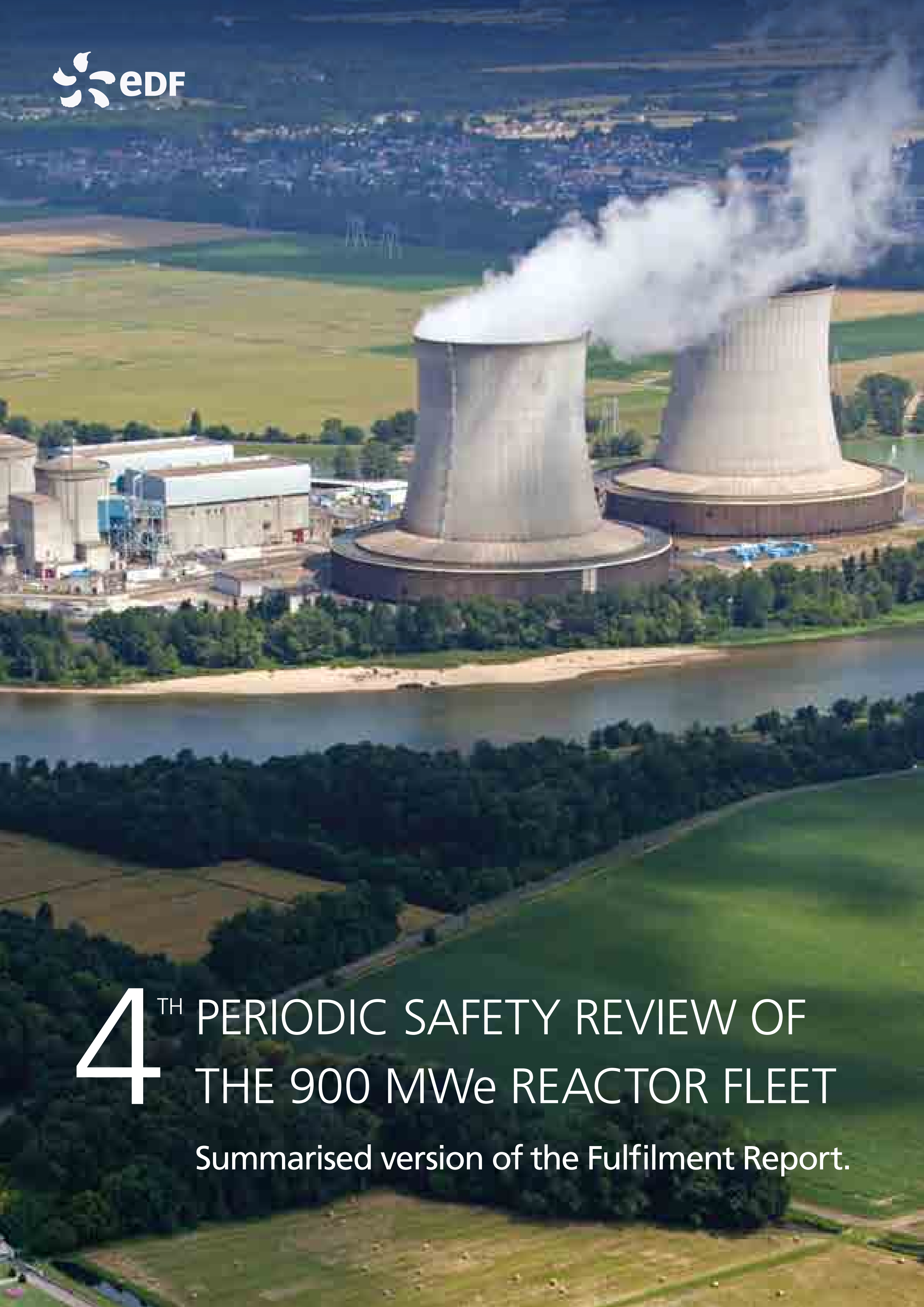

4[TH] PERIODIC SAFETY REVIEW OF THE 900 MWe REACTOR FLEET

Summarised version of the Fulfilment Report.

TABLE OF CONTENTS

Cover photo
Aerial view of Saint-Laurent-des-Eaux NPP, Loir et Cher
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Summary

For the 4th periodic safety review of its 900-MWe reactor fleet, EDF's general policy is to aim for nuclear-safety objectives that have been set for 3rd generation reactors which include EDF's standard-bearer, the Flamanville-3 EPR. The prerequisite for fulfilling this general objective is to ensure that power plants comply with current regulations by: The prerequisite for fulfilling this general objective is to ensure that power plants comply with current regulations by:

- Carrying out targeted inspections via the plant compliance review;
- Carrying out a set of additional investigations to identify and address potential weaknesses in the maintenance programme;
- Implementing a review programme that focuses on core-cooling and safeguard systems, as well as their support functions;
- Conducting an exhaustive review of measures taken to address compliance issues.

This general objective is translated into specific objectives for the nuclear-safety review, which cover **4 main safety-related topics:**

1. Accidents without core melt
- > Complying with nuclear-safety requirements for postulated accidents discussed in the final safety analysis report.
- > Seeking to ensure that radiological consequences are mitigated to the extent of not requiring measures to protect the public.

2. Internal/external hazards
- > Verifying that plant facilities can withstand revised hazard levels required by the periodic safety review and by internationally recommended standards (WENRA).
- > Targeting a core-melt risk factor of a few hundred thousand (1/100 000) per year.reactor, taking all initiating events into consideration.

3. Spent fuel pool
- > Taking measures to ensure that the likelihood of fuel assemblies becoming uncovered remains extremely small in the event of inadvertent drainage and loss of cooling.

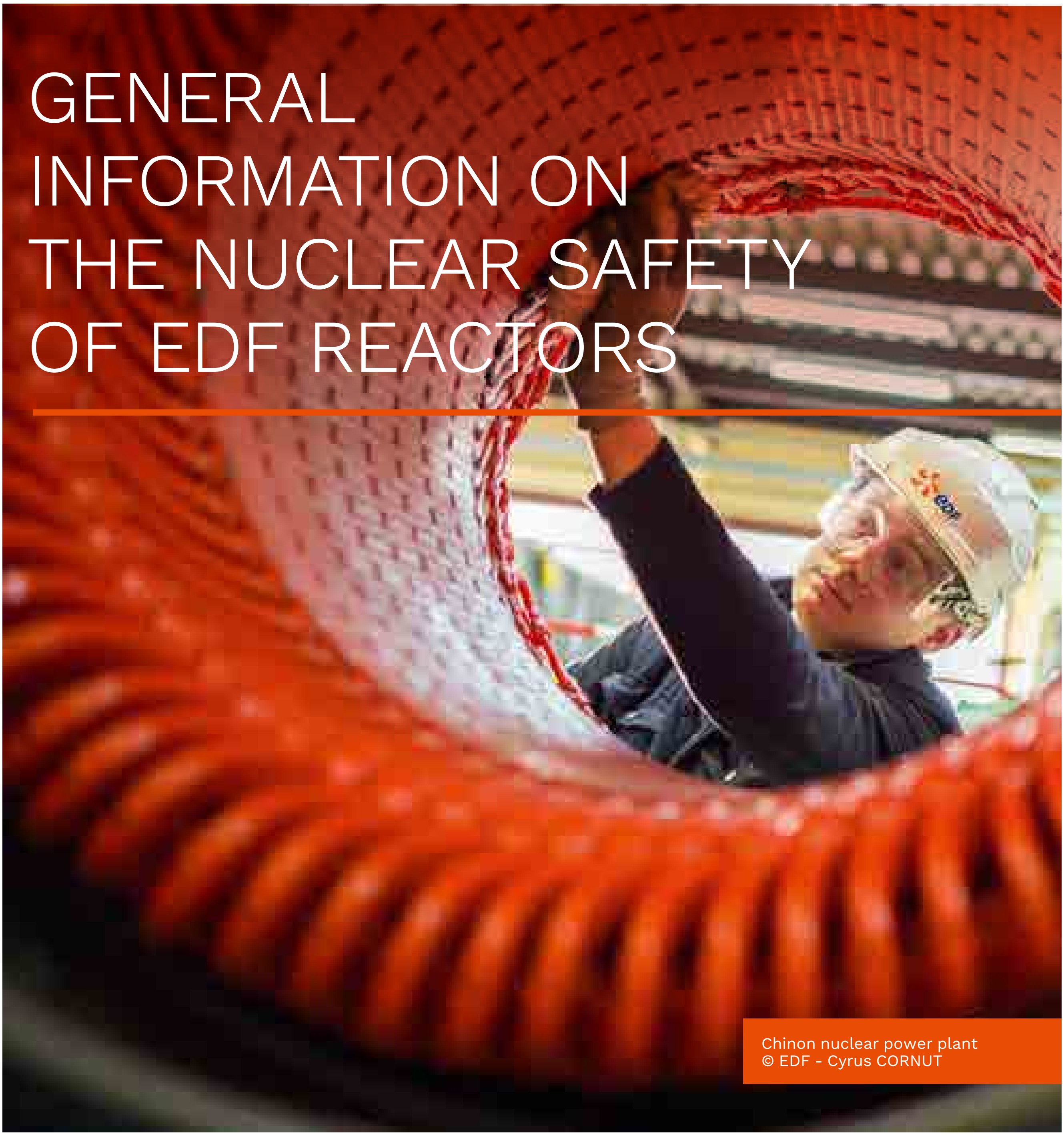
4. Core-melt accidents
- > Taking measures to ensure that the likelihood of early and large releases remains extremely small.
- > Taking measures to avoid long-term environmental consequences.

