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EDF PWR Fleet overview

Post-Fukushima Safety Improvements

Practical implementation and Challenges

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Outline

- EDF a global energy leader

- Nuclear generation in France:

experience and challenges
Long term operation
FLA 3 EPR construction progress

- Post Fukushima safety improvements

Results of "stress tests" in EDF reactors
Key additional measures
Main steps of deployment

- Conclusion

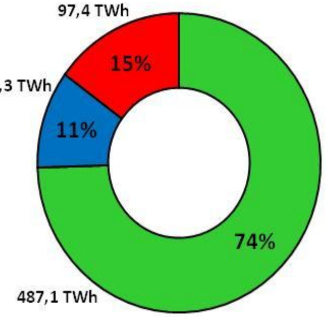
EDF - A Global Energy Utility - Leader in low carbon technology

Key figures 2013 - Worldwide

- 39,1 million **customer accounts**
- **653,9 TWhe** electricity generated
- 158 467 employees

- **Sales**: 75,6 bEu 53% France; **47% abroad**
- **Ebitda**: 16,7 bEu 64% France; **36% abroad**
- **CO2 emissions** : EDF Group **123 g/kwh**; EDF France **30 g/kwh**

- **EDF Group net generation mix worldwide: 140,4 GWe => 653,9 TWh 85% CO2 free**
  Nuclear 74,8 GWe => 487,2 TWh (74%); Fossil: 37,7 GWe => 97,4 TWh (15%);
  Hydro & other renewable 27,9 GWe => 69,3 TWh (11%)



- **EDF SA France net generation mix: 98,2 GWe => 461,9 TWh 95% CO2 free**
  Nuclear: 63,1 GWe => **403,7 TWh** (87,4%); **Fossil**: 15 GWe => **15,6 TWh** (3,4%);
  Hydro & other renewables: 20 GWe => **42,6 TWh** (9,2%) (+7 TWh with pumping)
  (nb: total production in France 550,9 TWh, EDF part 85%, 74% nuclear)

- **Electricity: covering the entire chain, R&D**
  from design, engineering, operation, transmission, distribution and supply.

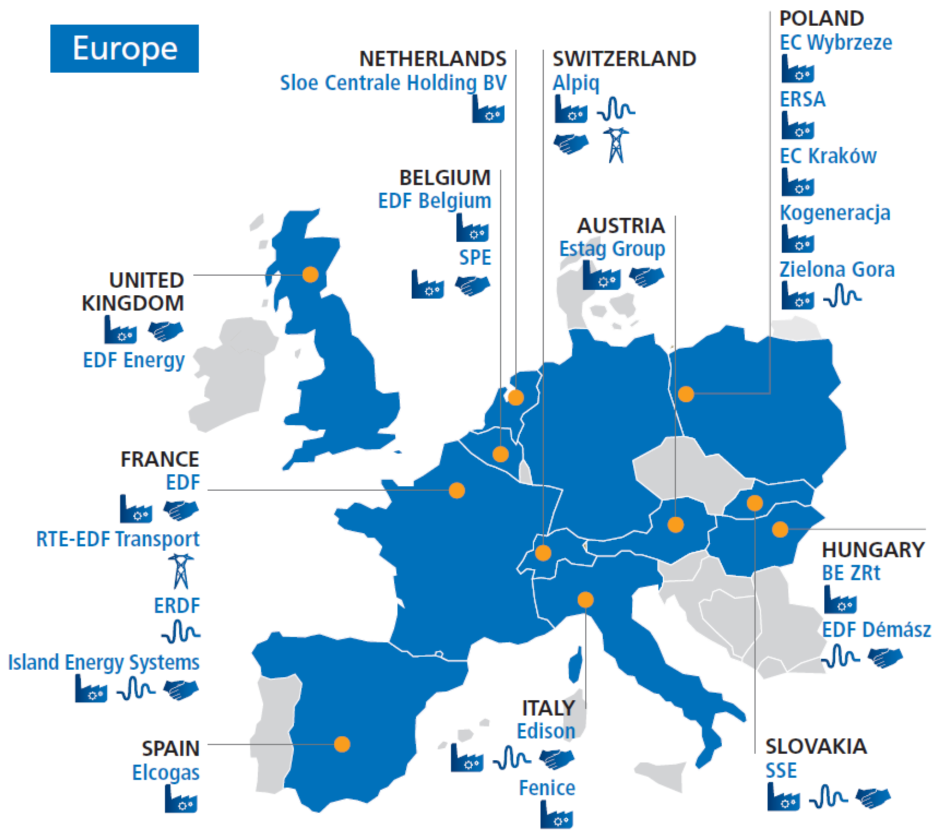
- **EDF nuclear expertise:** more than 30000 staff (Operation: 25000; Engineering: 5000; R&D: ≈ 1000 eq.)

