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FOLLOW-UP TO THE FRENCH NUCLEAR POWER PLANT STRESS TESTS

Closure report of the action plan
of the French Nuclear Safety Authority (ASN)

Décember 2020

asn.fr

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Key:

General recommendation resulting from the 2012 Peer Review

Peer Review:

Recommendation resulting from the 2nd extraordinary meeting of the Convention on Nuclear Safety (CNS) 2012.

CNS:

Recommendation specific to France, resulting from the 2012 peer review

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State of progress of prescriptions issued by ASN

Progress: completed

Summary

In December 2012, ASN published a national action plan in response to the recommendations of the 2012 European Peer Review of Stress Tests and the 2nd Extraordinary Meeting of the Convention on Nuclear Safety (CSN) in 2012. This action plan includes the prescriptions of ASN resolutions of June 26, 2012 aimed at increasing the robustness of nuclear power plants in extreme situations beyond the safety margins already available to the facilities.

This report presents the provisions defined by EDF in response to ASN prescriptions. These provisions contribute to the improvement of:

- the protection against internal or external aggression;
- the means of electrical power supply;
- the provisions to prevent accidents with core melt;
- the provisions to prevent the uncovery of fuel assemblies in the pool;
- the management of accidents with core melt;
- the emergency management;
- the means of intervention on sites through the implementation of the nuclear rapid action force (FARN).

The provisions defined by EDF enable to close the actions of the action plan and to respond to the recommendations resulting from the European stress tests peer review.

This report is thus the final version of the national action plan drawn up in 2012.

In addition, supplementary modifications to those issued from the action plan are being implemented in French nuclear power plants as part of continuous improvement. These improvements are notably presented at the periodic review of the Convention on Nuclear Safety.

1 INTRODUCTION

Following the accident at the Fukushima-Daiichi nuclear power plant, by resolutions dated May 5, 2011, ASN requested that the licensees of major nuclear facilities perform stress tests. These stress tests focused on the robustness of these nuclear facilities facing extreme situations of the type that resulted in the Fukushima accident.

They were carried out on the basis of specifications consistent with the ENSREG specifications developed for the European stress tests. This stress test exercise was in response to the Prime Minister's request of March 23, 2011 and the conclusions of the European Council of March 24 and 25, 2011.

The conclusions of the stress tests of French nuclear power plants were reviewed in 2012 within the framework of the European stress tests.

ENSREG and the European Commission issued a joint statement on April 26, 2012, stressing the need to implement an overall action plan to ensure that these stress tests would be followed by safety improvement measures implemented in a consistent manner in each country. It was drafted by ENSREG, and it included a recommendation on the publication by the end of 2012 of a national action plan developed by the Nuclear Safety Authority of each Member State.

In December 2012, the ASN published an action plan for France. This action plan presented actions in response to the recommendations resulting from the 2012 Peer Review and the 2nd Extraordinary Meeting of the Convention on Nuclear Safety (CSN) in 2012. This action plan included studies on the one hand and the implementation of modifications to the installations on the other. It was subject to an ENSREG peer review in 2013. It was then updated in 2014 and 2017 to present the progress of the actions.

This report follows the same structure as those developed in 2012, 2014 and 2017. It includes elements of these reports in order to provide a self-supporting report. It presents the actions carried out in France following the European stress tests.

2 FOLLOW-UP OF THE RECOMMANDATIONS RESULTING FROM THE EUROPEAN PEER REVIEW

2.1 NATURAL HAZARDS

2.1.1 Hazard frequency

Peer Review: *The use of a return frequency of 10^{-4} per annum (0.1g minimum peak ground acceleration for earthquakes) for plant reviews/back-fitting with respect to external hazards safety cases.*

CNS: *Re-evaluating the hazards posed by external events, such as earthquakes, floods and extreme weather conditions, for each NPP site through targeted reassessment of safety.*

Recommendation specific to France resulting from the 2012 peer review

It is recommended that ASN should consider introducing Probabilistic Seismic Hazard Analysis in France for the design basis of new reactors and for future revisions of the seismic design basis of existing reactors, in order to provide information on event probability (annual frequency of occurrence) and to establish a more robust basis for Design Basis Earthquake specifications.

The methodology used in France to assess external natural hazards is based essentially on a deterministic approach. The most penalising historical event based on a given period of observation - usually one hundred or one thousand years - is considered, to which large conventional margins are added. The external hazards, particularly earthquakes and flooding, were the subject of a targeted reassessment as part of the stress tests conducted in France in 2011. In view of the available comparative data and the improvements made to the reactors during the periodic safety reviews, implementation of the chosen methodology for earthquakes and flooding leads to a very high level of safety.

With regard to earthquakes, the methodology currently used to determine the seismic risk in France complies with the methodology and criteria prescribed by the IAEA. Within the framework of the ongoing periodic reviews, probabilistic studies to complement the seismic hazard analysis are also carried out. Through a set of resolutions dated 21 January 2014, ASN set the extreme seismic hazard defined by a response spectrum:

- encompassing the safe shutdown earthquake (SSE) for the site, plus 50%,
- encompassing the probabilistic site spectra with a return period of 20,000 years,
- taking into account the particular site effects, in particular the nature of the soil, in its definition.

ASN has therefore introduced a probabilistic component.

With regard to the flood risk, ASN published guide N. 13[1] in 2013 concerning how to address the external flood risk for nuclear facilities. The hazards to be taken into consideration are defined on the basis of in-depth knowledge of the different areas concerned, hydrology and meteorology (11 different hazards considered). It is based on deterministic methods, incorporating margins and combinations integrated into the hazards, taking into account a "probabilistic" exceedance target of less than 10^{-4} per year.

All external hazards are periodically reassessed as part of the periodic safety reviews carried out every 10 years.

Progress: completed

[1] http://www.french-nuclear-safety.fr/References/ASN-Guides-non-binding/ASN-Guide-No.-13

2.1.2 Secondary effects of seismic events

Peer Review: *The possible secondary effects of seismic events, such as flood or fire arising as a result of the event, in future assessments.*

The indirect (secondary) effects of seismic events have been examined as of the second periodic safety reviews of the 900 MWe reactors. They were the subject of French stress tests concerning: the "seismic interaction"[2] approach, the loss of the off-site electrical power supplies, the conditions of site access after an earthquake, the fire and explosion risks induced by an earthquake, and the flooding risks induced by an earthquake (failure of dams, embankments, systems or equipment).

The analysis of these studies led ASN to set prescriptions ECS–11, ECS–9 and ECS–12 to study the behaviour of these structures beyond their design baseline requirements.

ECS–11: Robustness of the Fessenheim and Tricastin embankments

Before 31 December 2013, the licensee will send ASN a study stating the level of seismic robustness of the embankments and the other structures protecting the facilities against flooding and, according to this level of robustness, presenting:

- the consequences of a failure of these structures,
- the technical solutions envisaged to protect the equipment of the hardened safety core which is the subject of the prescription ECS–1.

The licensee submitted the summary of its studies at the end of 2013. These required in-situ surveys of the structures to ensure that the studies were appropriate to the reality of the structures.

The demonstration of the seismic stability of the embankments and other protective structures of the Fessenheim nuclear power plant against flooding is acquired for the extreme seismic hazard.

The demonstration of the seismic stability of the embankments and other protective structures against flooding of the Tricastin nuclear power plant is acquired for the seismic hazard of the nuclear safety demonstration. EDF has identified a portion of the embankment that requires reinforcement work to ensure its resistance to extreme earthquakes. While waiting for this work (end of 2022), EDF has implemented compensatory measures.

ECS–9: Reinforcement of the seismic interaction approach

No later than 31 December 2012, the licensee shall take the necessary steps to prevent equipment whose operational availability is required for the safety demonstration from being damaged by other equipment items in the event of an earthquake.

Before 31 December 2013, the licensee shall present ASN with the results of the application of this approach, along with the intermediate results, before 30 June 2013.

The seismic event approach is in force in the safety standard. EDF carried out an assessment of the application of this approach.

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[2] *The purpose of the "seismic interaction" approach is to prevent damage to a necessary item in the event of an earthquake by an item or structure not subject to any seismic-resistance requirement.*

ECS–12: Verification of the seismic design basis of the fire-fighting system

Before 30 December 2012, the licensee shall submit to ASN:

- a study evaluating the resistance to a safe shutdown earthquake (SSE) of the structures and equipment contributing to nuclear safety of the fire sectoring, fire detection and fixed extinguishing systems, subject to an operating basis earthquake resistance requirement,
- for items for which the ability to withstand the SSE cannot be proven, a programme of modifications to guarantee protection of fire safety functions in the event of an SSE.

EDF carried out studies and defined the modifications to be implemented to ensure the equipment seismic resistance.

Progress: completed

2.1.3 Protected volume approach

Peer Review: *The use of a protected volume approach to demonstrate flood protection for identified rooms or spaces.*

Following the flooding of the Blayais site in 1999, EDF put in place a protected volume perimeter[3] on all the sites. The conformity of this protected volume was specifically inspected by ASN during the targeted inspections conducted in 2011.

Following the stress tests, ASN has set the prescriptions ECS–4 and ECS–5.

ECS–4: End of the Blayais OEF work (Blayais, Bugey, Cruas, Dampierre, Gravelines, Penly, Saint-Laurent-des-Eaux sites)

Before 31 December 2014, the licensee shall carry out work to protect the facilities against flooding.

