCN-2016-016677 of July 18, 2016: Extreme external attacks to be taken into account for the implementation of the "hard core"

[60] ASN letter referenced CODEP-DCN-2015-001288 of 20 January 2015: Seismic reassessment of equipment - DERESMA approach

[61] ASN letter referenced CODEP-DCN-2012-068588 of 9 January 2013: 900 MWe series - CPY - "PTD n ° 2" documentary report - "Grands Chaud" reference system

[62] ASN letter referenced CODEP-DCN-2014-058834 of 2 January 2015: Protection against strong winds

[63] ASN letter referenced CODEP-DCN-2014-054236 of December 10, 2014: Consideration of meteorological attacks - Tornado

[64] Letter from ASN referenced CODEP-DCN-2011-006777 of 4 May 2011: Guidelines for generic studies to be carried out for the safety review of 1300 MWe reactors associated with their third ten-yearly outage

[65] Letter from ASN referenced CODEP-DCN-2019-013282 of April 14, 2019: Strategies for managing hard core provisions for preventing fuel melting in reactors and pools

[66] ASN letter referenced CODEP-DCN-2019-003198: Electronuclear reactors - EDF - Feasibility, in terms of radiation protection, of accidental operation

[67] Letter from ASN referenced CODEP-DCN-2021-001388 of 7 January 2021: Examination of the provisions for training and preparation for extreme situations implemented by EDF - Following additional safety assessments

[68] ASN letter referenced CODEP-DCN-2019-007339 of 1er July 2019: All levels - Organization of firefighting

[69] ASN letter referenced CODEP-DCN-2019-036024 of October 16, 2019: All levels - Organization of firefighting

[70] Opinion and recommendations of the standing group of experts for nuclear reactors (meeting of January 28 and February 10, 2016) referenced CODEP-MEA-2016-007211 of February 18, 2016: Extreme external attacks retained for the "hard core" of water reactors under pressure from EDF under construction or in operation

[71] ASN letter referenced CODEP-DCN-2014-004806 of January 27, 2014: Safety review associated with the third ten-yearly reactor inspection (VD3 1300) - Fire

[72] ASN letter referenced CODEP-DCN-2015-000461 of 23 February 2015: Safety review associated with the second ten-yearly outage of the 1,450 MWe reactors (VD2 N4) - Guidelines for the review program

[73] ASN letter referenced CODEP-DCN-2017-000082 of February 17, 2017: VD4-900 - Non-admissibility of deliverables received

[74] ASN letter referenced CODEP-DCN-2011-029192 of 1er August 2011: Repository of safety requirements for protection against the risk of internal fire for the EPR (ETC-F index G) and EPRESSI method

[75] Letter from the DGSNR referenced DGSNR / SD2 / N ° 760/2003

[76] ASN letter referenced CODEP-DCN-2014-005838 of 7 March 2014: Safety review associated with the third ten-yearly reactor outage (VD3 1300) - Explosion

[77] Letter from ASN referenced CODEP-DCN-2019-036712 of September 17, 2019: Completeness of the internal flood reference system, consideration of the risk of earthquake-induced internal flooding by rupture of piping and maintenance

[78] ASN letter referenced CODEP-DCN-2013-052468 of 18 November 2013 relating to the risks of homogeneous dilution

[79] ASN letter referenced CODEP-DCN-2012-039293 of 3 October 2012: Nuclear power reactors - EDF - All levels - Risk of criticality in the event of dilution when shutdown

[80] Letter from ASN referenced CODEP-DCN-2017-001478 of 12 January 2017: Electronuclear reactors - EDF - New method of studying the accident involving loss of primary coolant by intermediate-sized breach

[81] ASN Opinion no.2012-AV-0139 of 3 January 2012 on the additional safety assessments of priority nuclear installations with regard to the accident at the Fukushima Daiichi nuclear power plant

[82] ASN Decision No. 2013-DC-0360 of July 16, 2013 on controlling nuisances and the impact on health and the environment of BNIs

[83] Fundamental Safety Rule (RFS) n ° 2001-01 of May 31, 2001

[84] ASN Guide 2/01 index 0 of 26 May 2006: Seismic risk taken into account in the design of civil engineering structures for basic nuclear installations, with the exception of long-term radioactive waste storage

[85] ASN Guide n ° 13 of 8 January 2013 relating to the protection of basic nuclear installations (BNIs) against external flooding

[86] ASN Guide No. 22 of 18 July 2017 relating to the design of pressurized water reactors

[87] ASN Guide No. 21 of 6 January 2015 for dealing with deviations from compliance with a requirement defined for an element important for protection (EIP)

[88] ASN letter referenced DEP-SD2-0152-2005 of April 27, 2005: Risk of clogging in an accidental situation of the filters of the recirculation circuit sumps

[89] Rules NV65: Rules defining the effects of snow and wind on constructions and annexes - CSTB - April 2000

[90] Opinion and recommendations of the standing group of experts for nuclear reactors (meeting of March 21, 2018) referenced CODEP-MEA-2018-018336 of April 17, 2018: Aging of systems, structures and components (SSC)

[91] Opinion and recommendations of the standing group of experts for nuclear pressure equipment (meeting of March 15, 2018) referenced CODEP-MEA-2018-014211 of March 20, 2018: Controlling aging

[92] Opinion and recommendations of the standing group of experts for nuclear pressure equipment (meeting of November 20, 2018 and 1er November 2018) referenced CODEP-MEA-2018-055796 of November 22, 2018: Operation of the core zone of the 900 MWe reactor vessels for the period of 10 years following their fourth ten-yearly inspection