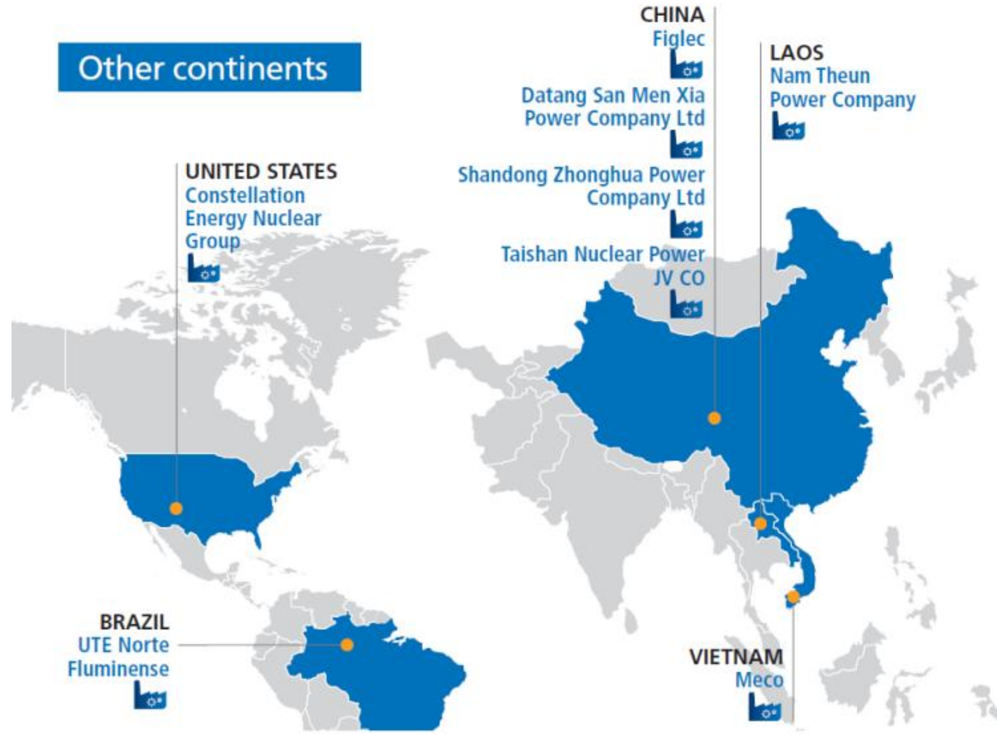
- **Solidly anchored in Europe (**France, Italy, Poland, UK...); **Industrial operations in China, Brazil and USA**

- **Renewable**: a developing activity worldwide (> 4 GW; Wind:11,3 TWh in 2013)

- **Natural gas**: sales > 245 TWh France: 22 TWh (4,4% market share); Italy: 15,7 bm3 or 176 TWh (22,5%); UK: 31 TWh (5%); Belgium: 16 TWh (18%)

EDF - Map of operations





Other businesses

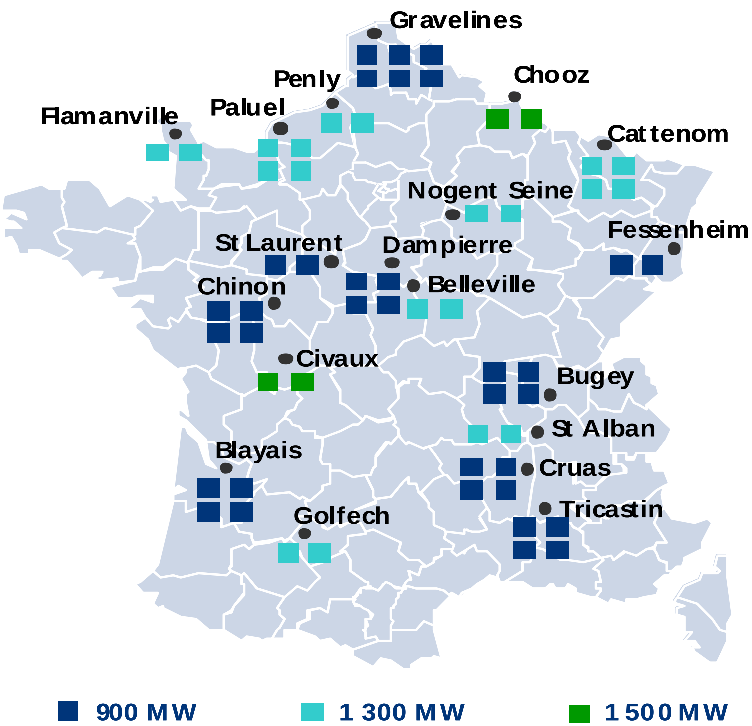
- EDF Énergies Nouvelles
- Tiru
- Électricité de Strasbourg
- Dalkia
- EDF Trading

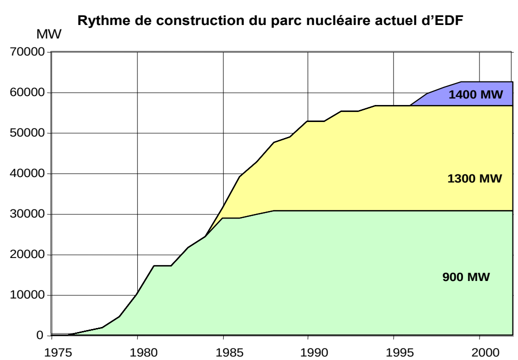
Generation
Distribution
Services
Transmission

Nuclear generation in France

Experience & challenges

EDF Nuclear facilities in France





58 Pressurized Water Reactors (PWR) on 19 sites: 63,13 GW

Three standardized series:
=> a major safety and economic benefit

- 900 MW: 34 units, 31 GW
- 1300 MW: 20 units, 26 GW
- 1500 MW (N4): 4 units, 6 GW

Experience as architect engineer / constructor and operator of the French nuclear fleet unique in the world

- safety and transparency as a major priority
- average operation time: 28 years (12 to 36 years)
- Experience feedback: ~ 1600 reactor years
- Periodic 10 years Safety Reassessment process

=> Long Term Operation: technical goal up to 60 years

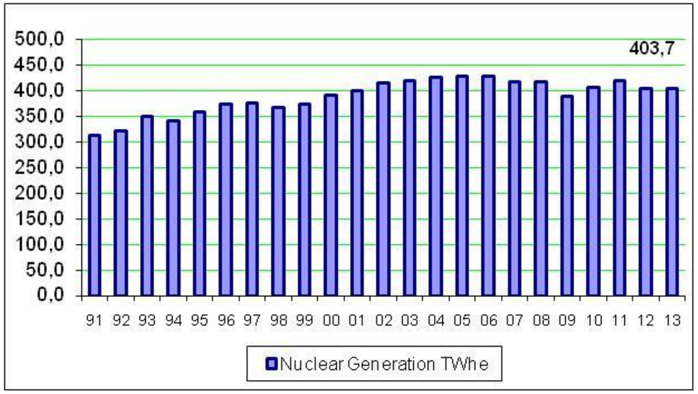
EPR under construction: Flamanville 3

Decommissioning program: 9 reactors
(6GGR, HWGCR Brennilis, Creys Malville, Chooz A)