In addition to the risk-informed review (incident and accident conditions) covered by nuclear safety, EDF takes measures to comply with regulations governing the "environmental nuisance" part of the periodic safety review (normal operating conditions) by carrying out multi-year assessments of water abstractions and usage, discharges/releases, environmental nuisances and waste management. Further to this environmental nuisance management review, improvement actions are implemented. Additionally, the environmental nuisances resulting from plant operations and affecting people and the environment are reassessed.
The 4th periodic safety review of the 900-MWe reactor fleet also includes a section on continued operation, which covers ageing management, obsolescence and the requalification of components for accident conditions. It is based on an extensive programme designed to verify that components are able to fulfil their functions, with some of these components being replaced
The 4th periodic safety review of the 900-MWe reactor fleet coincides with the 40th year of operation. It brings with it significant nuclear-safety enhancements on each of the reactors in question. The associated design and upgrade work accounts for about ten million engineering hours and around 7 billion Euros worth of work.

The fulfilment report (NRO in French) sets out EDF's responses to the objectives set for this review and details all the associated measures: design studies, equipment, operational measures.

(1) Western European Nuclear Regulators' Association.

GENERAL INFORMATION ON THE NUCLEAR SAFETY OF EDF REACTORS



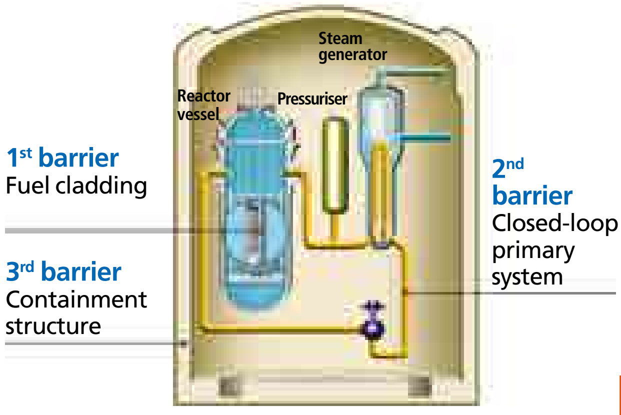
Chinon nuclear power plant
© EDF - Cyrus CORNUT

On a nuclear facility, the general nuclear-safety objective is to establish and maintain effective barriers that prevent accidents and mitigate consequences for people and the environment. Design and operating arrangements established for this purpose focus on prevention in order to prevent abnormal conditions from occurring and if they do, to mitigate their consequences.

For this purpose, nuclear facilities are equipped with three physical, resilient, leak-tight and independent barriers that serve to contain radioactivity:

- Fuel cladding;
- The reactor coolant pressure boundary
- The containment structure.

The three safety barriers



Nuclear safety relies on the concept of **defence in depth** which entails the use of successive and sufficiently independent barriers in order to guard against human, technical and operational failures.

During the design phase and operating period, defence in depth takes place at four levels:

1. **Prevention of incidents.** This first level relies on a combination of design margins, high manufacturing standards and human-factors engineering in order to maintain the facility within its normal operating limits. In terms of equipment, automation and control systems are used to bring the plant back within these limits.
2. **Detection of incidents:** Implementation of measures in order to prevent abnormal conditions from resulting in an accident and to restore normal operating conditions. If normal operating conditions cannot be restored, these measures are designed to take the plant into safe conditions and to maintain these conditions.
   At this second level, measures are taken to maintain the integrity of the fuel cladding (the first barrier) and of the primary system (the second barrier) by using controls and protection systems to ensure that safety functions fulfil their purpose: automatic reactor trip, adding more water to cool the reactor, etc.

The safe state of a reactor relies on **three basic safety functions:**
- Controlling the nuclear chain reaction,
- Cooling the fuel,
- Containing radioactivity.

3. **Mitigating the consequences of accidents** that could not be avoided, or preventing their escalation by resuming control of the plant in order to take it into safe conditions and to maintain these conditions.
   This third level relies on safeguard systems: the safety injection system, the containment spray system and the auxiliary feedwater system, as well as abnormal and emergency operating procedures.
4. **Managing severe core-melt accidents** that could not be avoided, in order to mitigate the consequences for people and the environment.
   At this fourth level, measures are taken to maintain the integrity of containment, the third barrier. Arrangements designed to fulfil this objective include the last-resort containment release filtration system after containment is opened, or passive recombiners that prevent the build-up of hydrogen which is formed when the fuel cladding melts (elimination of explosion hazards), or additional portable equipment such as pumps and their power systems.
   This level also includes the "hardened safety core" which, among other enhancements, features diversified sources of water in order to restore a supply of water to the steam generators or spent-fuel pool, as well as additional sources of power.

The “hardened safety core” comprises a set of permanently installed and robust components, supplemented by portable components, which are designed to prevent very large radioactive releases and long-term consequences for the environment in extreme conditions potentially following an extreme external natural hazard.

Tricastin, Rhône-Alpes nuclear power plant.

SCOPE AND MILESTONES OF THE 4TH PERIODIC SAFETY REVIEW OF THE 900-MWE REACTOR FLEET

Tricastin,
Rhône-Alpes nuclear power plant.
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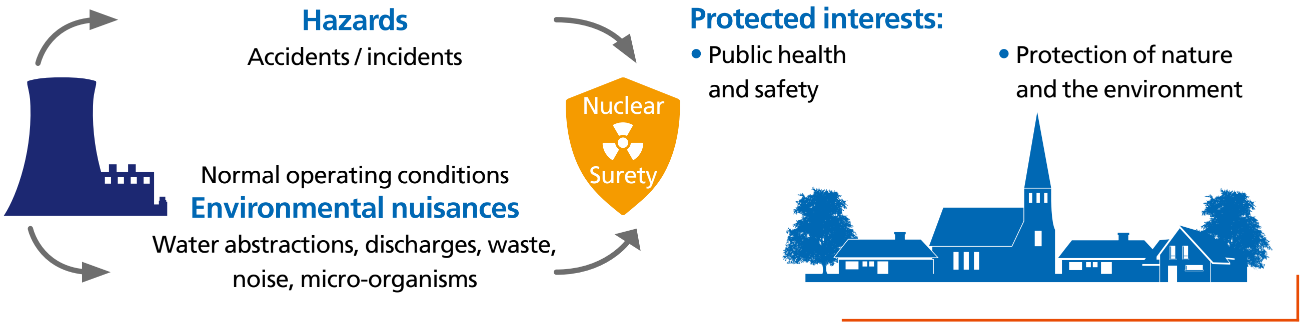
As required by current legislation(2), EDF carries out ten-yearly reactor safety reviews, the objectives of which are to:

- Assess the facility's condition and its compliance with current regulations; this is the part of the review that focuses on compliance and ageing management;
- Reassess the hazards and/or environmental nuisances potentially resulting from plant operations and affecting public health & safety and/or nature and the environment, which are identified by legislation as "protected interests" (see diagram). This part of the review focuses on "reassessment" in order to continuously improve performance when it comes to protecting these interests.