Work to protect the facilities against flooding has been carried out.

ECS–5: Conformity of the protected volume

No later than 30 June 2012, the licensee shall carry out work to restore the conformity of the protected volume. The licensee shall implement the organisation and the resources to ensure that, with the passage of time, the protected volume retains its efficiency as assigned in the safety case.

Work to restore the conformity has been carried out by 30 June 2012. In addition, EDF has updated its baseline safety requirement for the periodic inspection for the protected volume.

Progress: completed

[3] The protected volume perimeter, which encompasses the buildings containing equipment capable of guaranteeing the safety of the reactors, was defined by EDF such as to ensure that an influx of water from outside this perimeter does not lead to flooding of the premises situated inside this perimeter.

2.1.4 Advanced warning

Peer Review: *The implementation of advanced warning systems for deteriorating weather, as well as the provision of appropriate procedures to be followed by operators when warnings are made.*

The licensee has taken operational measures to protect the sites from extreme meteorological conditions (flooding, extreme heat, extreme cold, low water, etc.) more specifically including alert systems in the event of a foreseeable hazard (high temperatures, riverside or coastal flooding, possibly combined with extremely high winds, rainfall) and agreements with outside organizations such as Météo France and the Prefecture. ASN checked that these systems were operational during the targeted inspections carried out in 2011. The conclusions of these inspections led ASN to issue prescription ECS–7 for the Cruas and Tricastin sites.

ECS–7: Measures to cope with site isolation in the event of flooding (Cruas, Tricastin sites)

Before 31 December 2012, the licensee shall demonstrate to ASN that it has implemented an organisation and resources able to deal with site isolation in the event of flooding.

These measures serve to overcome the lack of resources and provide for the monitoring of certain meteorological and hydrological parameters, among other things. The use of special operating rules is decided on the basis of predetermined meteorological or hydrological criteria (monitoring of river levels or sea level) to allow the safe shutdown of the reactors.

EDF has implemented an organisation and resources able to deal with site isolation in the event of flooding.

Progress: completed

2.1.5 Seismic instrumentation

Peer Review: *The installation of seismic monitoring systems with related procedures and training.*

Recommendation specific to France resulting from the 2012 peer review

The seismic instrumentation could be improved to a state of the art concept. It is also recommended to consider an upgrade of the corresponding safety rule RFS 1.3.b (1984)

The operating conditions of the seismic instrumentation installed on the sites were specifically verified by ASN during the targeted inspections conducted in 2011. The findings led ASN to set prescription ECS–8 in order to verify the conformity of the seismic instrumentation with the recommendations of RFS I.3.b[4].

ECS–8: Conformity of seismic instrumentation with RFS 1.3.b

Before 30 September 2012, the licensee shall check the conformity of its facilities with the provisions of basic safety rule I.3.b, the application of which is stipulated in the safety analysis report. The licensees shall submit to ASN an exhaustive summary of this review and the corrected deviations, plus a plan of action listing the correction time-lines for any remaining deviations.

[4] *Basic safety rule I.3.b 08/06/1984 concerning seismic instrumentation.*

EDF has verified the conformity of the seismic instrumentation. Based on the documentation about seismic instrumentation transmitted by EDF, ASN considers that the technology used enables these equipment items to fulfil their assigned safety function satisfactorily. ASN thus considers that updating of the basic safety rule relative to the seismic instrumentation is not necessary.

Progress: completed

2.1.6 Specific inspections and verifications of facilities

Peer Review: *The development of standards to address qualified plant walkdowns with regard to earthquake, flooding and extreme weather – to provide a more systematic search for non-conformities and correct them (e.g. appropriate storage of equipment, particularly for temporary and mobile plant and tools used to mitigate beyond design basis (BDB) external events).*

The Order of 7 February 2012[5] includes requirements applicable to the identification and treatment of deviations. Thus, the licensee has set up processes for detecting deviations during normal reactor operation, periodic checks, maintenance operations, conformity reviews during the periodic safety reviews. These processes particularly concern the material and organisational measures implemented in the event of an earthquake, flooding, or other hazards. These processes for systematically searching out deviations have resulted in hazard protection reinforcements.
Specific field verifications are carried out in the "compliance" part of periodic safety reviews as well as for the development of seismic PSAs.
Stress tests have also provided the opportunity to carry out specific investigations of the condition of the installations, including walkdowns of the actual condition of the installation.

Progress: completed

2.1.7 Assessment of margins with respect to the flood risk

Peer Review: *The analysis of incrementally increased flood levels beyond the design basis and identification of potential improvements, as required by the initial ENSREG specification for the stress tests.*

For the various hazards considered for each site, the licensee presented the margins between the flood level reached and the level of the protections, within the framework of the current design, and drew conclusions regarding the additional measures to be taken, where applicable. The licensee has also studied several situations which it considers to be representative for evaluating the cliff-edge effects. These situations use assumptions that go beyond the design basis. The conclusions of these studies led ASN to set prescription ECS–6.

ECS–6: Reinforcement of protection against flooding

Before 31 December 2013, the licensee shall present ASN with the modifications it intends to make, before 31 December 2017, to reinforce the protection of the facilities against the risk of flooding beyond the baseline requirement in effect on 1 January 2012, for example by raising the protected volume to protect against

[5] *Order of 7 February 2012 setting out the general rules applicable to basic nuclear installations.*

situations of total loss of the heat sink or electrical power supplies, for the beyond-design-basis scenarios, more particularly maximum rainfall and flooding induced by the failure of on-site equipment under the effect of an earthquake.

The modifications were carried out on all the sites concerned.

Progress: completed

Recommendation specific to France resulting from the 2012 peer review

The peer review team recommends to perform a comparative evaluation between the level of Design Basis Flood defined according to ASN requirements with the methodologies used in other European countries.

In the framework of ETSON, a comparison of the methods used in Europe to define hazard was carried out in 2014-2015.

Progress: completed

2.1.8 Assessment of margins with respect to natural hazards

Peer Review: *In conjunction with recommendation 2.1 and 3.1.7, the formal assessment of margins for all external hazards including, seismic, flooding and severe weather, and identification of potential improvements.*

Within the framework of the stress tests, the licensee assessed the margins with respect to the seismic and flood risks. The licensee also studied the margins in the event of extreme meteorological conditions such as wind, lightning, hail, and their combination, in the event of loss of the heat sink and electrical power supplies.

The analysis of these studies has led ASN to request additional studies (ECS–13 and ECS–15). ASN has favoured the application of modifications that effectively improve the safety of the facilities over detailed studies of margins which can be completed subsequently.

ECS–13: Study of the implementation of reactor trip in the event of an earthquake

Before 31 December 2012, the licensee shall submit to ASN a study of the advantages and drawbacks of implementing automatic reactor trip in the event of seismic loading, enabling the reactor to be shut down to the safest state, if the seismic level corresponding to a spectrum with half the amplitude of the design response spectrum of the site is exceeded.

EDF has examined the advantages and drawbacks of implementing a system of reactor trip in the event of an earthquake.

ECS–15: Heat sink design review

Before 30 June 2012, the licensee shall produce and submit to ASN an overall review of the design of the heat sink with regard to hazards having an impact on the flow and quality of water and the risk of clogging of the heat sink.

EDF has carried out studies and has proposed several changes which bring about an improvement in the monitoring of heat sinks and their protection against external hazards.

Progress: completed

Recommendation specific to France resulting from the 2012 peer review

The peer reviewers confirm the conclusion drawn by ASN that further studies need to be conducted in order to provide a complete and systematic design basis and safety margin assessment with respect to extreme weather conditions.
ASN states in the report that it asked the licensee to conduct the analyses for those climatic phenomena which are related to flooding. It is recommended to include also tornadoes, heavy rainfall, extreme temperatures and the relevant combinations of extreme weather conditions in these complementary studies. The review team recommends to consider extreme meteorological conditions in the required definition of the "hardened safety core".

ASN has defined the natural hazards to be considered for the definition of the hardened safety core, in particular extreme meteorological conditions.

Recommendation specific to France resulting from the 2012 peer review

The safety margins for seismic events above the Design Basis Earthquake have been roughly estimated by the licensee. It is appreciated that a more systematic evaluation will be required by ASN either by performing Probabilistic Safety Assessment or Seismic Margin Assessment.

EDF has written guides for verifying the seismic behaviour of equipment beyond their design basis requirements. EDF also develops seismic probabilistic safety assessments for the reactors periodic safety reviews.

Progress: completed

2.2 LOSS OF SAFETY SYSTEMS

***CNS:** Upgrading safety systems or installing additional equipment and instrumentation enhance the ability of each nuclear power plant to withstand an unexpected natural event without access to the electrical power grid for an extended period of time, including for an external event affecting multiple units.*

On completion of the stress tests, ASN considered that continuation of operation of the facilities examined required an increase in their robustness to extreme situations beyond the existing safety margins at that time. Consequently, ASN has set, amongst others, prescription ECS–1, the scope of which satisfies several of the peer review's recommendations, as well as the recommendation resulting from the second extraordinary meeting of the Convention on Nuclear Safety.

ECS–1.I to III: Defining the structures and components of the *"hardened safety core"*.