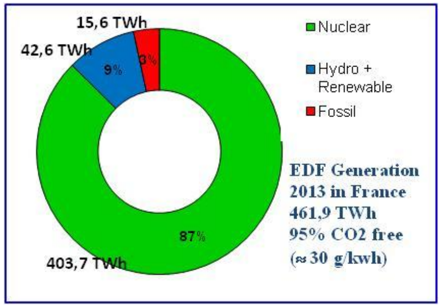
EDF Nuclear Generation in France and abroad (2013)

- **EDF in France: 63,13 GWe => 403,7 TWhe**

  kd : average 78% (top10: 91 to 99,5%); kif: 2,6%
  ku : 93,6% (frequency control, load follow..)
  Load rejection success rate: 88% (average)



A sustainable fuel cycle: reprocessing, recycling,
Use of MOX fuel on 22 units 900 MW (30% core)
HL Waste management : vitrification, storage, future disposal..



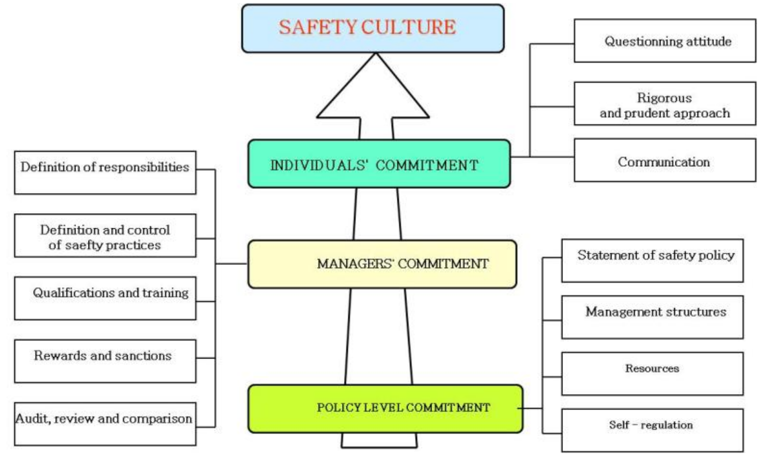
Main recent technical issues:
- Steam Generators replacement policy (SGs replaced on 23 units)
- generator stators, main transformers …
- maintenance, outage management

- **EDF Group abroad (nuclear):**

- **UK: EDF Energy : 8,74 GW nuclear** => **60,5 TWh** (14 AGR, 1 PWR at Sizewell)
- **Other international participation in nuclear generation: ≈ 2,89 GWe => ≈ 22,9 TWh**

  5 reactors (49,99%) in US with CENG: Calvert Cliffs 1/2, Ginna, Nine Mile Point 1 & 2(82% - BWRs)
  Tihange 1 (50%) in Belgium, other participation in Belgium (EDF Luminus) & Switzerland (Alpicq)

Priority to safety - Main indicators and actions



- **Safety and Quality in Operation as a First Priority**

- EDF Group Safety Policy: safety culture and transparency
- stable results in safety & radioprotection
- safety improvement: operating experience, periodic reassessment process...

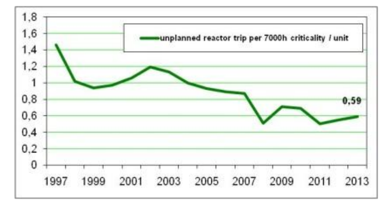
Internal independent control structures:

=> General Inspectorate for Nuclear Safety at EDF Presidency
=> Nuclear Inspectorate at Nuclear Generation Division
=> Safety Quality Mission at each plant

International assessments and peer reviews:

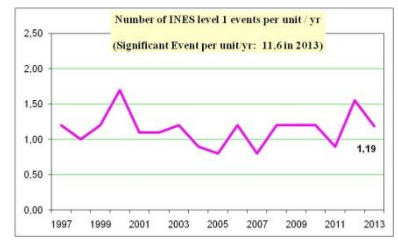
IAEA Osart (1/yr), **WANO peer reviews** (2 to 3 /yr)

International controls (Euratom)**:** safeguards, material accounting…

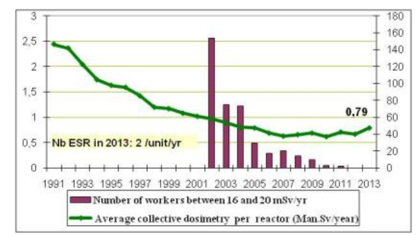


- **Main Challenges ahead :**

- 30-40 year inspection and safety reassessment for Long Term Operation (> 40 years)
Implementing the technical conditions to enable to operate the NPPs up to 60 years:
. pursuing safety improvements through experience feedback & Periodic Safety Reviews
. **post FKH action plan to cope with severe hazards ("hard safety core", fast action force...);**
. prevention of material ageing and obsolescence



- Flamanville 3 EPR to be commissioned in 2016;
EPR construction in Taishan 1/2 (30% EDF with CGNPC)
Preparing for 2 EPR construction at Hinckley Point in UK
Drawing benefit from experience feedback; optimization of construction and design



EDF strategy for sustainable nuclear generation
Key Progress and Challenges

Remain a reference for the nuclear industry worldwide
- Nuclear safety and safety culture as a first priority at all levels
- Experience feedback and efficiency of defense in depth, emergency preparedness,
- post FKH experience feedback: Complementary Safety Assessment, Fast Action Force...
- Competitiveness, availability and operational performances ...