Article L593-18 of the environment code.

Protection of interests from hazards and environmental nuisances



Periodic safety reviews take the following inputs into consideration:

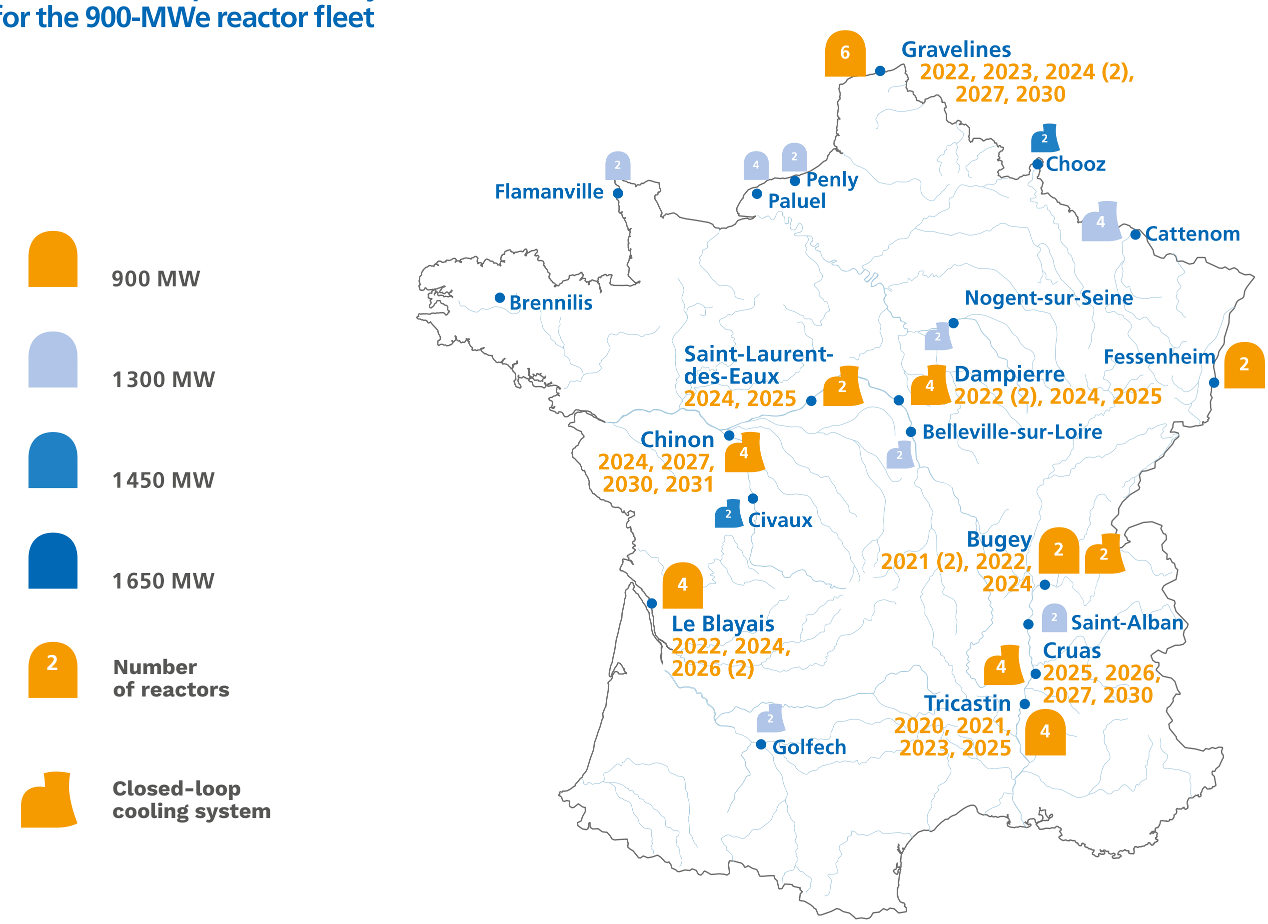
- Lessons learned from French and international operating experience;
- Results of research studies (R&D) and advances made thanks to knowledge and technology improvements;
- Adjustments and changes required to meet more challenging objectives seeking more effective control of hazards and environmental nuisances.

This process adopts an approach that is commensurate with nuclear and environmental-safety significance.

The periodic safety review process is divided into two phases. The first covers all the facilities of 900-MWe nuclear power plants; this is the generic phase which runs for a period of 5 to 6 years. During the second phase, each reactor is reviewed individually. This phase lasts about ten years.

France's nuclear power plants

Dates of the 4th periodic safety reviews for the 900-MWe reactor fleet



The generic phase beings with EDF issuing a review outline (abbreviated to "DOR" in French) which describes the topics covered by the review scope and the objectives that EDF has set itself for the review.
For the 4th periodic safety review of the 900-MWe reactor fleet (abbreviated to 4 RP 900), EDF has generally chosen to aim for nuclear-safety objectives that have been set for the latest-generation reactors which include EDF's standard-bearer, the Flamanville-3 EPR.

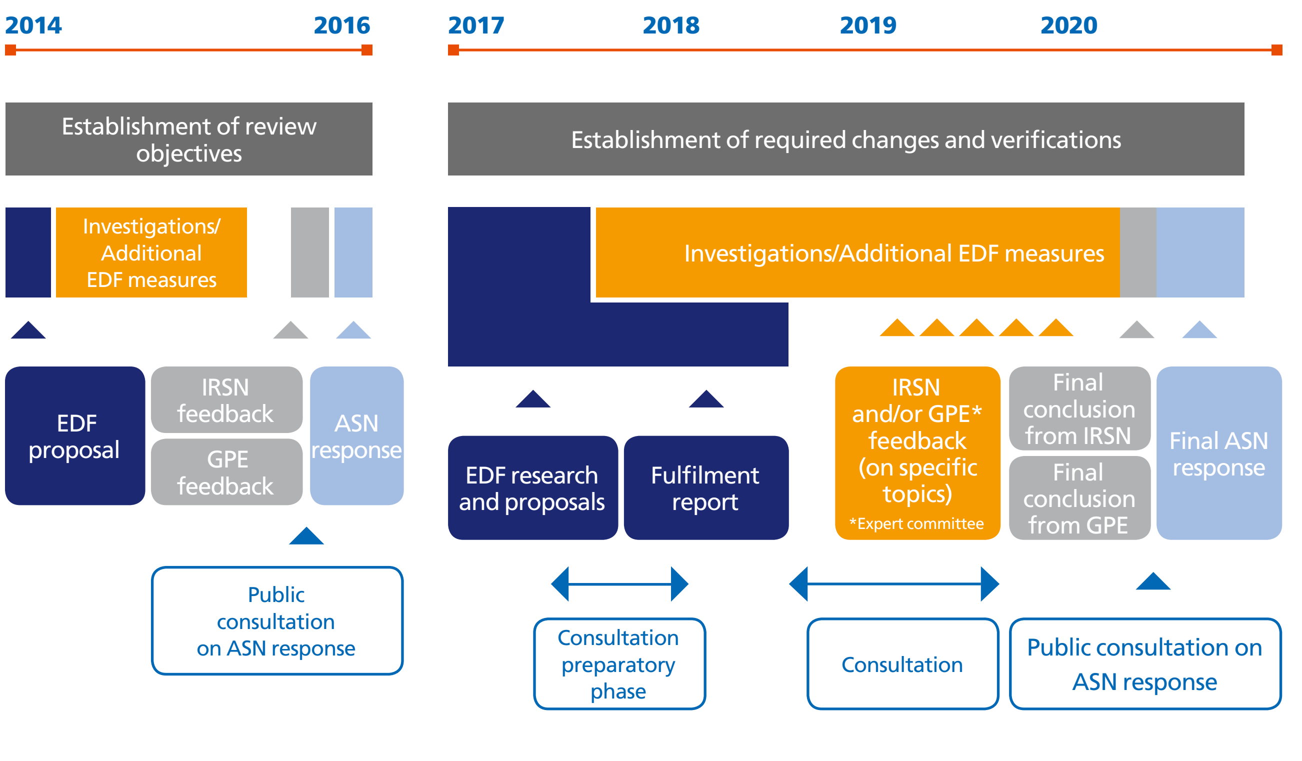
The DOR is being reviewed by France's nuclear regulatory authority (ASN), who refers to the French Institute of Radiation Protection and Nuclear Safety (IRSN), its technical support branch, and consults with the standing committee of experts (GP). This "review outline" strand of the periodic safety review's generic phase took place over the period running from early 2014 to early 2016. It was completed in April 2016 with the ASN reaching a decision on the generic objectives of 4 RP 900, accompanied by a set of requirements for the licensee.
The next step of the generic phase involves EDF issuing a Fulfilment Report that sets out all the responses that EDF has provided in order to meet the review's objectives, as well as EDF's responses to the regulator's requirements issued with regard to the review outline.