I. Before 30 June 2012, the licensee shall propose to ASN a hardened safety core of robust material and organisational measures designed, for the extreme situations studied in the stress tests, to:

- prevent an accident with fuel melt, or limit its progression,
- limit large-scale radioactive releases,
- enable the licensee to perform its emergency management duties.

II. Within this same time-frame, the licensee shall submit to ASN the requirements applicable to this hardened safety core. In order to define these requirements, the licensee adopts significant fixed margins in relation to the requirements applicable on 1 January 2012. The systems, structures and components (SSC) which are included in these measures shall be maintained in a functional state, in particular for the extreme situations studied in the stress tests. These SSC shall be protected against the internal and external hazards induced by these extreme situations, for example: falling loads, impacts from other components and structures, fires, explosions.

III. For this hardened safety core, the licensee installs SSC that are independent and diversified in relation to the existing SSC, in order to limit common mode risks. If applicable, the licensee shall justify the use of undiversified or existing SSC.

EDF presented the elements of the “hardened safety core” comprising:

- the objectives associated with the hardened safety core and its functional perimeter,
- the initiating events considered when defining the hardened safety core and their levels,
- the choices adopted when considering the events that these initiating events induce on the facility and the hardened safety core,
- the implementation conditions for the hardened safety core, more specifically the facility states in which it can be used,
- the requirements associated with the equipment of the hardened safety core,
- the methods and criteria used to demonstrate compliance with the requirements,
- the consideration of organisational and human factors in the implementation of the hardened safety core provisions,

- the emergency management provisions planned to meet the requirements of the hardened safety core.

Progress: completed

2.2.1 Cooling systems and alternate heat sink

Peer Review: *The provision of alternative means of cooling including alternate heat sinks. Examples include steam generator (SG) gravity alternative feeding, alternate tanks or wells on the site, air-cooled cooling towers or water sources in the vicinity (reservoir, lakes, etc.) as an additional way of enabling core cooling.*

During the stress tests, the licensee analysed situations entailing loss of heat sink and loss of electrical power supplies to the reactors, going beyond the situations studied in the current baseline requirements, more specifically considering scenarios which, on the one hand, have a lasting effect on all the reactors on a site and which can, on the other, be induced by an earthquake or external flooding, including of a level greater than that considered in the current baseline requirements. These additional studies have led ASN to issue prescriptions ECS–16 and ECS–17.

ECS–16: Emergency water supply resources and emergency water make-up in the reactor coolant system

I. Before 30 June 2013, the licensee shall present ASN with the intended modifications for installing technical backup devices for long-term removal of residual heat from the reactor and the spent fuel pool in the event of loss of the heat sink. These devices must meet the requirements concerning the hardened safety core presented in prescription ECS–1 above. Pending the commissioning of the ultimate backup electrical power supplies mentioned in paragraph II of prescription ECS–18, these devices must be kept functional in the event of prolonged and complete loss of the electrical power supplies, using temporary electrical systems if necessary.

II. Before 31 December 2012, the licensee shall present ASN with the modifications it intends to make for the installation, before 31 December 2013 unless specifically justified, of systems to ensure the injection of borated water into the reactor core in the event of total loss of site electrical power supplies when the reactor primary coolant system is open.

Before 30 June 2013, the licensee shall propose final requirements to ASN for these provisions and shall indicate whether or not they are part of the hardened safety core.

EDF presented the modifications (new shafts, basins or tanks depending on the site), as well as their requirements, to provide new means to ensure cooling of the reactor and the fuel pool.

EDF implemented modifications on 900 MWe reactors to manage situations when the primary coolant system is open. This is a mobile pump powered by the generator set installed in response to the ECS–18.III prescription. On the P4, P'4 and N4 type reactors, EDF has justified that the existing means make it possible to inject borated water into the primary coolant system in these situations.

ECS–17: Reinforcement of the facilities to manage long-duration situations of total loss of heat sink or total loss of electrical power supplies

No later than 31 December 2013, the licensee shall examine the requirements assigned to the equipment needed to manage total loss of heat sink or total loss of electrical power situations, with regard to temperature resistance, resistance to earthquakes, flooding and the effects induced on the facility by these hazards.

Before 31 December 2013, the licensee shall submit a summary of this review to ASN, along with proposals for changes to the baseline safety requirements and the resulting facility reinforcements in order to deal with these situations, in particular for long-duration scenarios.

EDF has defined the requirements with regard to temperature resistance, resistance to earthquakes, flooding assigned to the equipment needed to manage total loss of heat sink or total loss of electrical power situations.

The need for changes in the reference systems is examined as part of the periodic safety review process.

Progress: completed

2.2.2 Electrical power sources

Peer Review: *The enhancement of the on-site and off-site power supplies. Examples include adding layers of emergency power, adding independent and dedicated backup sources, the enhancement of the grid through agreements with the grid operator on rapid restoration of off-site power, additional and/or reinforced off-site power connections, arrangements for black start of co-located or nearby gas or hydro plants, replacing standard ceramic based items with plastic or other material that are more resistant to a seismic event. Another example is the possible utilization of generator load shedding and house load operation for increased robustness, however, before introducing such arrangements the risks need to be properly understood.*

During the stress tests, the licensee analysed situations with loss of electrical power supplies to the reactors going beyond the situations covered by the current baseline requirements, in particular considering scenarios which, on the one hand have a lasting effect on all the reactors on a site and which, on the other hand, could be caused by an earthquake or external flooding, including of a level higher than that considered in the current baseline requirements. These additional studies led ASN to set prescriptions ECS–18.II&III.

ECS–18.II: Additional electrical power supply means

As early as possible, given the constraints of fleet-wide deployment, and in any case before 31 December 2018, the licensee shall - for each reactor on the site - install an additional electrical power supply capable of supplying the systems and components of the hardened safety core as per prescription ECS–1 if the other off-site and on-site electrical power supplies are lost.

These systems must meet the requirements concerning the hardened safety core as per prescription ECS–1.

EDF has carried out major work on all of its sites. For each of the 56 reactors in operation, EDF has built a "bunkerized" building, which must resist extreme hazards. This large building houses the ultimate backup diesel generator set (DUS) and the means to ensure its cooling and power supply, as well as its fuel tanks.

EDF has put this equipment into operation for 54 of the 56 reactors in operation. Concerning the two other reactors (Paluel site), the DUS for reactor No. 2 is at the end of the test phase and should be operational by the end of December 2020; the DUS for reactor No. 1 is currently being tested and should be operational by the end of February 2021.

The delays in the commissioning of the DUS on all the reactors are the result of difficulties encountered in construction operations, hazards encountered during commissioning tests, and specific measures implemented to limit the spread of the Covid-19 pandemic.

ECS–18.III: Installation of provisional emergency electrical power supplies pending installation of the means required by prescription ECS–18.II

In the meantime, and no later than 30 June 2013, the licensee shall install a temporary system on each reactor for supplying:

- the I&C (Instrumentation and Control system) necessary in the event of loss of the off-site and on-site electrical power supplies,
- the control room lighting.

The licensee installed a backup diesel generator on each reactor within the required time frame.

Finally, each site can have mobile means provided by the nuclear rapid intervention force (FARN, cf. §2.3.14), including diesel generators.

Progress: completed

2.2.3 Electric backup batteries

Peer Review: *The enhancement of the DC power supply. Examples include improving the battery discharge time by upgrading the existing battery, changing/diversifying battery type (increasing resistance to common-mode failures), providing spare/replacement batteries, implementing well-prepared load shedding/staggering strategies, performing real load testing and on-line monitoring of the status of the batteries and preparing dedicated recharging options (e. g. using portable generators).*

Recommendation specific to France resulting from the 2012 peer review

The reviewers recommend ASN to also consider the benefits of recharging the batteries before their complete depletion in case of a total Station Black Out (total loss of electrical power supplies) in addition to the foreseen battery capacity increase.

Electric batteries provide and guarantee continuity of the electrical supply to certain key equipment items in the event of loss of the off-site electrical power supplies and when the emergency generator sets are not operating. The protection, capacity and life of these batteries were specifically studied within the framework of the stress tests. ASN has set prescription ECS–18.I.

ECS–18.I: Increased battery life

I. Before 30 June 2012, the licensee shall present ASN with the modifications it intends to make before 31 December 2014 in order to significantly increase the operating life of the batteries used in the event of loss of the off-site and on-site electrical power supplies.

The operating life of the batteries has been increased from 1 hour to 2 hours. These batteries can be recharged by the DUS.

Progress: completed

2.2.4 Operational and preparatory actions

> ***Peer Review:*** *Implementation of operational or preparatory actions with respect to the availability of operational consumables. Examples include, ensuring the supply of consumables such as fuel, lubrication oil, and water and ensuring adequate equipment, procedures, surveillance, drills and arrangements for the resupply from off-site are in place.*

The actions to be implemented further to a large-scale event are of a material and organisational nature. Aspects considered include the autonomy of the sites in all circumstances - especially further to an event leading to site isolation - the bringing in of outside resources, and personnel training.

These aspects are subject to ASN inspections. In addition, the FARN (cf. §2.3.14) has set up an organization and means to supply the sites with consumables, including in cases where access conditions deteriorate.