Plant Long Term Operation management
- Periodical 10 years Safety Reassessment: **technical goal up to 60 years**

Fuel cycle efficiency, reprocessing & MOX recycling, HLW vitrification & waste management
- A major asset for sustainable nuclear energy

Succeed in the EPR Flamanville-3 construction project, while drawing experience feedback
- public debate and acceptance; safety, quality, schedule, cost, etc.

Being a major player in the international development of Nuclear Power
- International cooperation: IAEA, WANO, WNA, ENEF, R&D (EPRI, JAEA..)
- New Nuclear Build projects: China (2 EPR), UK (EPR GDA), USA (licensing US EPR),
- Prospects in Poland, Saudi Arabia, RSA...
- Optimization of EPR, Development of a GEN 3 reactor (1000/1100 MW) with Areva and CGNPC

Developing the skills and competences needed to achieve these objectives
- International Master in Nuclear Energy, skill academies ....

Periodic Safety Reviews: the key to Plant Lifetime Management

Every 10 years, a safety reassessment process is performed for each standardized series

- Reassess safety references & compliance checking
- Take into account operating experience and best international practices
- Implement modifications: components, structures, systems, documentation
- Analyze ageing mechanisms to manage fitness for LTO service

=> An on going process for maintenance, preparation, strategic decision, studies, implementation

	VD1 10 years	VD2 20 years	VD3 30 years	VD4 40 years
900 MWe 3loops (34)	Done	Done	2009 to 2020	2019 to 2030
1300 MWe 4 loops (20)	Done	2005 to 2014	2015 to 2024	2025 to 2034
1500 MWe	Done	2019 to 2022	2029 to 2032	2039 to 2042

A 40 years operation time can be technically attained for existing plants

- A sustained R&D effort on long-term behaviour of main components and aging ability,
- Creation of Material Ageing Institute at EDF R&D, with major utilities (inc. REA...), and laboratories
- ASN agreement up to 40 years for first 900 MW plants (FSH 1/2, Bugey 2/4, TRI 1..), under some conditions

EDF objective is to maintain the technical option up to 60 years, under ASN control

- A global refurbishment programme, to be implemented by 2015 and after, inc. post FKH action plan
- Pursuing the continous safety level and environment protection improvement program;
- Anticipation program for aging effects or obsolescence of components

The EPR Project at Flamanville 3

Significant milestones reached :

First nuclear concrete, 2007, december

Main civil engineering, dome of the reactor building installed, reactor pressure vessel introduced

Convergence on digital I&C discussions with ASN

Robustness of the design, including severe accidents

some adaptions after FKH : water reserve to increase autonomy, reinforced water tightness, longer autonomy (diesel fuel, batteries...), connections for mobile means...

A start-up schedule focused on 2016 :

Construction : electromechanical and primary circuit settings, end of external dome

On site fuel delivery : 2015

Results of "Stress tests"

in EDF reactors

Main steps of deployment

Results of "Stress tests" in EDF reactors and EPR

The methodology has been defined by ASN, consistent with EU requirements, with a two steps approach:
(1) Reassessment of the existing means and margins according to the current design basis (current safety reference standards)
(2) Analysis beyond design; if necessary implementation of additional means

6 review areas: Earthquake, Flooding, Loss of cooling water supply, Loss of power; Severe accident management; Contractors

==> Following this work, the current good level of safety with adequate margins for all nuclear facilities has been confirmed.

Most of the lessons learned were already anticipated as part of the periodical 10 year safety reassessment process, especially for flooding hazard (following Blayais event in 1999).

==> The new analyses led EDF to put forward supplementary measures, taking potential situations even further than previous hypothesis.

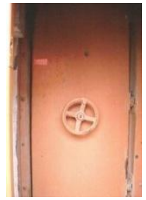
Improvements for existing NPPs following CSA

- **Enhancing robustness of systems designed to protect key safety functions against external hazards (earthquakes, flooding...)**

- flooding: protection of equipment and materials (dams or dykes, building leaktightness...)
- Supplementary protection of electrical switchyards against flooding
- Earthquake: reinforcement of supports and anchorages, electrical equipment, automatic trip...

- **Increasing water make-up and electrical power supply capacity, to cool the reactor and avoid fuel uncovery** (reactor core, spent fuel pool)

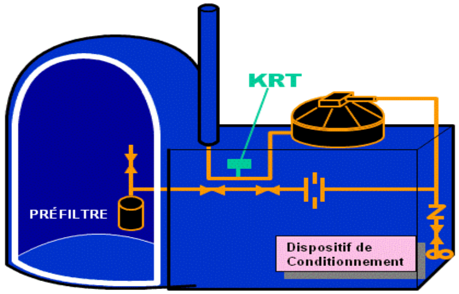
- additional water reserve (basin, underground table…)
- reinforcement of the back up cooling water supply (tank...)
- implementation of one additional back up diesel generator on each unit: back up supply of AFW pumps, water make-up to RCS and spent fuel pool, thermal pump to supply water in RCS
- spent fuel pool operation: instrumentation (level, temperature), supply systems, fuel handling..



- **Protective measures in case of core meltdown, minimizing radioactive releases**

to avoid significant long-term contamination of surrounding areas

- robustness and efficiency of U5 containment filter to limit external releases (cesium...), seismic resistance, improvement of fitration capabilities (iodine),
- soda in reactor building sumps (to trap iodine)