[93] Opinion and recommendations of the standing group of experts for nuclear pressure equipment (meeting of October 15, 2019) referenced CODEP-MEA-2019-043861 of October 25, 2019: Keeping the core zone of the 900 MWe reactor vessels in service during the 10-year period following their fourth ten-year visit outside Fessenheim

[94] Opinion and recommendations of the standing group of experts for nuclear pressure equipment (meeting of September 8, 2020) referenced CODEP-MEA-2020-046842 of September 29, 2020: Keeping the core area of the 900 MWe reactor vessels in service during the 10-year period following their fourth ten-year visit outside Fessenheim

[95] Opinion and recommendations of the standing group of experts for nuclear pressure equipment (meeting of October 8, 2019) referenced CODEP-MEA-2019-042869 of October 25, 2019: Update of regulatory reference files as part of the pursuit of operation of 900 MWe reactors beyond the fourth ten-yearly outages

[96] Opinion and recommendations of the standing group for nuclear pressure equipment (meeting of May 25, 2019) referenced CODEP-MEA-2019-023649 of May 27, 2019: Serviceability of the austeno-ferritic stainless steel molded elbows of the main primary circuit of the reactors of 900 MWe, with the exception of the reactors of the Fessenheim power plant, up to 20 years after their 4e ten-year visit

[97] Opinion and recommendations of the standing group of experts for nuclear reactors (meeting of January 30 and 31, 2019) referenced CODEP-MEA-2019-006797 of February 18, 2019: Accident studies associated with the fourth safety review of 900 MWe reactors (VD4 900 MWe)

[98] Opinion and recommendations of the standing group of experts for nuclear reactors (meeting of February 20 and 21, 2019) referenced CODEP-MEA-2019-010085 of March 21, 2019: VD4-900 - Internal and external attacks

[99] Opinion and recommendations of the standing group of experts for nuclear reactors (meeting of July 11 and 12, 2019) referenced CODEP-MEA-2019-032606 of July 19, 2019: Probabilistic safety studies carried out as part of the 4th periodic reviews of 900 MWe reactors

[100] Opinion and recommendations of the standing group of experts for nuclear reactors (meeting of March 27 and 28, 2019) referenced CODEP-MEA-2019-014016 of April 17, 2019: Control of severe accidents in the context of the deployment of post-Fukushima modifications

[101] Regulation (EC) No. 1907/2006 of the European Parliament and of the Council of 18 December 2006 on the registration, evaluation and authorization of chemical substances, as well as the restrictions applicable to these substances (REACH), establishing an agency European Chemicals Directive, amending Directive 1999/45 / EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Directive 76/769 / EEC Council and Directives 91/155 / EEC, 93/67 / EEC, 93/105 / EC and 2000/21 / EC of the Commission

[102] Regulation (EU) No 528/2012 of the European Parliament and of the Council of 22 May 2012 concerning the making available on the market and the use of biocidal products

[103] REACH Regulation (EC) n ° 1272/2008 of the European Parliament and of the Council of December 16 2008 on the classification, labeling and packaging of substances and mixtures, amending and repealing directives 67/548 / EEC and 1999/45 / EC and amending Regulation (EC) No. 1907/2006

[104] Letter from EDF referenced D455617307787 index B1 of September 5, 2018: Note of response to objectives

[105] ASN booklet entitled "Nuclear power plants beyond 40 years: the challenges of 4e periodic review of 900 MWe nuclear reactors'

[106] Fundamental safety rule I.2.a of 5 August 1980 relating to the taking into account of the risks associated with falling airplanes

[107] Fundamental safety rule I.2.d of May 7, 1982 relating to the taking into account of risks related to the industrial environment and to communication routes

[108] Report of the steering committee on social, organizational and human factors (COFSOH) - Developing safety - Summary of the work of working group D - September 2019

[109] Opinion of the standing group of experts for nuclear reactors (meeting of November 12 and 13, 2020) referenced CODEP-MEA-2020-055957 of November 19, 2020: Review of the fourth periodic review of 900 MWe reactors

APPENDIX: IRSN OPINION COLLECTED AS PART OF THE PHASE GENERIC OF THE FOURTH PERIODIC REVIEW 900 MWE REACTORS

ASN obtained the opinion of IRSN on:

- controlling the compliance of installations;
- the sufficiency of the program of additional specific tests;
- updating of regulatory reference files for primary and secondary main circuits;

- the service life of the tanks;
- containment;
- the diesel power balance;
- risks associated with internal and external attacks for CPY type reactors; the EDF
- guides for verifying the dimensioning with regard to the earthquake; risks
- associated with tornadoes;
- the risk associated with the fall of a general aviation
- aircraft; risks associated with internal fire and explosion;
- studies of the consequences for nuclear safety of a transformer fire;
- accident studies for CPY type reactors and the recirculation function;
- the impact of the transposition to reactors in operation of incidental and accidental situations and of the delays before the operators' first intervention taken into account in the safety studies of the Flamanville EPR reactor;
- probabilistic safety studies for CPY type reactors;
- the recirculation function, the study of the consequences of an accident of loss of primary coolant cumulated with an earthquake and the acceptability of the function of the emergency water supply of the steam generators forming part of the "hard core" (ASG-ND);
- safe storage and handling of fuel in fuel building storage pools;

- serious accidents;
- additional expertise relating to the limitation and prevention of serious accidents;
- the method for evaluating the radiological consequences of accidental atmospheric releases;
- accident and stress studies and probabilistic safety studies for the reactors at the Bugey nuclear power plant;
- the safety review of the general nuclear auxiliaries (BANG) building of the Bugey nuclear power plant and of the conditioning auxiliaries (BAC) buildings of the other 900 MWe power plants;
- examination of EDF's organization for the design, construction and operation of modifications;
- the summary of its expertises relating to the review.

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