Progress: completed

2.2.5 Instrumentation and measuring

> ***Peer Review:*** *The enhancement of instrumentation and monitoring. Examples include separate instrumentation and/or power sources to enable monitoring of essential parameters under any circumstances for accident management and the ability to measure specific important parameters based on passive and simple principles.*

Recommendation specific to France resulting from the 2012 peer review

> *Further qualification to Severe Accident environmental conditions and against external hazards; and ensuring electrical power supply (Spent fuel pools instrumentation will be included into the hardened safety core).*
> *[…]*
> *In case of loss of the electrical power supplies for the operating Nuclear Power Plants, the instrumentation that detects entry into the Severe Accident situation is no longer available in the control room.*
> *[…]*
> *For the operating NPPs in the event of an earthquake, the availability of the instrumentation useful in SA situations is not guaranteed because it is not earthquake classified. These should therefore also be integrated into the hardened safety core.*
> *[…]*

During the stress tests, complementary studies were conducted to examine the robustness of the instrumentation & control necessary for diagnosis and guidance of the operating team during electrical power failure. The conclusions of this work led ASN to set prescriptions ECS–19 and ECS–20.

ECS–19: Redundancy of instrumentation for detecting reactor vessel melt-through and hydrogen in containment

I. As early as possible, given the constraints of cross-fleet deployment, and in any case before 31 December 2017, the licensee shall install redundant means in the reactor pit to detect vessel melt-through as well as in the containment to detect the presence of hydrogen.

Instrumentation in the control room shall indicate corium melt-through of the vessel.

II. Before 31 December 2013, the licensee shall propose final requirements to ASN for these provisions and shall indicate whether or not they are part of the hardened safety core.

EDF has defined the requirements associated with its redundant instrumentation. EDF has set up these instrumentations for all of its 19 sites. EDF considers that this equipment does not belong to the hardened safety core.

ECS–20: Reinforcement of pool condition instrumentation

I. Before 30 June 2012, the licensee shall present ASN with the modifications to be made, for measuring both the condition of the fuel storage pool (temperature and water level in the spent fuel pool) and the radiological atmosphere in the fuel building hall.

II. Pending their implementation:

- By 31 December 2012 at the latest, the licensee shall provide its national emergency organisation with charts indicating the times to reach boiling point in the event of total loss of cooling, according to the residual power of the fuel stored in the spent fuel pool.
- No later than 31 December 2013, the licensee shall ensure that level measurement in the event of total loss of electrical power supplies is available.

The fuel pools are equipped with instrumentation for measuring the water level: this instrumentation is now electrically backed up. It is also currently reinforced to ensure its resistance to earthquakes and damaged environmental conditions.

The fuel pools have temperature sensors: the temperature measurements are only used to ensure initiation of incidental or accidental procedures. Abacuses are used to evaluate the onset of boiling and can compensate for the absence of temperature measurement in deteriorated conditions.

The fuel pools have activity measuring chains in the hall of the fuel building that are used in particular in case of fuel handling. For other accidental situations, these measurements are not used because the actions of the operators (water makeup) are carried out from premises located outside the pool hall or the fuel building.

Progress: completed

2.2.6 Improvement in safety at shutdown and in the different reactor states

Peer Review: *The enhancement of safety in shutdown states and mid-loop operation. Examples of improvements include, reducing or prohibiting mid-loop operation, adding dedicated hardware, procedures and drills, the use of other available water sources (e. g. from hydro-accumulators), requiring the availability of SGs during shutdown operations and the availability of feed water in all modes.*

During the stress tests, the licensee analysed situations with loss of heat sink and loss of electrical power supplies to the reactors, going beyond the situations considered in the current baseline requirements. It considered all the states of reactor and fuel storage pool, and scenarios which firstly have a lasting effect on all the reactors on a site and secondly could be caused by an earthquake or external flooding, including of a level higher than that considered in the current baseline requirements. For each of these situations, the times before the fuel becomes exposed in the event of loss of the cooling systems and the electrical supplies have been evaluated. ASN issued the prescriptions indicated in §2.2.1 to §2.2.5.

Progress: completed

2.2.7 Reactor primary coolant pump seals

Peer Review: *The use of temperature-resistant (leak-proof) primary pump seals.*

The licensee has installed high-temperature seals on all reactor primary pumps which purposes are to withstand loss of cooling for an extended period.

Progress: completed

2.2.8 Ventilation

Peer Review: *The enhancement of ventilation capacity during SBO to ensure equipment operability.*

Many items of equipment cannot function in the medium and long term if they, or the premises in which they are situated, are not ventilated or cooled. As improving the robustness of certain items of equipment required for cooling the reactor or the spent fuel pool is part of the hardened safety core, this also implies that the robustness of their means of ventilation must also be considered. At the end of the stress tests ASN issued prescription ECS–17.

As indicated in §2.2.1, prescription ECS–17 requests an assessment of the requirements for the equipment necessary to manage situations of total loss of the heat sink or power supply. This includes the requirement for ventilation to ensure the operability of equipment in these situations.

Progress: completed

2.2.9 Main and emergency control rooms

Peer Review: *The enhancement of the main control room (MCR), the emergency control room (ECR) and emergency control centre (ECC) to ensure continued operability and adequate habitability conditions in the event of a station black-out (SBO) and in the event of the loss of DC (this also applies to Topic 3 recommendations).*

Total loss of electrical power supplies (loss of the off-site sources and the on-site diesel generators), also called station black-out (SBO), is a situation that leads to the loss of the dynamic containment ensured by the ventilation systems, and particularly the main control room ventilation function and this ventilation's filtration via iodine trap.

ASN has issued prescription ECS–18.III.

As indicated in §2.2.2, prescription ECS–18.III requires the installation of emergency power supplies. These allow the supply of the necessary reactor control system from the control room, the lighting in the control room, and the ventilation-filtration system.

Progress: completed

2.2.10 Spent fuel pool

Peer Review: *The improvement of the robustness of the spent fuel pool (SFP). Examples include reassessment/upgrading SFP structural integrity, installation of qualified and power-independent monitoring, provisions for redundant and diverse sources of additional coolant resistant to external hazards (with procedures and drills), design of pools that prevents drainage, the use of racks made of borated steel to enable cooling with fresh (unborated) water without having to worry about possible recriticality, redundant and independent SFP cooling systems, provision for additional heat exchangers (e. g. submerged in the SFP), an external connection for refilling of the SFP (to reduce the need for an approach linked to high doses in the event of the water falling to a very low level) and the possibility of venting steam in a case of boiling in the SFP.*

CNS: *Installing additional equipment and instrumentation in spent fuel pools to ensure cooling can be maintained or restored in all circumstances, or performing additional technical evaluations to determine if additional equipment and instrumentation are needed*

The stress tests included an in-depth examination of the consequences of a major natural hazard on the systems that evacuate the residual heat from the fuel stored in pools, on the integrity of the pools in the fuel building or the reactor building and the systems connected to them, and the risks of storage rack deformation and falling loads.

The conclusions of the analyses have led ASN to issue prescriptions ECS–16.I, ECS–18.II, ECS–20, ECS–21, ECS–22, ECS–23 and ECS–25.

As indicated in §2.2.1 and §2.2.2, prescriptions ECS–16.I and ECS–18.II impose the implementation of makeup means for the pool, powered by complementary electrical supply means.

As indicated in §2.2.5, prescription ECS–20 requires the implementation of reinforced instrumentation of the condition of the spent fuel pool.

ECS–21: Additional measures to prevent or mitigate the consequences of a fuel transport package falling in the fuel building.

(Bugey and Fessenheim sites)

Before 31 December 2012, the licensee shall send ASN a study of the consequences of an accident involving a fall by a spent fuel transport package, including in the extreme situations studied by the stress tests. A study of possible additional measures to prevent or mitigate the consequences of this fall shall be presented before 31 December 2013.

EDF has analysed the study of consequences of accidental fall of a transport package. EDF defined damping equipment to mitigate the consequences in case of fall.

ECS–22: Reinforcement of the measures to prevent accidental rapid draining of the fuel storage pools

Before 30 June 2012, the licensee shall present ASN with the modifications to be made to its facilities in order to reinforce prevention of the risk of accidental draining of the fuel building pool:

- measures to prevent complete and rapid siphon emptying of the pool in the event of rupture of a connected pipe,
- automation of isolation of the cooling system intake line.

The measures to prevent complete and rapid siphon emptying of the pool in the event of rupture of a connected pipe, as well as the automation of isolation of the cooling system intake line, have been implemented on all reactors.

ECS–23: Placing a fuel assembly in safe position during handling

Before 30 June 2012, the licensee shall submit to ASN a study of the possible measures, in the event of total loss of electrical power supplies and accidental emptying, to ensure the safe positioning of a fuel assembly being handled in the fuel building, before the ambient conditions no longer allow access to the premises.

EDF defined modifications, in the event of total loss of electrical power supplies and accidental emptying, to ensure the safe positioning of a fuel assembly being handled in the fuel building, in less than two hours.

ECS–25: Reinforcement of the provisions for managing a transfer tube leak or in the compartment drainage pipes

I. Before 31 December 2012, the licensee shall submit to ASN a study of the possible changes to equipment or operating conditions in order to prevent uncovering of the assemblies during handling, as the result of a break in the transfer tube between the pools in the reactor and fuel buildings or in the compartment drainage pipes.