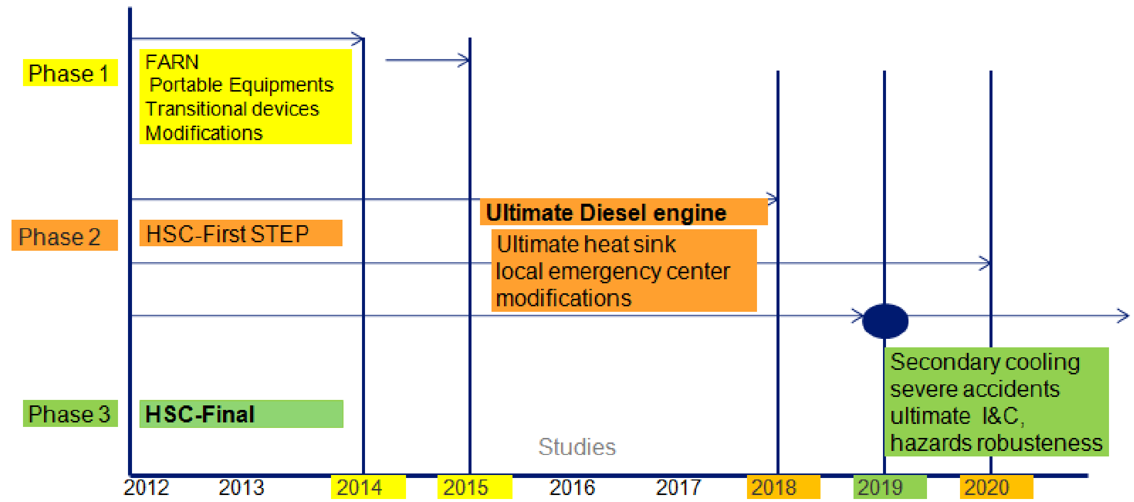


- **Reinforcing site and national emergency preparedness organizations:**

- personnel and equipment; event involving multi-units on site

Post Fukushima Actions Plan

Carrying out of the EDF commitment to sustain and implement the safety objective: No large releases with long term contamination of large territories (CNS - IAEA - August 2012)



Extensive works and large investments for EDF to meet this objective under extreme and severe situations

Main actions done, according to ASN requirement:

Medium-low power generator sets have been installed in each unit - june, 2013

Additional portable pumps in each unit, end 2013

FARN-operationnal for 2 units on site (2013)

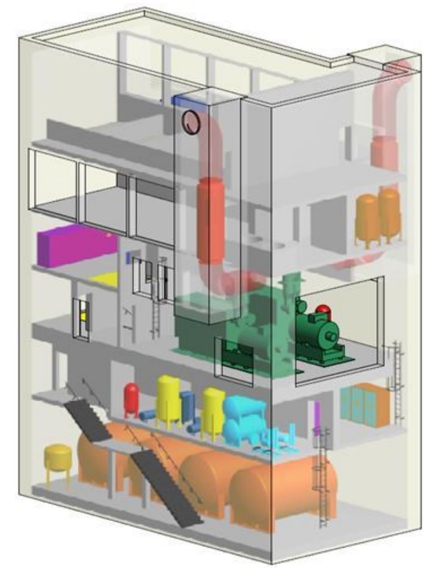
Emergency preparedness : means of communication, organisation, training for accidents

Key additional measures

• Implementation of a "Hardened safety core" of systems, structures and components designed to prevent large radioactive releases to the environment in extreme conditions considered by ECS reviews.

- protected against extreme external hazards exceeding the scope of the current design basis.,

- to increase mitigation and robustness beyond design



• Nuclear Rapid Response Force (FARN)

- The setting up a supplementary "resilient" line of defense through a national "Rapid Action Force" (FARN) ready to support a site in trouble within 24h (event involving multi-units), with adequate Logistics,

- reinforcement of crisis management premises on site

Nuclear Rapid-Response Force

Objectives: **to re-establish and/or maintain reactor cooling with the aim of avoiding any core fusion or any significant release**

Missions:

Intervene
- **Intervention within 24 hours** (1 corporate and 4 regional dedicated teams…), in support of shift teams

Evaluate
- Situation of site
- Positioning of rear base (10 to 30 km)

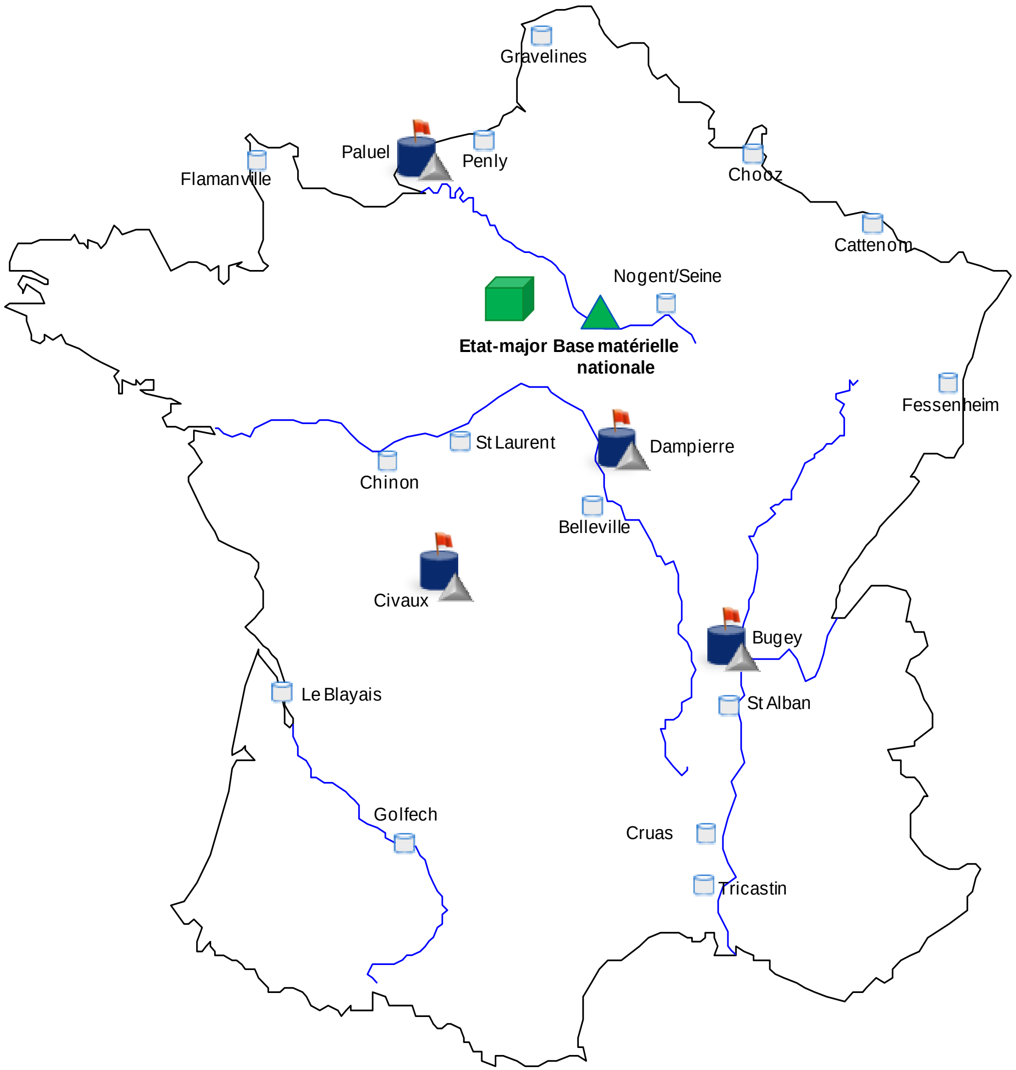
Act
- **Reinject water into the installation**
- **Plug & play connections (power, pumps…)**
- **take up of operation after 24 h**