At this stage, a public consultation on the generic phase of 4 RP 900 is held under the leadership of the High Committee for Transparency and Information on Nuclear Safety (HCTISN), based on the Fulfilment Report submitted by the project owner. This will take place from the third quarter of 2018 until early 2019.

After the standing expert committee has met to review all these reports, the generic phase will conclude with a letter setting out the regulator's position with regard to the licensee, followed by a set of generic requirements. A public consultation will be held on a draft of this letter.

The next stage will consist of periodic safety reviews – reactor by reactor – with a report setting out the findings for each reactor. This report updates the information contained in the Fulfilment Report and includes any particularities of the site in question. It describes the measures that EDF plans to take in order to rectify abnormalities or to enhance the protection of interests(3). It sets out the modifications that have been completed or that are being planned at the time when the report is issued. Public enquiries will be held on the reports setting out the review findings of each individual reactor.

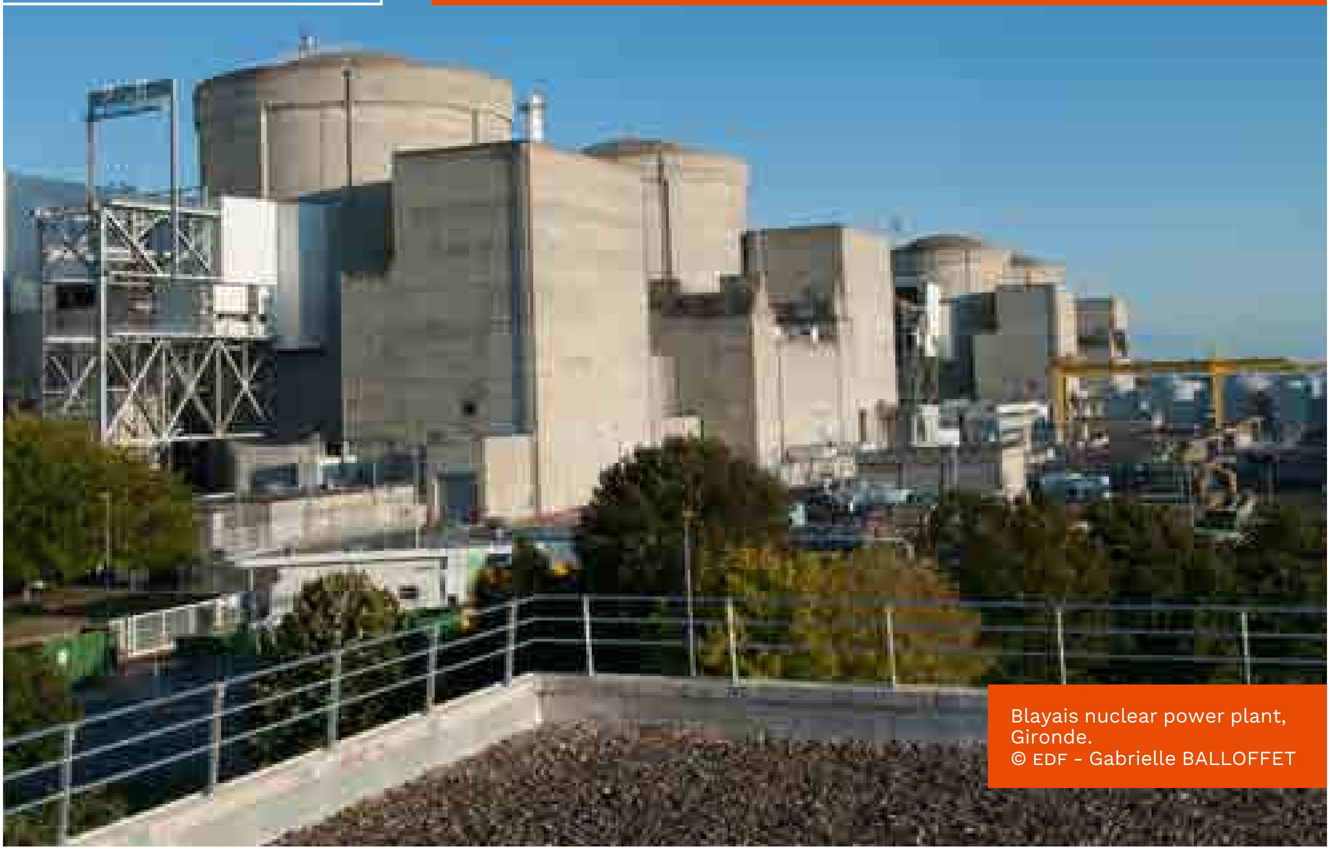
Generic phase of the 4th periodic safety review of the 900-MWe reactor fleet



The fulfilment report and this summarised version are divided into 3 sections:
- A first section focusing on "hazards" covering incident & accident conditions and a second section focusing on "environmental nuisances" covering the impacts and environmental nuisances caused by the facility in normal operating conditions, including water abstractions and discharges, waste, micro-organisms and noise.
- A third section on the subject of ageing management with a view to life extension following 40 years of operation, including evidence to prove that components can be requalified for accident conditions.

(3) Article L.593-19 of the environment code

2 RISK-INFORMED PART OF THE REVIEW



Blayais nuclear power plant, Gironde.

2.1 Plant compliance

2.1.1 Plant compliance review

The plant compliance review is informed by operating experience from EDF's nuclear fleet in order to supplement existing operational and maintenance arrangements (surveillance tests, maintenance programmes) by carrying out physical inspections and/or document reviews. For purposes of 4 RP 900, EDF has selected a number of topics which will be reviewed in this way. Specific examples include civil structures, fire risk and internal flooding risk.

Plant compliance with current regulations is verified by means of:

- In situ inspections carried out by the licensee before and during the 4th ten-yearly outage (VD4) which takes place throughout the period of the 4th periodic safety review;
- A review of operating documents, inspection/testing programmes, operating procedures and instructions, associated plans and drawings

The ten-yearly outage covers a period during which the reactor is shut down in order to undergo the main inspections and maintenance operations required by the periodic safety review. The following tests and inspections are performed during this outage: reactor vessel inspection; hydrostatic testing of systems to verify their leak-tightness; testing of the containment structure's mechanical strength. The ten-yearly outage takes about 130 days to complete, compared with 25 days for refuelling outages and 50 days for maintenance outages, which take place every 12 to 18 months in the interval between two ten-yearly outages.

The results of the plant compliance review are appended to the review findings report.

2.1.2 Programme of additional investigations

The programme of additional investigations seeks to corroborate the assumptions used for drawing up maintenance programmes. These are based on the assumption of no deterioration in areas that not considered to be damage-prone and which are consequently not monitored. For purposes of 4 RP 900, the scope includes:

- Mechanical components of the primary and secondary systems;
- Other mechanical components: pipes, tanks, heat exchangers, pumps, valves of particular importance for the protection of interests;
- Civil structures and containment structure.