II. Before 31 December 2012, the licensee shall present ASN with the possible changes to equipment or operating conditions to be made before 30 June 2013, in order to prevent the rapid loss of water inventory above the stored fuel assemblies, as a result of a break in the transfer tube between the pools in the reactor and fuel buildings or in the compartment drainage pipes.

EDF carried out a seismic resistance study as well as modification studies to prevent uncovering of the fuel assembly during handling in the event of a break in the transfer tube or in the compartment drainage pipes. EDF has taken organisational measures (by modifying the administrative lock-out conditions for valves to guarantee their positions) in order to prevent exposure of the fuel assembly in the event of a break in the compartment drainage pipes.

Progress: completed

2.2.11 Separation and independence of the safety systems

Peer Review: *The enhancement of the functional separation and independence of safety systems. Examples include the elimination of full dependence of important safety functions on auxiliary systems such as service water and the introduction of an alternate source of cooling.*

Pursuant to the international recommendations, the French regulations applicable in the field of nuclear safety, more particularly article 3.1 of the BNI order of 7 February 2012, provide for the implementation of successive and sufficiently independent levels of defence, and a cautious design approach integrating sizing margins and ensuring redundancy, diversification and adequate physical separation of items important for protection that fulfil functions necessary for the nuclear safety case.

Progress: completed

2.2.12 Accessibility

Peer Review: *The verification of assured flow paths and access under SBO conditions. Ensure that the state in which isolation valves fail and remain, when motive and control power is lost, is carefully considered to maximize safety. Enhance and extend the availability of DC power and instrument air (e. g. by installing additional or larger accumulators on the valves). Ensure access to critical equipment in all circumstances, specifically when electrically operated turnstiles are interlocked.*

Following the stress tests, ASN has issued prescriptions ECS–18.II&III, ECS–31 and ECS–35.I&II that more particularly require an increase in the robustness of the electrical power supplies and a verification of the feasibility of accident management measures for the situations studied in the stress tests.

As indicated in §2.2.2, ECS–18.II&III prescriptions require additional power supplies to reinforce the robustness of the installation in case of total loss of power supplies.

ECS–31: Modifications to ensure facility management further to releases

Before 31 December 2012, the licensee shall send ASN a file presenting the planned modifications on its site to ensure that, in the event of release of dangerous substances or opening of the U5 venting-filtration system, operation and monitoring of all the facilities on the site are guaranteed until a long-term safe state is reached; the corresponding deployment schedule shall also be provided.

EDF has implemented measures to mitigate the release of radioactive substances in accident situations:

- a provision to anticipate, in a situation of total loss of electrical power supply, the closing of high priority containment isolation valves ;
- the installation of alkalizing baskets in the buildings of the 1300 MWe and N4 type reactors to limit the source term released (basic pH of the sumps) in accident situations. This modification, which limits gaseous iodine releases, has a favourable effect on the radiological environment of the control room and on the accessibility of the site ;
- for 1300 MWe and N4 type reactors, the electrical back-up for the filtration of the space between the two walls of the reactor containment.

EDF has also implemented an electrical back-up for the filtration of the air entering the control room.

ECS–35.I and II: Feasibility of emergency management actions in extreme situations

I. No later than 31 December 2012, the licensee shall define the human actions required for management of the extreme situations studied in the stress tests. It shall check that these actions can effectively be carried out given the intervention conditions likely to be encountered in such scenarios. It shall for instance take account of the relief of the emergency teams and the logistics necessary for the interventions. It shall specify any material or organisational adaptations envisaged. On the deadline date, the licensee shall transmit a summary of the results of this work and the envisaged measures. On 30 June 2012, the licensee shall send ASN an interim report.

II. Before 31 December 2012, the licensee shall send ASN a list of the necessary emergency management skills, specifying whether these skills could be provided by outside contractors. The licensee shall provide proof that its organisation ensures the availability of the necessary skills in an emergency situation, including if outside contractors are used.

EDF has defined the human actions required and their competences needed for the management of extreme situations studied in the stress tests, as well as the measures to have specialized teams capable of intervening on the sites.

Progress: completed

2.2.13 Mobile equipment

Peer Review: *The provision of mobile pumps, power supplies and air compressors with prepared quick connections, procedures, and staff training with drills. Mobile devices are intended to enable the use of existing safety equipment, enable direct feeding of the primary or secondary side, allow extended use of instrumentation and operation of controls, allow effective fire-fighting, and ensure continued emergency lighting. The equipment should be stored in locations that are safe and secure even in the event of general devastation caused by events significantly beyond the design basis (this also applies to Topic 3 recommendations).*

The emergency procedures, which incorporate the new measures identified in the stress tests, provide for the use of mobile equipment situated either on or off the site, and whose availability and operability must be guaranteed. ASN has set prescription ECS–30.

French regulations require the licensee to ensure the availability and operability of the mobile means required for emergency management. This is verified during inspections.

In addition, all the installations have been modified to enable the connection of the mobile emergency means transported by the FARN (see §2.3.14).

ECS–30: Storage of mobile means.

[…]

III. No later than 30 June 2013, the licensee shall store its mobile resources necessary for emergency management in appropriate premises or zones able to withstand the SSE and flooding in the event of the flood safety margin level being reached.

This measure, implemented by EDF, is checked as part of the ASN inspections.

Progress: completed

2.2.14 Protection of the systems

Peer Review: *The provision for a bunkered or "hardened" system to provide an additional level of protection with trained staff and procedures designed to cope with a wide variety of extreme events including those beyond the design basis (this also applies to Topic 3 recommendations).*

The hardened safety core consisting of material and organisational measures aims at implementing an additional level of protection. ASN has set prescription ECS–1 (as indicated in §2.2).

Progress: completed

2.2.15 Multiple accidents

> ***Peer Review:*** *The enhancement of the capability for addressing accidents occurring simultaneously on all plants of the site. Examples include assuring preparedness and sufficient supplies, adding mobile devices and fire trucks and increasing the number of trained and qualified staff (this also applies to Topic 3 recommendations).*

Analysis of the management of multiple accidents affecting all or some of the reactors of a given site simultaneously has called into question the previously implemented material and organisational provisions. In this context ASN has issued prescriptions ECS–32 and ECS–36.II.

ECS–32: Multiple plant unit emergency organisation

Before 31 December 2012, the licensee shall reinforce its material and organisational measures to take account of accident situations simultaneously affecting all or some of the facilities on the site.

The modified on-site emergency plan (PUI) has been deployed on all EDF sites since 15 November 2012. It takes into account accident situations simultaneously affecting several facilities on a given site.

ECS–36.II: The nuclear rapid intervention force (FARN)

II. On 31 December 2012, this organisation will be deployable for intervention on a reactor on the site. It shall be able to intervene simultaneously on all the reactors of the site by the end of 2014.

The FARN (see §2.3.14) has the human and equipment resources to act simultaneously on all the reactors on the same site.

Progress: completed

2.2.16 Inspection of equipment and training programmes

> ***Peer Review:*** *The establishment of regular programs for inspections to ensure that a variety of additional equipment and mobile devices are properly installed and maintained, particularly for temporary and mobile equipment and tools used for mitigation of BDB external events. Development of relevant staff training programmes for deployment of such devices.*

The checks carried out by the licensee to verify the presence, operability and maintenance of the equipment and other material provisions are required by the regulations applicable to nuclear facilities, and are themselves subject to regular inspections by ASN.

The correct implementation of the monitoring and maintenance programmes and the training of the teams were examined during targeted inspections carried out by ASN in 2011. The findings led ASN to issue a prescription (ECS–5) requiring lasting conformity of the protected volume.

As indicated in §2.1.13, prescription ECS–5 requests that the licensee shall implement the organisation and the resources to ensure that the protected volume maintains over time its efficiency as assigned in the safety case. On certain sites, protection of the facilities against flooding is based on the setting of mobile equipment. Compliance with this prescription more particularly requires the implementation of a specific monitoring programme and increased training of the personnel concerned. These aspects are checked in the course of the normal inspection programme for the facilities.

Progress: completed

2.2.17 Additional studies in areas where uncertainties remain

Peer Review: *The performance of further studies in areas where there are uncertainties. Uncertainties may exist in the following areas:*

- *The integrity of the SFP and its liner in the event of boiling or external impact.*
- *The functionality of control equipment (feed water control valves and SG relief valves, main steam safety valves, isolation condenser flow path, containment isolation valves as well as depressurisation valves) during the SBO to ensure that cooling using natural circulation would not be interrupted in a SBO (this is partially addressed in recommendation 3.2.10).*
- *The performance of additional studies to assess operation in the event of widespread damage, for example, the need for different equipment (e.g. bulldozers) to clear the route to the most critical locations or equipment. This includes the logistics of the external support and related arrangements (storage of equipment, use of national defence resources, etc.).*

The stress tests analysis of the robustness of the facilities in the event of loss of the electrical power supplies or the heat sink revealed, in addition to the safety enhancement measures mentioned earlier, the need to analyse certain phenomena in more detail, in particular the study of how the behaviour of the fuel and the water in the spent fuel pool evolves over time in loss of cooling situations. ASN formulated prescription ECS–24 in this respect.