Deploy
- **Large scale equipment (3-4 days)**
  - Protection, Intervention, Control
  - logistics

Prepare
- Actions to remain in effect, after the first days of autonomous action
- **Management throughout the entire duration of the situation (water provision, effluent processing, awste etc.)**

Organization of the FARN- EDF WORKFORCE

A two level, national and regional, organization



1 national FARN headquarter

(reconnaissance team, about 30 people, 5 on-call teams, country wide intervention)

1 national equipment base

(mid and long term equipment, back bases modules)

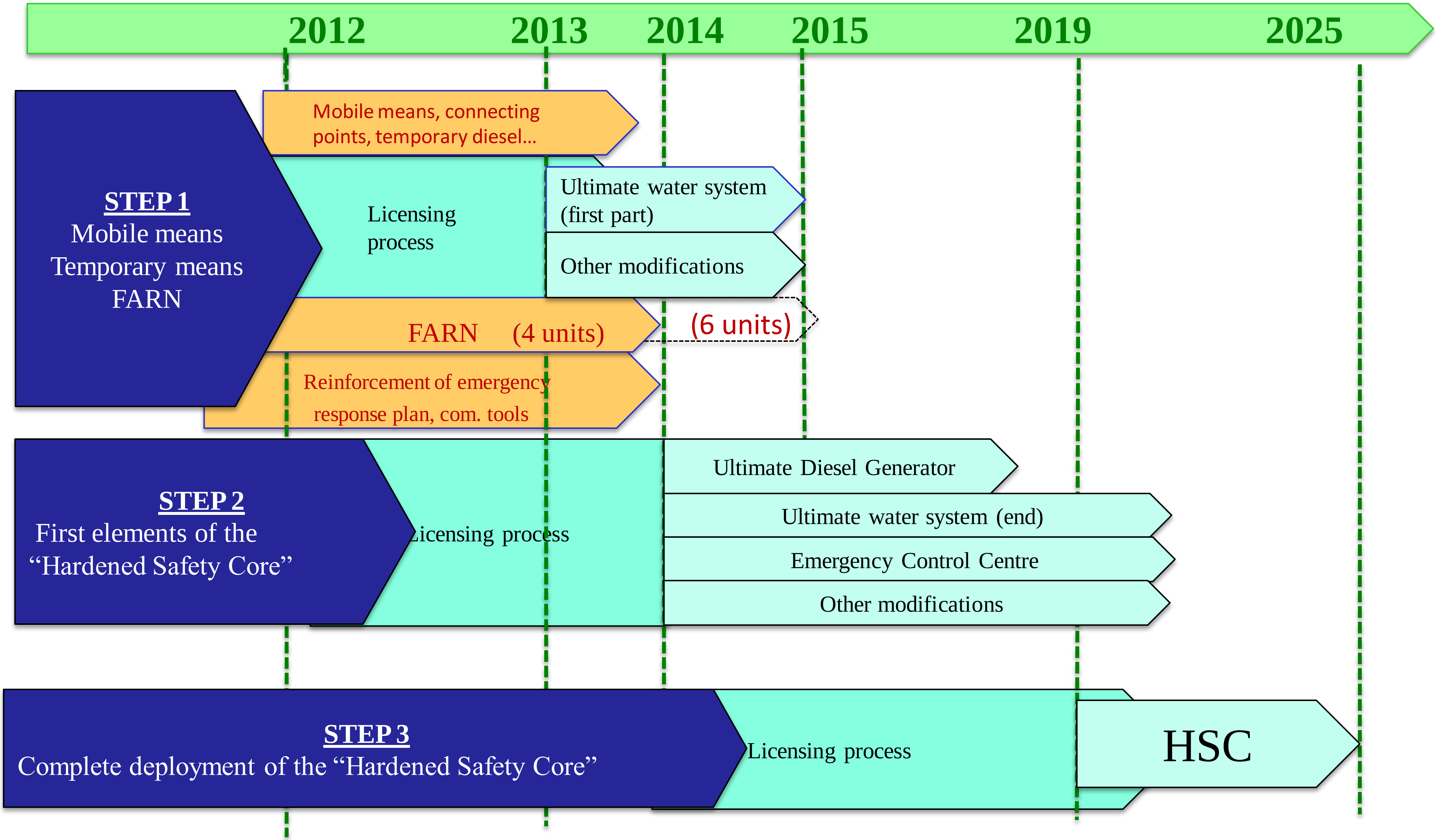
4 regional FARN HR bases with regional equipment bases nearby

hosted by 4 Farn'ed NPPs
(Civaux, Dampierre, Paluel, Bugey)
(about 4 x 70 people in 5 teams of 14 on-call people each, country wide intervention)