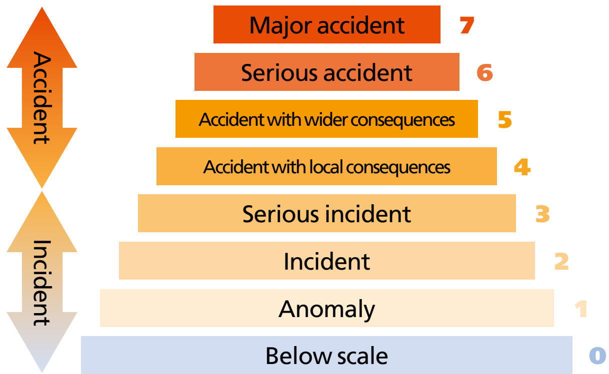
Examinations included in programme of additional investigations are performed during the 4th ten-yearly outage. If degraded conditions are found, they are addressed in accordance with procedures and where necessary, maintenance specifications are adjusted.

The results of the programme of additional investigations are included in the review findings report issued for each facility, as well as in the life-extension application which also focuses on ageing management (see paragraph 4).

2.1.3 Measures to resolve deviations

EDF implements the measures required to rectify any identified deviations, at the very latest by the end of the 4th ten-yearly outage, in accordance with the regulator's guide entitled "Resolution of deviations". A description of safety-significant deviations (reportable safety-significant events with an INES rating of 1 or higher) is provided in the review findings report.

In order to help the public and the media immediately understand the severity of a nuclear incident or accident, a severity scale was established following the Chernobyl accident (Ukraine, 1986), based on the same principle as the Richter scale which indicates the size of an earthquake. Internationally used since 1991, the INES scale (International Nuclear Event Scale) comprises 8 levels, from 0 to 7. To date, two events have been given an INES-7 rating: the accident at the Chernobyl plant in the Ukraine in April 1986 and the accident at the Fukushima Daiichi plant in Japan in March 2011.



The INES scale

2.1.4 System compliance review programme

On a ten-yearly basis and as required by the periodic safety review process, EDF assesses the design of its facilities' safety features against a set of new reference standards. It also reviews the design studies supporting the topics covered by the review. For purposes of 4 RP 900, EDF is reviewing the compliance of the following systems:

- **Systems associated with core cooling** and core safeguards or with the fuel being stored in the spent fuel pool (inside the fuel building), extended to important support functions such as those supporting the cooling function.
- **Electrical power sources:** On the occasion of this review, EDF has decided to replace existing components with new and more robust components: the emergency turbine-generator set will be replaced with a station black-out diesel; enhancements will be made to the performance of existing systems: longer emergency-battery life.
- **Core cooling-water function**, which relies on the safety injection system and the containment spray system: this review has shown that all systems and components directly and indirectly supporting this function are in sound operating condition and has not highlighted the need for plant design or operational changes.

- **Ventilation systems:** The action plan implemented by EDF ensures that ventilation system performance complies with safety standards established for extremely hot weather, extremely cold weather and internal explosion hazards.

2.2 Reassessment

The reassessment of nuclear-safety standards or in other words, measures taken to enhance the protection of interests against potential consequences due to plant operations (incidents and accidents), entails the inclusion of new requirements in the current regulations. These new requirements stem from:

- A comparison of current regulations with those applying to newer facilities;
- An ongoing review of all safety-related lessons learned from French and international operating experience;
- Knowledge advances.

In seeking to meet the nuclear-safety standards exhibited by the most advanced technologies, EDF is taking measures to enhance the robustness of its facilities in the four key areas on which nuclear-safety fundamentals rely:

Saint Laurent des Eaux nuclear power plant, Loir et Cher.
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ACCIDENTS WITHOUT CORE MELT

Objectives

Meeting the nuclear-safety criteria of accident studies by knowledge advances into consideration.

Seeking to ensure that radiological consequences are mitigated to the extent of not requiring measures to protect the public.

INTERNAL/EXTERNAL HAZARDS

Objectives

Verifying that plant facilities can withstand revised hazard levels required by the periodic safety review and by internationally recommended standards (WENRA).

Targeting a total core-melt risk factor (including external/internal hazards) of around 10^{-5}/year.reactor.

CORE-MELT ACCIDENTS

Objectives

Taking measures to ensure that the likelihood of early and large releases remains extremely small.

Taking measures to avoid long-term environmental consequences.

SPENT FUEL POOL

Objectives

Taking measures to ensure that the likelihood of fuel assemblies becoming uncovered remains extremely small in the event of inadvertent drainage and loss of cooling.

An accident probability factor of 10^{-5}/year.reactor means that the probably of an accident is 1/100 000 over one year of reactor operation.

Considering the large number of enhancements being made for 4 RP 900, EDF is conducting a cross-functional impact assessment of these changes. This assessment includes:

- **Personnel:** Human-factor impact of 4 RP 900 on the different sites;
- **Plant:** Verifications to ensure that all the necessary post-modification commissioning tests having performed.

2.2.1 Accidents without core melt

As part of the 4 RP 900 review, all FSAR accident studies are updated to verify compliance with safety requirements by incorporating knowledge advances and state-of-the-art practices. For this purpose, EDF has conducted several types of research:

- Deterministically postulated accident scenarios which include knowledge advances and tried & tested methods, some of these already being used at Flamanville 3. They demonstrate compliance with safety requirements and with the limits set for the associated radiological consequences;
- Supplementary studies confirming plant resilience to specific additional scenarios. More specifically, an exercise combining emergency conditions and operator response times, performed at Flamanville 3, has shown that the current or planned protection systems enable 900-MWe reactors to comply with safety requirements;
- Probabilistic safety analyses regarding the risk of core melt with radiological releases, the results of which show an improvement since the 3rd periodic safety review with a significantly lower core-melt risk.

Deterministic and probabilistic analyses
The safety case for France's nuclear reactors is based on a deterministic approach, i.e. design features are substantiated by the analysis of a limited number of design-basis accidents and the application of rules and criteria with conservative margins built in. This approach is supplemented by the conduct of probabilistic safety analyses (PSA), the purpose of which is to assess nuclear plant-related hazards in terms of the frequency of undesired events and their consequences.

In line with the objectives for 3rd-generation reactors and for purposes of the 4th periodic safety review on its 900-MWe reactor fleet, EDF is seeking to ensure that ionising radiation exposure levels affecting the considered populations in the event of an accident without core melt are low enough not to require measures to protect the public(4).

Research conducted to date shows that this objective has been met for all accidents covered by the final safety analysis report with the exception of a steam-generator tube rupture accident. In order to fully meet this objective, plans for 4 RP 900 include the introduction of additional operating standards for the quality of reactor-coolant chemistry in order to lower activity levels in atmospheric releases, as well as a more reliable means of considering meteorological variables to better assess the spread of releases in the atmosphere.

2.2.2 Internal/external hazards

Nuclear power plants are designed to be protected from internal or external hazards caused by natural phenomena or human activity, which could directly or indirectly result in damage to the structures, systems and components supporting fundamental safety functions.

For purposes of 4 RP 900, hazard analyses are being updated and extended in order to consider plant condition, plant operating experience, knowledge advances and regulations applying to similar facilities.

- **Deterministic analyses**

To begin with, analyses include a deterministic component which seeks to take the reactor into a safe state and maintain this safe state in the event of hazards occurring at a reassessed level in keeping with the review.

The hazards being considered are those identified by legislation (government decree on basic nuclear installations):

The government decree on basic nuclear installations (BNI) issued in February 2012 lays down the general rules pertaining to basic nuclear installations. French law includes regulations that are aligned with international best practice. BNI provisions essentially cover the organisational arrangements and accountabilities of BNI licensees, the nuclear safety case, the control of environmental nuisances and their impact on health and the environment, waste management, emergency preparedness and emergency response.

(4) An effective dose of 10 mSv for sheltering (and of 50 mSv for evacuation) a thyroid dose equivalent of 50 mSv for stable iodine administration.

- **Internal hazards:** fire, explosion, flooding, failure of pressurised equipment, collision and dropping of loads, electromagnetic interference, hazardous material emissions, malicious acts.
- **External hazards (natural or caused by humans):** earthquakes, extreme weather conditions (flooding, snow, heatwave, extremely cold weather, high winds, hurricanes), hazards specific to water intake systems and structures (frazil ice, icing-up, clogging agents, hydrocarbon spills, silting, low water levels), lightning and electromagnetic interference, fire, hazards from industrial facilities located nearby (explosion, hazardous materials), airplane crashes, malicious acts.