ECS–24: Thermohydraulic development of a pool accident

Before 31 December 2012, the licensee shall submit to ASN a study of the evolution over time of the behaviour of the fuel and the water present in the spent fuel pool, in emptying and loss of cooling situations. The licensee shall in particular evaluate the ambient radiological atmosphere in a pool boiling situation, along with the hydrogen concentrations, as a result of radiolysis, that could be reached in situations involving a loss of ventilation in the fuel building. At that time, the licensee shall propose and justify the measures that could be taken.

The studies submitted describe the kinetics and consequences of boiling in the spent fuel pool. The measures consist in maintaining a sufficient water inventory in the pool through water make-up, and then providing cooling by mobile means.

EDF has evaluated that, in case of a situation of loss of ventilation, the maximum concentration of hydrogen reached in the hall of the spent fuel building due to the radiolysis of water is homogeneous and lower than the lower flammability limit in dry air, comparable to the lower explosive limit (4%).

Progress: completed

2.3 SEVERE ACCIDENT MANAGEMENT

Recommendation specific to France resulting from the peer review of 2012

The main improvements to be made in order to cope with severe accidents, possibly affecting multiple units and caused by natural hazards have been pointed out by ASN. One recommendation of the peer review process is to guarantee their implementation.

The prescriptions prescribed by ASN have application deadlines and are legally binding. ASN is particularly vigilant in monitoring the implementation of all the prescriptions it has issued.

Progress: completed

2.3.1 WENRA reference levels

Peer Review: *The incorporation of the WENRA reference levels related to severe accident management (SAM) into their national legal frameworks, and ensure their implementation in the installations as soon as possible. This would include:*

- *Hydrogen mitigation in the containment - Demonstration of the feasibility and implementation of mitigation measures to prevent massive explosions in case of severe accidents.*
- *Hydrogen monitoring system - Installation of qualified monitoring of the hydrogen concentration in order to avoid dangerous actions when concentrations that allow an explosion exist.*
- *Reliable depressurization of the reactor coolant system – Hardware provisions with sufficient capacity and reliability to allow reactor coolant system depressurization to prevent high-pressure melt ejection and early containment failure, as well as to allow injection of coolant from low pressure sources.*
- *Containment overpressure protection - Containment venting via the filters designed for severe accident conditions.*
- *Molten corium stabilization - Analysis and selection of feasible strategies and implementation of provisions against containment degradation by molten corium.*

Following publication of the TSN Act in 2006 and its application decrees, ASN completely revised the general technical regulations applicable to BNIs.

The order of 7 February 2012 setting the general rules for basic nuclear installations takes up the WENRA reference levels that come under this level of regulatory text. This order also provides a foundation for several of the requirements expressed by ASN further to the stress tests. This order was supplemented by several ASN statutory resolutions or guides published in order to continue implementation of the WENRA reference levels.

Concerning the implementation of the reference levels on site, in particular those concerning severe accidents:

- all the reactors in operation are equipped, since the end of 2007, with hydrogen passive autocatalytic recombiners (PAR) intended to prevent global hydrogen detonation in the reactor containment;
- all the reactors in operation are equipped with a redundant instrumentation dedicated to severe accident management, able to detect reactor vessel melt-through and the presence of hydrogen in the containment;

- the prevention of high pressure meltdown sequences is based on voluntary opening of the pressuriser safety relief valve tandems. A system was installed to allow valve opening, even in the case of total loss of power supply;
- all the reactors in operation are equipped with the venting-filtration U5 system to limit the pressure in the reactor containment in the event of an accident;
- On the Flamanville 3 EPR, the CHRS (Containment Heat Removal System), included at the design stage, allows the residual power removal from the containment as well as the corium cooling.

Progress: completed

2.3.2 Provisions for ensuring equipment resistance to severe accidents

Peer Review: *Adequate hardware provisions that will survive external hazards (e.g. by means of qualification against extreme external hazards, storage in a safe location) and the severe accident environment (e.g. engineering substantiation and/or qualification against high pressures, temperatures, radiation levels, etc.), in place, to perform the selected strategies.*

Recommendation specific to France resulting from the peer review of 2012

Several equipment items required for severe accident management are not qualified for earthquakes.
[…].
Passive autocatalytic re-combiners (PAR) designed for design based accidents (DBA) are seismically qualified but those for severe accidents do not have seismic qualification
[…].
Qualification against external hazards of the hydrogen recombiners and the venting filters in use on the reactor fleet will be requested.

On the reactors currently in operation, the current baseline safety requirements do not require the equipment for mitigating the consequences of a severe accident and radioactive releases to take external hazards into account.

ASN formulated prescription ECS–1.II and ECS–29.

As indicated in §2.2, prescription ECS–1.II requires that the equipment used to mitigate the consequences of a severe accident and radioactive releases be robust to hazards beyond the current level taken into account.

ECS–29: Reinforcement of the U5 venting-filtration system ("sand-bed filter")

Before 31 December 2013, the licensee shall submit to ASN a detailed study of the possible improvements to the U5 venting-filtration system, taking account of the following points:

- resistance to hazards,
- limitation of hydrogen combustion risks,
- efficiency of filtration in the case of simultaneous use on two reactors,
- improved filtration of fission products, in particular iodine,
- radiological consequences of opening the device - in particular for accessibility of the site - and the radiological atmosphere of the emergency premises and control room.

The licensee has submitted to ASN a detailed study of the possible improvements to the U5 venting-filtration system, considering in particular its resistance to hazards.

Progress: completed

2.3.3 Provisions for the management of severe accidents induced by a severe external event

Peer review: *The systematic review of SAM provisions focusing on the availability and appropriate operation of plant equipment in the relevant circumstances, taking account of accident initiating events, in particular extreme external hazards and the potential harsh working environment.*

ASN has instructed EDF (ECS–35.I&II) to check that the emergency management actions planned for in extreme situations studied for the stress tests are effectively achievable. It also instructed EDF (ECS–14.I) to take into consideration the industrial risks induced in extreme situations by nearby risk-prone facilities.

As indicated in §2.2.12, prescription ECS–35.I&II calls for ensuring the feasibility of emergency management actions in extreme situations.

ECS–14.I: Integration of industrial risks in extreme situations.

I. No later than 31 December 2013, the licensee shall supplement its ongoing studies with the inclusion of the risk arising from activities taking place near its facilities, in the extreme situations studied by the stress tests and in conjunction with neighbouring licensees responsible for these activities (nuclear facilities, installations classified on environmental protection grounds or other facilities liable to constitute a hazard). By that deadline, the licensee shall propose any modifications to be made to its facilities or their operating procedures as a result of this analysis.

EDF has carried out, for all sites, studies to determine the risks induced by potential hazards due to the industrial environment on a NPP site and the possible modifications to be made. EDF indicates that the studies to verify the robustness of the hardened safety core functions take this risk into account.

Progress: completed

2.3.4 Enhancing the severe accident management guides (SAMG)

Peer review: *In conjunction with the recommendation 2.4, the enhancement of SAMGs taking into account additional scenarios, including, a significantly damaged infrastructure, including the disruption of plant level, corporate-level and national-level communication, long-duration accidents (several days) and accidents affecting multiple units and nearby industrial facilities at the same time.*

Following the stress tests, ASN has issued the following prescription.

ECS–14.II: Coordination with neighbouring industrial operators in the event of an emergency

II. No later than 30 September 2012, the licensee shall take all steps, for example by means of agreements or detection and alert systems, to ensure that it is rapidly informed of any event liable to constitute an off-site hazard for its facilities, in order to protect its staff against these hazards and to ensure that emergency management is coordinated with the neighbouring operators.

EDF has defined alert systems for all of its sites in order to better coordinate with neighbouring operators.

Progress: completed

CNS**:** *Performing or planning an evaluation of the guidance that is to be used by the operator to manage emergency situations resulting from severe accidents caused by extreme natural phenomena at NPPs, including for low power and shutdown states. These documents include emergency operating procedures to prevent core damage, severe accident management guidelines to prevent containment failure, and extensive damage mitigation guidelines to address accidents that result in fires or explosions that affect a large portion of a NPP.*

Recommendation specific to France resulting from the peer review of 2012

The French SAMGs however, do not cover accidents in the SFP, and do not include multi-unit events. Shutdown states are currently only implemented for the 900 MWe series, their implementation for the other series of the French reactor fleet is foreseen.

The reactors in operation have severe accident management guides (SAMGs), which are designed to provide assistance to emergency teams in order to ensure the best possible containment of radioactive products. Indeed, when the emergency teams apply the SAMG, the priority is no longer the prevention of core melt but that of the containment. In these guides, possible actions to reduce the consequences of a severe accident are described.

The different work carried out in the context of stress tests took into account scenarios that had not been considered in the past. Their conclusions are taken into account for the revisions of the documents relating to the management of severe accidents. In particular, these documents cover, for all reactors, reactor shutdown states.

Progress: completed

2.3.5 Validation of the severe accident management guides (SAMG)

Peer Review: *The validation of the enhanced SAMGs.*

The various documents relative to severe accident management are validated following the usual processes established by the licensees and ASN.

Progress: completed

2.3.6 Severe accident simulation exercises

Peer Review: *Exercises aimed at checking the adequacy of SAM procedures and organizational measures, including extended aspects such as the need for corporate and nation level coordinated arrangements and long-duration events.*

The crisis organization of the EDF nuclear fleet is designed to take into account emergency situations, in particular to avoid any radioactive release into the environment or to limit them as much as possible. It is based on two levels:

- the local level at each site under the direction of the NPP director or his representative. It is structured into teams that cover the four main areas required to manage emergency (expertise, decision, action, communication);
- the National Emergency Organization (ONC), which supports the local level with specialists from EDF's corporate services. The emergency organization of the EDF nuclear fleet is equipped with human and material means that can be called upon 24 hours a day and 7 days a week by a nuclear power plant.