4 local rear bases predefined for each of the 19's NPPs

(one to be requisitioned by the prefect in case of severe situation on the NPP)

Three main steps to implement modifications



Step 1: 2012-2015
Mobile & temporary means, FARN

- Short term covering by emergency means and temporary modifications for beyond design SBO and Loss of Ultimate Heat Sink (several units of a site, long duration):
  - Mobile devices (pumps, pipes, generators,…)
  - Temporary provisions (diesel generator , ...)
  - Upgrade of the crisis organisation
  - Automatic reactor shutdown in case of earthquake
  - Reinforcement of earthquake and flood protections

Ultimate water supply

Hook up points

Temporary diesel

Step 2 : 2015 – 2019
First elements of the "Hardened Safety Core"

- **Mid term covering with definitive SSCs for beyond design SBO and LUHS:**
- **Progressive deployment of the "Hardened Safety Core":**
  - Construction of the DUS (ultimate back-up diesel)
  - Implementation of ultimate water supply
  - Protection against extreme flooding
  - Erection of Emergency Control Centres (ECC)
  - Reinforcement of Filtered Containment Venting system against earthquake
  - Passive tight seals for Reactor main Cooling Pumps
  - Reinforcement of shift teams on the NPPs (ability to manage a Fukushima type of event on their own)

Step 3: 2019 - …
Complete deployment of the "Hardened Safety Core"

- **Final completion of the "Hardened Safety Core" as part of the Plant Life Extension program**
  - Implementation of the last step of HSC from 2019 :
    - Diverse SG residual heat removal (dedicated feed water pump, dedicated SG tank, ultimate water supply and steam relief valves)
    - Dedicated ultimate injection pump to the primary system
    - Specific independent I&C and control panel
    - Containment residual heat removal
    - Reactor cavity pit flooding system

- **Compliance with up-to-date safety standards taking into account the lessons learned from Fukushima accident**

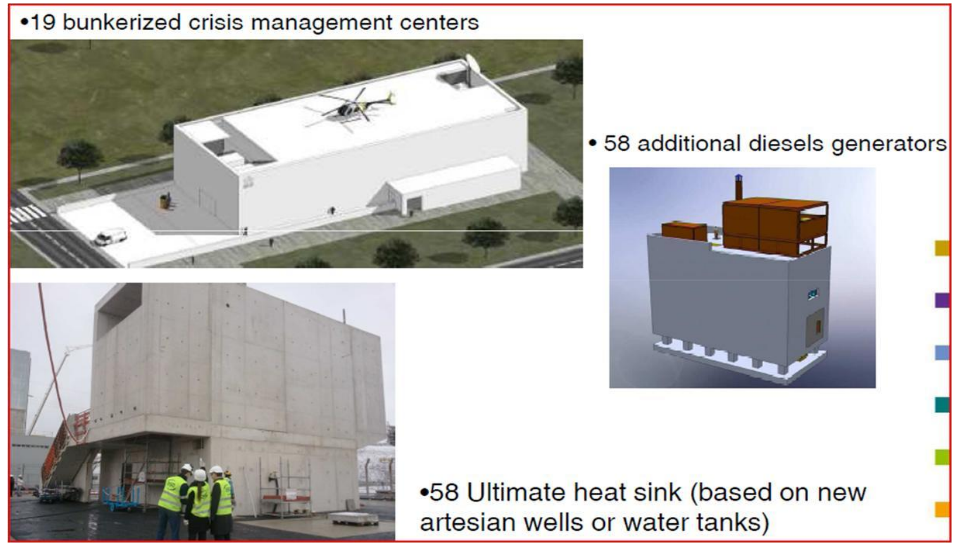
Technical issues and challenges
The "Hardened Safety Core" ... to be built on 58 units

Objectives of the "Hardened Safety Core"

- Prevent or mitigate the progress of an accident with fuel melt
- Avoid large-scale radioactive releases
- Enable the operator to perform its emergency management duties

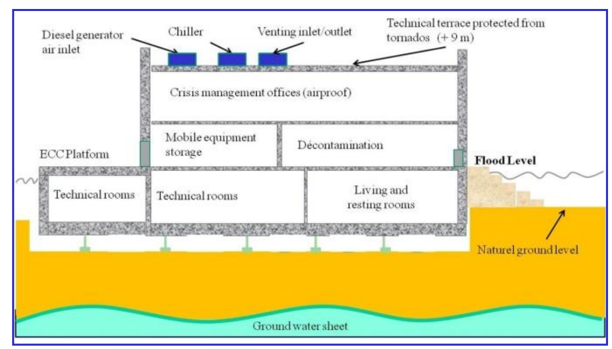
A set of independent and diversified equipment able to remain functional under extreme natural conditions

Earthquake; Flooding; Other extreme natural hazards



Strengthened equipment including

- An additional ultimate electricity generating set for each reactor
- A diverse emergency cool-down water supply for each reactor
- New emergency control centre at each site and remaining habitable during long-duration emergencies
- Mobile devices and means of communication
- Technical and environmental instrumentation



Complying with safety requirements for Hardened Safety Core

- **High resistance level against external hazards : significant margins on design levels**
    - Seismic level >= 1,5 x Safe Shutdown Earthquake
      and with spectra bounding of events with a return period > 20 000 yrs
    - flooding level > design flood level + 1m (sea)
      or + 30% (river) with rupture of upstream dam
    - lightning, hail, rainstorm and tornadoes