The level of these hazards is reassessed against the state of the art and knowledge advances in this area.
Additionally, EDF ensures that hazards which are not explicitly mentioned in legislation are not considered, since:

- They are covered by other hazards that are factored into plant design (e.g. certain measures providing protec¬tion against wind-blown projectiles can also provide protection against hail);
- They are not relevant for French facilities (e.g. sand or salt storms, avalanches, volcanos);
- They fall outside the scope of analysis as they are highly unlikely (e.g. meteorite).

The robustness of EDF facilities has also been compared with the most advanced European standards for existing reactors, also including WENRA reference standards. In practice, the analysis involves:

- Conducting vulnerability assessments by conservatively considering the combination of the hazard with a failure affecting active components designed to prevent the hazard or mitigate its consequences (concept of "aggravating factor" in the assessments);
- Assessing vulnerability to operator response times to ascertain the absence of a cliff-edge effect [(5)];
- Assessing, where technically appropriate, the vulnerability of plant response to meteorological hazard levels with an annual frequency rate of 10^{-4}, i.e. less than once every 10 000 years.

Based on the results of these assessments, modifications were designed for more effective protection against reassessed hazard levels (e.g. protection against on-site and off-site flooding, improved ventilation of switchgear rooms – see appendix). These results prove that the facilities are capable of withstanding hazards postulated in the final safety analysis report whilst demonstrating their robustness when measured against international recommendations (WENRA).

- **Probabilistic assessments**

Improvements made since the commissioning of France's nuclear fleet as regards the description of plant behaviour in incident and accident conditions gradually made it possible to conduct probabilistic safety analyses within an increasingly broader scope. Since the 3rd periodic safety review of the 1300-MWe reactor champ fleet, the nuclear-safety case has included probabilistic factors for selected hazards. The 4th periodic safety review of the 900-MWe fleet goes a step further by requiring the conduct of probabilistic assessments and probabilistic safety analyses for a very wide range of hazards: fire, earthquake, on-site flooding, bursting of river banks, sea levels, on-site explosion.

For purposes of the fourth periodic safety review, EDF is seeking to achieve a core-melt probability factor (regardless of cause) that approaches the objective set for third-generation reactors, i.e. 10-5 per year.reactor.

The main hazards contributing to core-melt risk are fires that could potentially occur in the electric building, as well as earthquakes. Lessons have been learned from these probabilistic safety analyses on how to improve a plant's nuclear safety levels: for example, protecting cables from spurious instrumentation and control signals following a fire in the electrical building. These analyses highlight the benefit of having a "hardened safety core": station black-out diesel, diversified water sources, a "hardened core" instrumentation and control system capable of withstanding design-basis earthquakes.
Upon completion of the fourth periodic safety review, the core-melt probability factor for 900-MWe reactors is 4 to 6 10^{-5}/year.reactor, all initiators combined, thereby meeting the objective.

2.2.3 Spent fuel pool

In terms of nuclear safety, EDF has set itself the objective of ensuring that the likelihood of fuel assemblies becoming uncovered remains extremely small in the event of inadvertent drainage and loss of cooling

For purposes of the fourth periodic safety review, EDF is consolidating the fuel building's safety levels in accident conditions by taking the following measures:

- Installing additional equipment to address the risk of inadvertent spent fuel pool drainage: motor-operated valves on the suction side and check valves on the discharge side of the spent fuel pool cooling system;
- Adding a flame-proof system to guard against the risk of fire spreading from one cooling-system pump to another (see appendix).

Deterministic analyses show that safety requirements have been met for all postulated initiating events in consideration of existing measures. Furthermore, a specific assessment shows that the residual heat removal function and the required spent fuel pool inventory would not be compromised in the event of an internal hazard.
Probabilistic assessments show that the likelihood of fuel assemblies becoming uncovered in the event of inad-

(5) Cliff-edge effect: Sudden change in a plant's behaviour which suffices to bring about a slight alteration of the postulated accident scenario, the consequences of which are then significantly worsened.

vertent drainage and loss of spent fuel pool cooling is extremely small (around 10-8/year.reactor) thanks to the new capabilities of the "hardened safety core" (e.g. replenishment of spent fuel pool inventory) and the response of the FARN (nuclear accident rapid-response unit).

Further to the Fukushima accident, EDF decided to set up a nuclear accident rapid-response unit (FARN), that would provide a struggling nuclear plant with off-site assistance. The FARN is capable of providing support in the areas of operations, maintenance and logistics on a site where an accident has occurred, restoring access to water, air and electrical power within 24 hours.

In addition, the behaviour of spent fuel pools on the 900-MWe reactor fleet was assessed in accident scenarios used for the Flamanville-3 EPR but not considered in the initial design. This assessment highlighted the robustness of these spent fuel pools.

Last but not least, the installation of a new portable cooling system (PTR b – see appendix) has diversified the heat sink and enables plants to restore their spent fuel pool cooling function without reaching boiling point in the event of a loss of the design-basis cooling system. This type of measure has brought the safety level of 900-MWe reactors closer to that of Flamanville-3 EPR reactors.

2.2.4 Core-melt accidents

For purposes of the fourth periodic safety review and with regard to core-melt accidents, EDF is seeking to ensure that the likelihood of early and large releases remains extremely small, whilst taking measures to avoid long-term environmental consequences.

In order to achieve this goal, EDF is seeking to ensure that the following measures can be taken in the event of a core-melt accident:

- Residual heat can be removed from the core without opening the containment pressure relief system (known as U5);
- In degraded conditions with the consequent formation of corium[6] which melts through the reactor vessel, the corium can be stabilised on the reactor building base-mat, thereby remaining contained.

In order to achieve these objectives, EDF is taking the following measures that come in addition to existing measures:

- Installation of a new "hardened core" containment-cooling system for cooling the corium either inside or outside the reactor vessel and for removing residual heat without having to use the containment pressure relief and gaseous release filtration system (see appendix);
- The capture of any leaks from this "hardened-core" containment-cooling system in order to more effectively stop contamination from spreading in the event of a core-melt accident;
- Stabilisation of corium once the latter has spread across the reactor-building base-mat and has been flooded with water, thereby guarding against the potential loss of containment due to base-mat melt-through (see appendix);
- Enhanced seismic resistance of the containment pressure relief and gaseous release filtration system.

In the event of a core-melt accident, people would be much less exposed to ionising radiation thanks to these modifications:

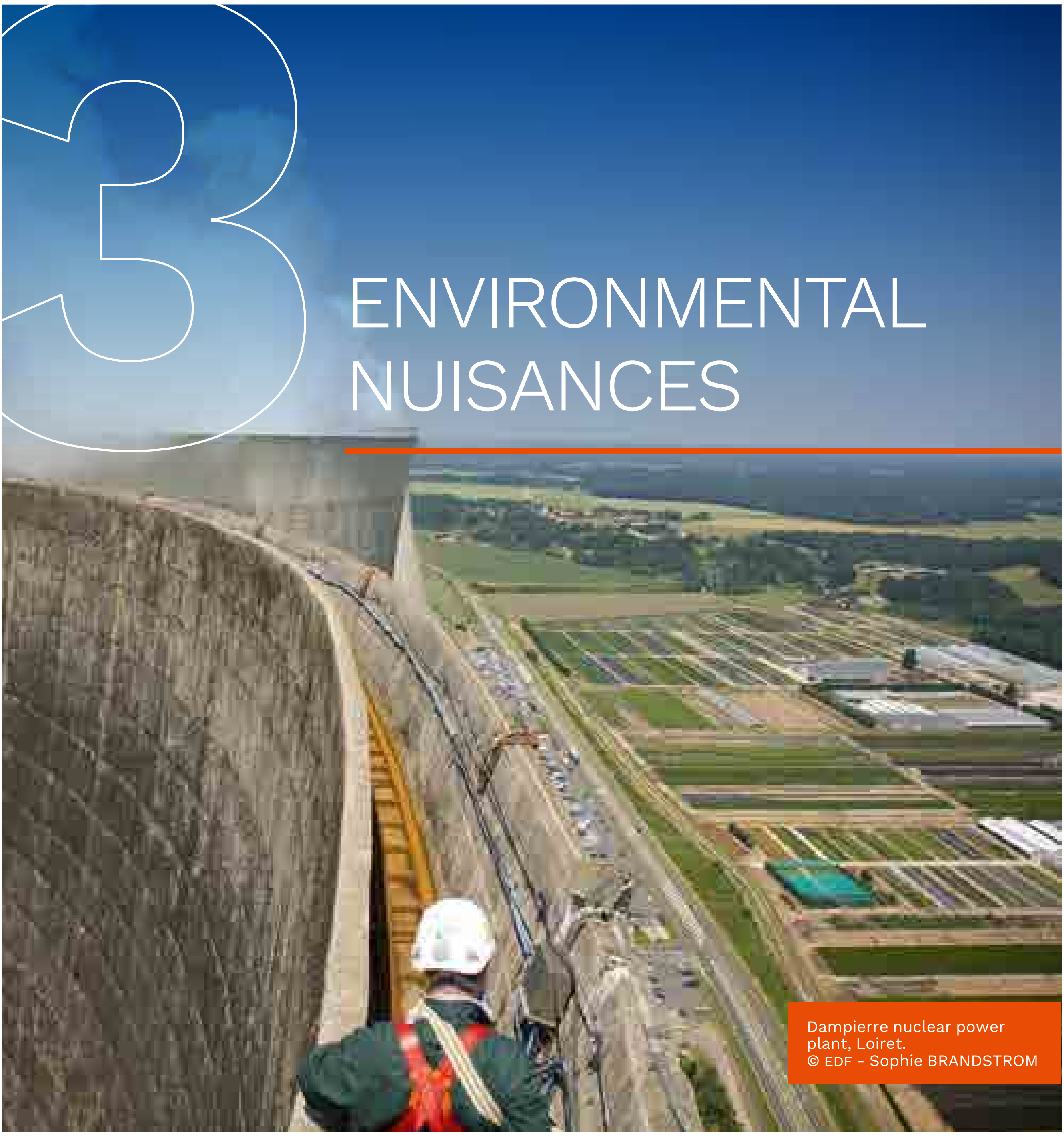
- Effective doses calculated at 7 days are reduced by a factor of 20; thyroid doses at 7 days are reduced by a factor of 30 to 50; long-term effective doses (life time) are reduced by a factor of 3 to 4;
- Calculated dose uptake for members of the public in such conditions are lower than the thresholds established for the implementation of countermeasures at distances of more than 5 km from the plant, for the evacuation of residents, and 10 km from the plant for stable iodine administration.

Measures taken for purposes of the fourth periodic safety review (4 RP 900) will ensure that the likelihood of early and large releases remains extremely small in the event of a core-melt accident (around 10^{-7}/year.reactor).

(6) Corium is the material that forms in the event of a reactor core-melt. It consists of nuclear fuel and reactor materials that melt when they come into contact with this fuel.

Gravelines nuclear power plant, Nord-Pas de Calais.

3 ENVIRONMENTAL NUISANCES



Dampierre nuclear power plant, Loiret.
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From a statutory perspective, environmental nuisances include the impact of plant operations on public health and the environment due to water abstractions and discharges during normal operating periods, as well as nuisances that may be caused by the spread of pathogenic micro-organisms and by noise.

EDF has also chosen to place waste management in this category as waste is generated by normal plant operations.

3.1 Plant compliance

As regards the part of the periodic safety review that focuses on environmental nuisances, the assessment of plant compliance with regulations looks at water abstraction and usage, nuisance management, waste management and the associated arrangements.
Each of the review finding reports will describe the extent to which the site complies with legislation, along with an analysis of lessons learned.

3.2 Reassessment

EDF runs a continuous improvement programme to control the environmental nuisances that may affect people and the environment as a result of plant operations (protected interests). EDF has set itself improvement targets by taking actions, the progress of which will be described in each of the review finding reports.

These actions are designed to improve the control of:
- Water abstraction and usage by gradually installing feedwater polishing plants;
- Discharges, by gradually conditioning the secondary system with ethanolamine as this is the best compromise between equipment protection and discharges to the environment;
- Environmental nuisances by using biocides in condenser-cooling water so as to guard against microbiological health hazards and comply with legislation governing pathogenic micro-organisms;
- Waste, by minimising the amounts of waste generated during steam-generator preventive cleaning operations.

Additionally, as part of the periodic safety review that focuses on environmental nuisances, those that have an impact on protected interests due to plant operations are reassessed. The findings of the assessments listed below will be described in the review finding reports:
- The effectiveness of measures used to prevent and reduce the impact of environmental nuisances caused by plant operations is assessed against the best available technologies;
- Chemical and radiological condition of the site's environment (soil) and surrounding areas;
- Review of limits set for the discharge of substances typically used on a nuclear power plant and identified by the environment code;
- Description of completed assessments, status of outstanding assessments and a tentative waste reconditioning schedule;
- Review of requirements relating to continuous radioactivity monitoring or the doubling of monitoring channels for the discharge of liquid radioactive waste;
- Monitoring of noise levels emitted by the site.

Saint Laurent des Eaux nuclear power plant, Loir et Cher.

4 CONTINUED OPERATION

Bugey nuclear power plant, , Rhône-Alpes.
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4.1 Ageing and obsolescence management

In order to manage ageing and obsolescence issues on its operating reactors, EDF relies on the three following processes:

- Management of ageing systems, structures and components;
- Maintenance;
- Management of obsolescent components and spares.

In order to extend the service life of its facilities after 40 years of operation, EDF's objectives are to:

- Show that replaceable components are able to fulfil their function after 40 years of operation or alternatively, replace or upgrade them;
- Show that non-replaceable components are able to fulfil their function after 40 years of operation (reactor vessel and containment structure).

A geing components which are likely to deteriorate in terms of performance and the failure of which could adversely affect nuclear safety undergo an ageing analysis or a continued-operation review, which are periodically updated.
For purposes of 4 RP 900, summary reports are issued to demonstrate the reactor vessel's ability to continue operating, based on conservative deterministic criteria (nuclear, material, mechanical, etc.).
These reports include a theoretical assessment of generic failure mechanisms (covering all reactor vessels of 900-MWe plants) and a specific assessment of each reactor vessel based on inspection results. For the purpose of this review, the use of hafnium (a neutron absorber) in fuel assemblies located opposite the most irradiated parts of the vessel will reduce neutron fluence (time integral of nuclear flux density) and the potential associated damage.
As far as containment structures are concerned, their mechanical condition is continuously monitored using a variety of methods (strain monitoring, for example) whilst surveillance tests are performed at design pressure (containment building pressure test performed during each ten-yearly outage) in order to verify its resilience over time, in terms of both mechanical strength and leak-tightness.
All reports have been submitted to the regulator and any modifications required as a result of their review will be implemented as part of 4 RP 900.

4.2 Components qualified for accident conditions

Equipment qualification for accident conditions is a process that seeks to ensure that the required components are able to fulfil their safety functions in the postulated accidents conditions. Initially, components were qualified for accident conditions on the assumption of a 40-year service life. As part of 4 RP 900, EDF must demonstrate that the components can be requalified for accident conditions after 40 years of operation or alternatively, replace or upgrade them. Expert appraisals of mechanical components have confirmed that the ageing mechanisms found on valves and pumps are in line with expectations andhave not identified any new ageing mechanisms. The ability of these components to continue operating after 40 years is confirmed by ongoing maintenance work involving the periodic replacement of non-metal parts that are susceptible to ageing.
With regard to electrical components, a number of methods are used to requalify them for accident conditions, ranging from document reviews, sampling and testing through to replacement. As far as 4 RP 900 is concerned, the outcome of this graduated and comprehensive process has resulted in a significant number of preventive component replacements in safety-related systems.

Bugey nuclear power plant, , Rhône-Alpes.