Public authorities (the Government, ASN and technical experts) and licensees in radiological emergencies intervene in their respective fields of competence relating to assessment, decision-making, action and communication, for which regular audioconferences are organized. Exchanges lead to decisions and orientations relating to the safety of the installation and the protection of the population. Similarly, relations between the communication units and the spokespersons of the emergency centers ensure consistency in the information provided to the public and the media.

In particular, exercises make it possible to train the people likely to be involved and to implement the various aspects of the emergency organization, as well as the procedures provided for in the various plans and reference systems (national plan, Government reference systems, emergency plans and municipal safeguard plans).

The organisational means and equipment necessary for emergency management are identified in the on-site emergency plans of the sites, along with their storage locations and deployment procedures. They are tested regularly and training in their use are provided during exercises.

The French regulations provide for the conducting of accident simulation exercises, including severe accident, at regular intervals. Each NPP carries out several exercises each year, including one in which the on-site emergency plan is deployed. In addition, each NPP carries out a national-scale exercise at intervals not to exceed 5 years.

French regulations require the licensee to ensure the operational nature of the organization and emergency means in the event of an accident affecting all or part of the installations on the same site.

These various points are verified during ASN inspections.

Progress: completed

2.3.7 Severe accident management training

Peer Review: *Regular and realistic SAM training exercises aimed at training staff. Training exercises should include the use of equipment and the consideration of multi-unit accidents and long-duration events. The use of the existing NPP simulators is considered as being a useful tool but needs to be enhanced to cover all possible accident scenarios.*

French regulations and the EDF on-site emergency plans (PUI) provide for regular and appropriate training of the personnel intervening on site, and the performance of several exercises on each NPP each year. Thus, each section of the site's PUI (radiological and toxic safety, climatic and similar hazards safety, etc.) must undergo an overall exercise every 3 years. The number of exercises per year and per site is determined according to the number of emergency team members, as each team member must attend one PUI exercise per year. Implementation of the new material and organisational provisions is accompanied by specific training actions to ensure their effectiveness.

The PUI plan takes into account accident situations affecting several installations on the same site at the same time. The implementation of this PUI plan has been accompanied by specific training for personnel.

Following the stress tests, ASN has issued prescriptions ECS–10 and ECS–35.III.

ECS–10: Reinforcement of team preparation in the event of an earthquake

Before 30 June 2012, the licensee shall send ASN a training programme for the operating teams to enhance their level of preparedness for earthquake situations. This programme shall in particular include regular in-situation training exercises. This programme shall have been followed by the reactor operating personnel in charge of the seismic instrumentation rack and of the associated operating measures no later than 31 December 2012. The other site operating teams shall receive information by 31 December 2012 and shall have followed the entire programme no later than 31 December 2013.

All operating teams have undergone a training program to reinforce their level of preparedness for earthquake situations. This training is carried out every 3 years.

ECS–35.III: Severe accident management training

III. Before 30 September 2013, the licensee shall provide the personnel concerned with the training and preparation needed to enable them to respond to particularly stressful accident situations. It shall ensure that the outside contractors liable to intervene in management of the emergency adopt similar requirements concerning the preparedness and training of their own staff.

EDF has updated its training system for the persons mobilised under the on-site emergency plan. EDF developed a training plan for the FARN (nuclear rapid intervention force) personal (cf. §2.3.14). No EDF subcontractors intervene in NPP emergency situations.

Progress: completed

2.3.8 Extension of the scope of the severe accident management guides (SAMG) to all reactor states

Peer Review: *The extension of existing SAMGs to all plant states (full and low-power, shutdown), including accidents initiated in SFPs.*

This point is addressed in §2.3.4.

Progress: completed

2.3.9 Improvement in communication

Peer Review: *The improvement of communication systems, both internal and external, including transfer of severe accident related plant parameters and radiological data to all emergency and technical support centre and regulatory premises.*

CNS: *Improving their radiation monitoring and communications capabilities and enhancing public communications, such as via dedicated public websites.*

Following the stress tests, ASN has issued prescription ECS–30.

ECS–30: Reinforcement of the means of communication

[…]

II. No later than 30 June 2012, the licensee sets up independent communication resources allowing direct contact between the site and the national emergency organisation defined in the interministerial directive of 7 April 2005.

These communication resources were implemented in June 2012.

In addition, EDF has a redundant and secure communication system, in addition to the additional satellite telephone resources that were deployed on the sites in 2012 to enable a link in an extreme case in redundancy of the resources already deployed.

Progress: completed

2.3.10 Presence of hydrogen in places where it is not planned for in the design

Peer Review: *The preparation for the potential for migration of hydrogen, with adequate countermeasures, into spaces beyond where it is produced in the primary containment, as well as hydrogen production in SFPs.*

In an accident situation, hydrogen can be produced inside the reactor vessel during the core degradation phase due to the oxidation of fuel element cladding and other materials present in the reactor vessel, or outside the vessel during the corium-concrete interaction, and by radiolysis of the water in the spent fuel pool (SFP). The hydrogen can also come from damaged hydrogen transport lines.

On completion of the stress tests, EDF undertook to study the hydrogen explosion risk in the buildings surrounding the reactor building. In this respect, EDF has verified the resistance of lines carrying hydrogen for the safe shutdown earthquake (SSE). At the end of these studies, EDF defined and implemented the necessary reinforcements.

The radiolysis aspect of the SFP is addressed in §2.2.17.

Progress: completed

2.3.11 Management of large volumes of contaminated water

Peer Review: *The conceptual preparations of solutions for post-accident contamination and the treatment of potentially large volumes of contaminated water.*

Following the stress tests, ASN has issued prescription ECS–27.I.

ECS–27.I: Study of the feasibility of installing a geotechnical containment or a system with the same effect

I. Before 31 December 2012, the licensee shall send ASN a feasibility study for the installation or renovation of a geotechnical containment or equivalent technical measure to prevent the transfer of radioactive contamination to groundwater and, by means of underground flow, to the surface waters, in the event of a severe accident leading to corium melt-through of the reactor vessel

EDF concluded that the implementation of a geotechnical system was not feasible on all sites at an economically acceptable cost. ASN requested that EDF continue its studies on this subject. In this regard, EDF is studying measures to limit leaks of contaminated water outside the buildings and means to reduce the contamination of the water. EDF is also studying, in order to limit the extent and duration of the contamination in case of leakage of contaminated water outside the buildings, the means to limit the dissemination of radioactive substances outside the site, through the soil and underground water.

Progress: completed

2.3.12 Radiation protection

Peer Review: *The provision for radiation protection of operators and all other staff involved in the SAM and emergency arrangements.*

CNS: *Improving their radiation monitoring and communications capabilities and enhancing public communications, such as via dedicated public websites.*

French regulations require the licensee to make provisions for the protection of persons present in the establishment in the event of an emergency, in particular adapted collective and individual protective equipment, operational dosimetry means, and radiation protection measuring means available in sufficient quantity for all persons present in the establishment.

French regulations require the licensee to have at its disposal, in the nuclear installation or in its vicinity, in particular mobile means enabling it to take samples and measurements inside or outside the establishment under all circumstances, especially in the event of an incident or accident. These points are subject to verification during ASN inspections.

Exercises involving simulated media pressure are organized every year to test the information capacities of the various players (*Préfets*, safety authorities, licensees at the local and national levels…).

Progress: completed

2.3.13 On-site emergency management premises

Peer Review: *The provision of an on-site emergency centre protected against severe natural hazards and radioactive releases, allowing operators to stay onsite to manage a severe accident.*

CNS: *Upgrading regional, off-site and on-site emergency response centres*.

The emergency premises for the reactors in service were designed without regulatory requirements relative to resistance to hazards.

ASN has therefore set the prescriptions ECS–30.I and ECS–1.IV to improve the resistance to hazards of crisis management premises for them to remain accessible and habitable during long-duration emergencies, including in the event of radioactive releases.

ECS–30.I: Designing the emergency premises to withstand earthquakes and flooding

I. The licensee shall ensure that the emergency situation management premises can withstand flooding in the event of the flood safety margin level being reached. Before 30 June 2012, it shall present ASN the conclusions of this verification and any modifications considered necessary. Before 30 June 2013, it shall perform any necessary reinforcement work.

The licensee checks that the emergency management premises can withstand the safe shutdown earthquake (SSE). Before 30 June 2012, it shall present ASN the conclusions of this verification and any modifications considered necessary. Before *[Date variable according to the sites, see below*], it shall perform any necessary works.

EDF has carried out, for all the sites requiring it, the necessary modifications and adjustments to the emergency premises to enable them to withstand the flood safety margin level and the safe shutdown earthquake.

ECS–1.IV: Defining the structures and components of the *"hardened safety core"*.

IV. The licensee shall take all necessary steps to ensure that the emergency organisation and resources are operational in the event of an accident affecting all or some of the facilities on a given site.