- **Operable during 24h following the event without any support from the outside, until FARN set-up**
  - Safety classification requirements for nuclear components (IPS-NC)
  - Study, specifications and manufacturing under rules and quality insurance
    - high resistance level as deterministic design basis for new SSC
    - high resistance level to check for existing SSC , methodology under discussion
  - Maintenance, periodic testing, procedures to be followed in the event of inoperability of a hardened safety core system

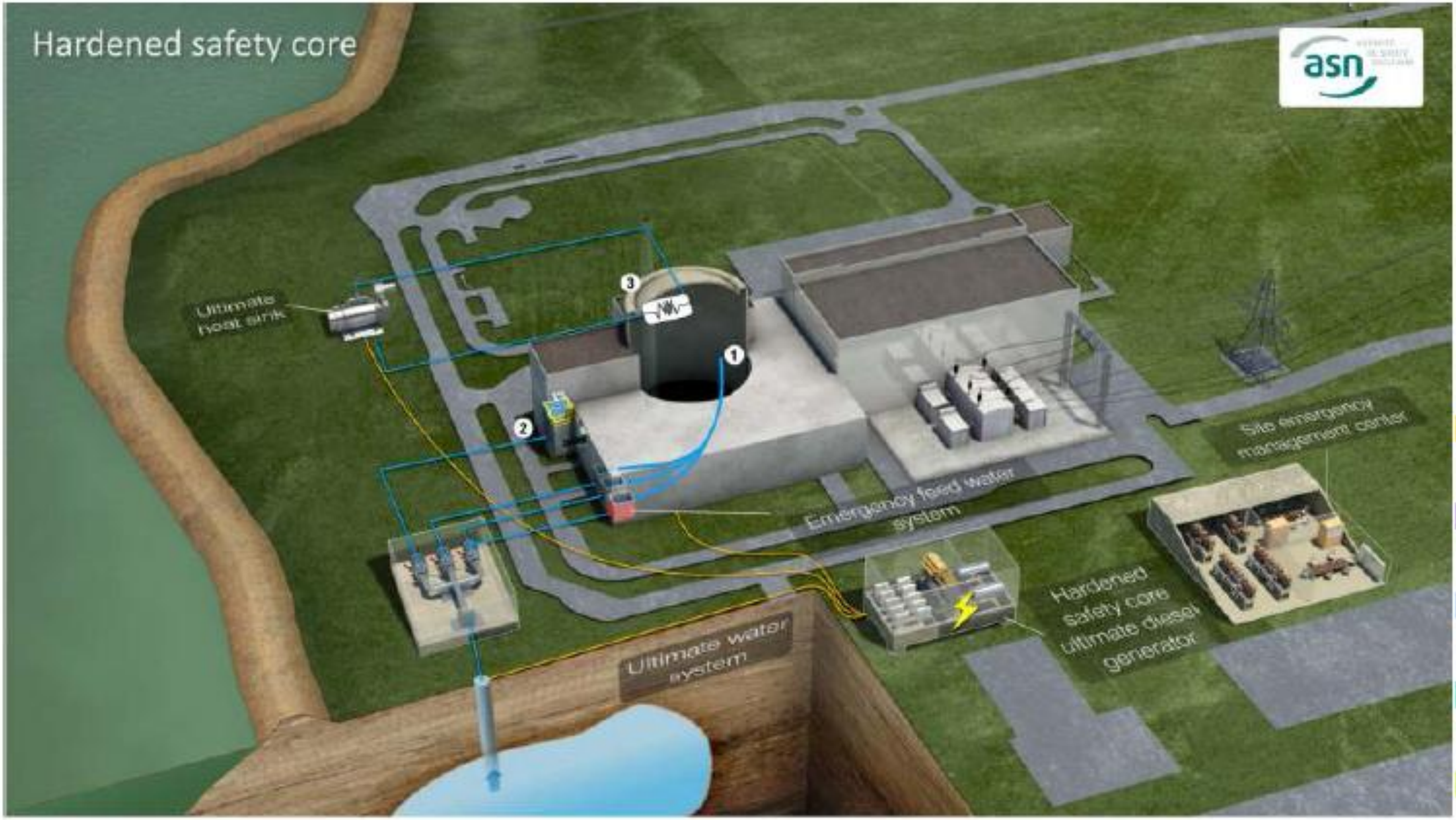
Limiting radiological consequences

Objective is to avoid large releases and long-term land contamination, including in the early phase after the accident:

- Filtered Containment Venting System (FCVS)
But necessity to improve the existing FCVS: seismic design, improved efficiency especially regarding organic iodine to meet radiological objectives
replacement of the sand bed filter by a new scrubber filter: industrial feasibility, costs...

=> Current studies: Design of a new system for containment residual heat removal
to avoid opening of the FCVS, even in case of severe accident,
with a diversified heat sink

Existing FCVS not removed, but not part of the HSC (studies for limited reinforcement against external hazards and modifications..)



1 : reactor cooling system   2 : fuel pool cooling system   3 : reactor containment cooling system

Conclusion: Post-Fukushima actions improve the safety of the French NPPs and prepare LTO

CSA highlight the need and benefit of Periodic Safety Reviews

- Need to check periodically the correctness and the robustness of the Design Basis and beyond (ability to prevent and mitigate severe accidents)
- Need to take into account operational experience and new knowledge with the objective of continuous safety improvement
- Operators shall have the capability of controlling and maintaining the design integrity and design changes of the plants by the integration of R&D, engineering and operating experience
- Benefit to have standardized fleets: homogeneity of the improvements

CSA modifications anticipate actions planned as part of EDF Plant Long Term Operation Program

- The main post Fukushima modifications (water ultimate supply; ultimate diesels…) were part of EDF LTO program before Fukushima
- With in addition new concepts: the "hardened safety core" and the FARN

Implementation of "CSA modifications" is an industrial challenge

For the EDF organization (Engineering and Operating divisions) and for the suppliers to deliver and construct in due time, with priority given to quality and safety.

Thank you for your attention

and questions...