Conclusions

For the 4th periodic safety review of its 900-MWe reactor fleet, EDF's general policy is to aim for nuclear-safety objectives that have been set for 3rd-generation reactors which include EDF's standard-bearer, the Flamanville-3 EPR. The prerequisite for fulfilling this general objective is to ensure that power plants comply with current regulations by:

The prerequisite for fulfilling this general objective is to ensure that power plants comply with current regulations by:

- Carrying out targeted inspections via the plant compliance review;
- Carrying out a set of additional investigations to identify and address potential weaknesses in the maintenance programme;
- Implementing a review programme that focuses on core-cooling and safeguard systems, as well as their support functions;
- Conducting an exhaustive review of measures taken to address compliance issues.

This general objective is translated into specific objectives for the nuclear-safety review, which cover **4 main safety-related topics:**

1. Accidents without core melt

> Complying with nuclear-safety requirements for postulated accidents discussed in the final safety analysis report.

> Seeking to ensure that radiological consequences are mitigated to the extent of not requiring measures to protect the public.

2. Internal/external hazards

> Verifying that plant facilities can withstand revised hazard levels required by the periodic safety review and by internationally recommended standards (WENRA).

> Targeting a core-melt risk factor of a few hundred thousand (1/100 000) per year.reactor, taking all initiating events into consideration.

3. Spent fuel pool

> Taking measures to ensure that the likelihood of fuel assemblies becoming uncovered remains extremely small in the event of inadvertent drainage and loss of cooling.

4. Core-melt accidents

> Taking measures to ensure that the likelihood of early and large releases remains extremely small.

> Taking measures to avoid long-term environmental consequences.

In addition to the risk-informed review (incident and accident conditions) covered by nuclear safety, EDF takes measures to comply with regulations governing the "environmental nuisance" part of the periodic safety review (normal operating conditions) by carrying out multi-year assessments of water abstractions and usage, discharges/releases, environmental nuisances and waste management.

Further to this environmental nuisance management review, improvement actions are implemented. Additionally, the environmental nuisances resulting from plant operations and affecting people and the environment are reassessed.

The 4th periodic safety review of the 900-MWe reactor fleet also includes a section on continued operation, which covers ageing management, obsolescence and the requalification of components for accident conditions. It is based on an extensive programme designed to verify that components are able to fulfil their functions, with some of these components being replaced

The 4th periodic safety review of the 900-MWe reactor fleet coincides with the 40th year of operation. It brings with it significant nuclear-safety enhancements on each of the reactors in question. The associated design and upgrade work accounts for about ten million engineering hours and around 7 billion Euros worth of work.

The fulfilment report (NRO in French) sets out EDF's responses to the objectives set for this review and details all the associated measures: design studies, equipment, operational measures.

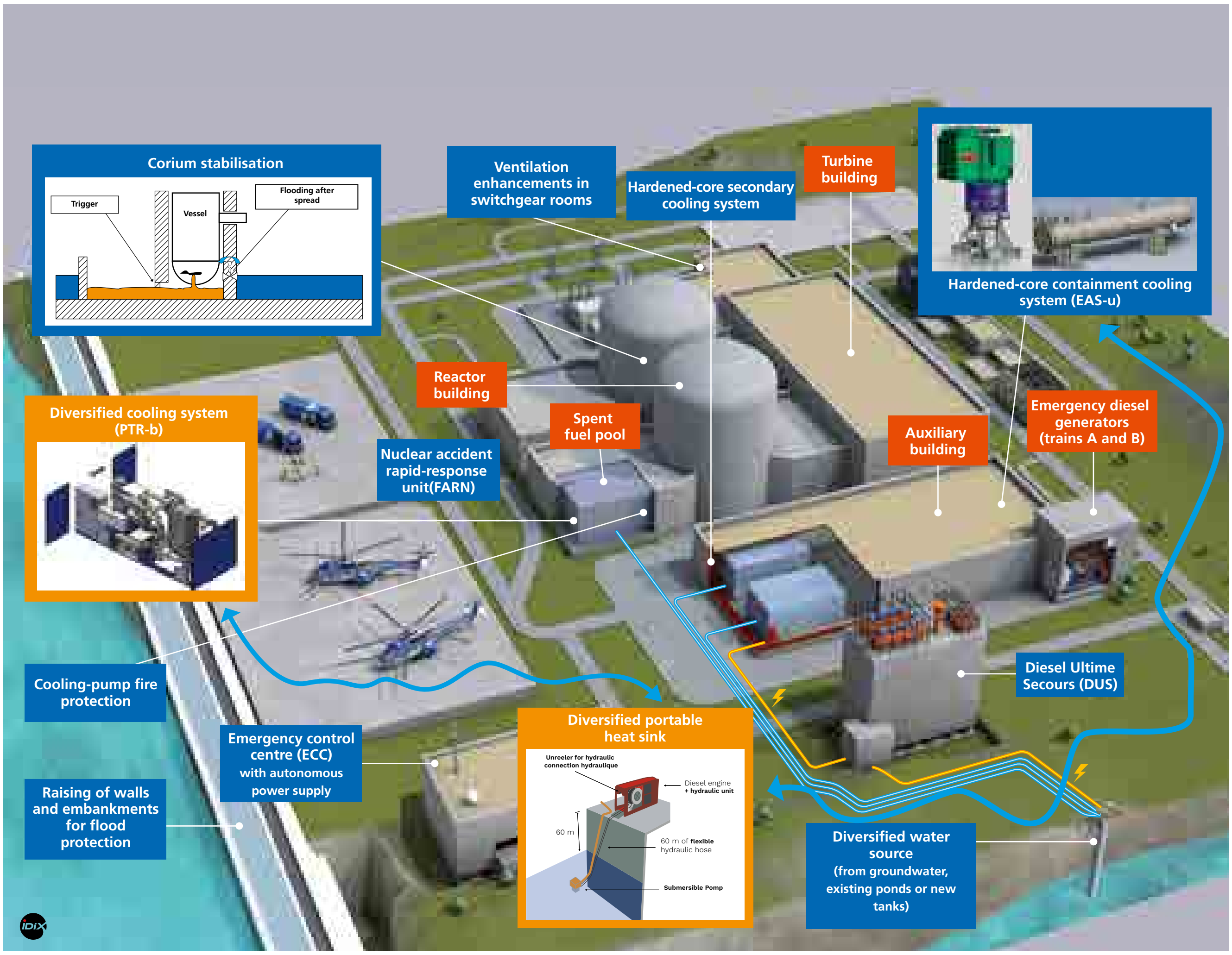
Tricastin nuclear power plant, Rhône-Alpes.

Appendix

Key measures taken to fulfil the objectives of 4 RP 900

The diagram shown below depicts a 900-MWe nuclear plant with the main modifications having been implemented before the 4th periodic safety review, in order to meet the objectives of 4 RP 900:

EAS-U : Emergency cooling system, designed to submerge and cool the corium inside or outside the reactor vessel, as well as to remove residual heat outside containment.
"Hardened-core" secondary cooling system: Residual heat removal system designed to remove residual heat outside containment by means of the steam generators (primary system pressurised or capable of being pressurised).
Diversified cooling system (PTR-b): Diversified system for cooling the spent fuel pool.
Raising of walls and embankments for flood protection.
Nuclear accident rapid-response unit (FARN): Team in charge of transporting equipment and people to assist plant personnel having to respond to an emergency with potential releases to the environment.
Diversified portable heat sink: Cooling system for EAS-u or PTR-b brought in by FARN.
Diversified water source: Water supply to the hardened-core secondary system auxiliary feedwater tank as well as replenishment of spent fuel pool inventory.
diesel (SBO): Additional power supply in the event of a station black-out.
Emergency control centre (ECC): Emergency response building with adequate accessibility, autonomy and habitability in the event of an emergency.
Cooling-pump fire protection: Cooling pumps are segregated by a thermal shield in order to prevent fire from spreading from one pump to another.
Ventilation enhancements in switchgear rooms: Modification of the ventilation system to increase its heat-up capacity, thereby ensuring that it complies with temperature requirements for safety-related equipment.
Corium stabilisation: System installed at the base of the reactor building in order to guard against the risk of losing containment in core-melt accident conditions through erosion of the base-mat.



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Sources of electricity sold by EDF in 2016:
85.9% nuclear, 7.2% renewable (of which 5.3% hydro), 1.9% coal, 3.7% gas, 1.3% fuel oil.
Indicateurs d'impact environnemental sur www.edf.fr

Energy is our future. Let's conserve it!