The licensee shall therefore include these steps in the hardened safety core defined in I. of this requirement and, in accordance with II of this requirement, shall issue requirements concerning:

- the emergency situation management premises, so that they offer greater resistance to hazards and remain accessible and habitable at all times and during long-duration emergencies, including in the event of radioactive releases. These premises shall enable the emergency teams to diagnose the status of the facilities and control the resources of the hardened safety core;
- the availability and operability of the mobile means vital for emergency management;
- the means of communication essential to emergency management, in particular comprising the means of alerting and informing the emergency teams and the public authorities and, should this prove necessary, the arrangements for alerting the population if the off-site emergency plan is triggered in reflex phase by delegation from the Préfet; the availability of parameters used to diagnose the status of the facility, as well as meteorological and environmental measurements (radiological and chemical, inside and outside the emergency situation management premises) enabling the radiological impact on the workers and general public to be evaluated and predicted;
- the active dosimetry resources, radiation protection measuring instruments and individual and collective protective means. These resources shall be available in sufficient quantity by 31 December 2012.

EDF has commissioned new emergency premises at the Flamanville site, which are robust to withstand extreme hazards. EDF has taken into account the lessons learned to optimize the design of the emergency premises at the other sites.

The availability of mobile means is discussed in §2.2.13.

The means of communication in case of emergency are discussed in §2.3.9.

The parameters required for diagnosing the installation are discussed in §2.2.5.

Dosimetry means are dealt with in §2.3.12.

Progress: completed

2.3.14 Support to the personnel on site

Peer review: *Rescue teams and adequate equipment to be quickly brought on site in order to provide support to local operators in case of a severe situation.*

CNS: *Upgrading regional, off-site and on-site emergency response centres*.

Following the stress tests, ASN has set prescription ECS–36.I to reinforce the emergency organisation.

ECS–36.I: The nuclear rapid intervention force (FARN)

I. Before 30 June 2012, the licensee shall present ASN with the measures it intends to take in order to provide specialised teams capable of relieving the shift crews and deploying emergency response resources in less than 24 hours, with operations starting on the site within 12 hours following their mobilisation. This system may be common to several of the licensee's nuclear sites.

These teams shall be sized so that they can respond on all the reactors of the site and have measuring instruments that can be deployed as of their arrival. The licensee shall specify the organisation and sizing of these teams, in particular:

- the activation criteria,
- the tasks incumbent upon the teams,
- the material and human resources at their disposal,
- the personal protective equipment,
- the system put into place to ensure the maintenance of these material resources and their permanent operability and availability;
- the training of their staff and the skills currency process.

EDF has set up a nuclear rapid intervention force (FARN) with equipment and human means at its disposal. The FARN is a national organization capable of rapidly providing equipment and human assistance to a site in an accident situation. All the installations have been modified to be able to connect the mobile emergency means transported by the FARN.

The activation of the FARN is decided at the national level on the basis of the analysis of the situation. The FARN is made up of a headquarters and four regional centres located at the nuclear power plants of Bugey, Civaux, Dampierre and Paluel.

The FARN's mission is to:

- intervene after 24 hours, in continuity and in relief of the operating shift teams which will have assumed the emergency actions of the site concerned, whose access infrastructures may be partially destroyed;

- act autonomously for several days (which implies logistic support capacities in the field of food and accommodation in particular);
- deploy heavy means of protection or intervention, unique for EDF's nuclear fleet, within a few days;
- ensure permanent liaison with the EDF's upper management, the management and teams of the NPP and the local public authorities in order to manage and coordinate interventions;
- prepare the sustainability of its actions beyond the first days of autonomy in the event of a long-term emergency.

The regional centres have on-call intervention teams of 14 people covering the various areas (processes, intervention, logistics). These teams are made up of dedicated EDF personnel, prepared for emergency situations, in particular through training (annual training volume of 33,000 hours) and as well regular training and role-playing. The FARN uses methods of adaptation to situations from the military world and civil security intervention units to be able to act in a wrecked environment and take stress into account.

The FARN has transport and handling equipment, redundant telecommunication means and equipment for water and electricity supply (pumps, compressors, generators...) to intervene simultaneously on all the reactors on a same site. The equipment is stored in specific premises in each centre. Each team is able to treat 2 reactors and can bring the necessary equipment to do so. The FARN has the human and equipment resources to intervene simultaneously on all the reactors on a same site (up to six reactors). Locations of potential rear bases are identified near the nuclear power plants.

At the end of 2020, 45 exercises were carried out on nuclear sites, each time involving about a hundred actors. FARN has also been involved in two real situations resulting from extreme climatic hazards and it brought:

- support to teams of technicians to reconstitute the power grid on the island of Saint-Martin after hurricane IRMA, with the installation of a life base for a month and a half;
- support for EDF Hydraulique teams in the Tina, Roya and Vésubie valleys for three weeks to clear the hydraulic structures.

Progress: completed

2.3.15 Level-2 Probabilistic Safety Assessments (Level-2 PSA)

Peer Review: *A comprehensive Level 2 PSA as a tool for the identification of plant vulnerabilities, quantification of potential releases, determination of candidate high-level actions and their effects and prioritizing the order of proposed safety improvements. Although PSA is an essential tool for screening and prioritizing improvements and for assessing the completeness of SAM implementation, low numerical risk estimates should not be used as the basis for excluding scenarios from consideration of SAM, especially if the consequences are very high.*

As part of the periodic safety reviews, the use of Level 1 and Level 2 PSAs leads to modifications to improve the safety of the installations.

The approach developed in the aftermath of the Fukushima-Daiichi nuclear power plant accident aims to define provisions for dealing with initiating accidents that go beyond the design basis, possibly combined accidents, irrespective of their probability of occurrence. This approach allows to cover highly improbable situations.

Progress: completed

2.3.16 Studies relative to severe accidents

Peer Review: *The performance of further studies to improve SAMGs. Examples of areas that could be improved with further studies include:*

- *The availability of safety functions required for SAM under different circumstances.*
- *Accident timing, including core melt, reactor pressure vessel (RPV) failure, basemat melt-through, SFP fuel uncovery, etc.*
- *PSA analysis, including all plant states and external events for PSA levels 1 and 2.*
- *Radiological conditions on the site and associated provisions necessary to ensure MCR and ECR habitability as well as the feasibility of AM measures in severe accident conditions, multi-unit accidents, containment venting, etc.*
- *Core cooling modes prior to RPV failure and of re-criticality issues for partly damaged cores, with un-borated water supply.*
- *Phenomena associated with cavity flooding and related steam explosion risks.*
- *Engineered solutions regarding molten corium cooling and prevention of basemat melt-through.*
- *Severe accident simulators appropriate for NPP staff training.*

CNS: *Developing probabilistic safety assessments to identify additional accident management measures or changes in radiation protection measures for workers on the site that might be needed to perform necessary activities in the event of a severe accident*

The topics mentioned in the peer review are systematically addressed in the periodic safety reviews. Indeed, the periodic safety reviews include a safety reassessment whose objective is to improve the safety level of the installation with respect to the requirements applicable to installations with more recent safety objectives and practices, taking into account the evolution of knowledge and as well national and international feedback.

In addition, some of these topics may also be compared with international practices at the meetings of the Advisory Committee of Experts on reactors dedicated to the analysis of operating experience feedback from the French and foreign reactors organized periodically.

Progress: completed

3 CONCLUSION

In December 2012, ASN published a national action plan in response to the recommendations of the 2012 European Peer Review of Stress Tests and the 2^{nd} Extraordinary Meeting of the Convention on Nuclear Safety (CSN) in 2012. This action plan includes the prescriptions of the ASN resolutions of June 26, 2012 aimed at increasing the robustness of nuclear power plants in extreme situations beyond the safety margins already available to the facilities.

This report presents the provisions defined by EDF in response to the ASN prescriptions. These provisions contribute to the improvement of:

- the protection against internal or external aggression, in particular reinforcement of protection against flooding;
- the means of electrical power supply: installation of additional electrical power supply (backup diesel-generators), increase of the autonomy of the batteries used in the event of complete loss of electrical power supply;
- the provisions to prevent accidents with core melt: e.g., installation of high-temperature reactor coolant pump seals capable of withstanding loss of cooling for an extended period of time, emergency water make-up in the reactor coolant system when it is open, installation of standardized pipe connections for mobile equipment (particularly for the FARN);
- the provisions to prevent the uncovery of fuel assemblies in the pool: e.g., provisions to prevent accidental rapid draining of the spent fuel pools, reinforcement of the spent fuel pool instrumentation;
- the management of accidents with core melt: e.g., redundancy of instrumentation for detecting reactor vessel melt-through and hydrogen in the containment;
- the emergency management: reinforcement of the seismic resistance and flood resistance of the emergency management premises, strengthening of the team preparation in the event of an earthquake, measures to cope with site isolation in the event of flooding, reinforcement of the communication means, multiple unit plant emergency organization, coordination with neighbouring industrial operators in the event of an emergency;
- the means of intervention on sites through the implementation of the nuclear rapid action force (FARN): capacity for simultaneous intervention on all reactors of an accidented site in less than 24 hours. The FARN provides water, compressed air and electricity supply with its own mobile equipment.

The provisions defined by EDF enable to close the actions of the action plan and to respond to the recommendations resulting from the European stress tests peer review. This report is thus the final version of the national action plan drawn up in 2012.

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