Improvements in defense in depth on French NPPs following Fukushima Accidents

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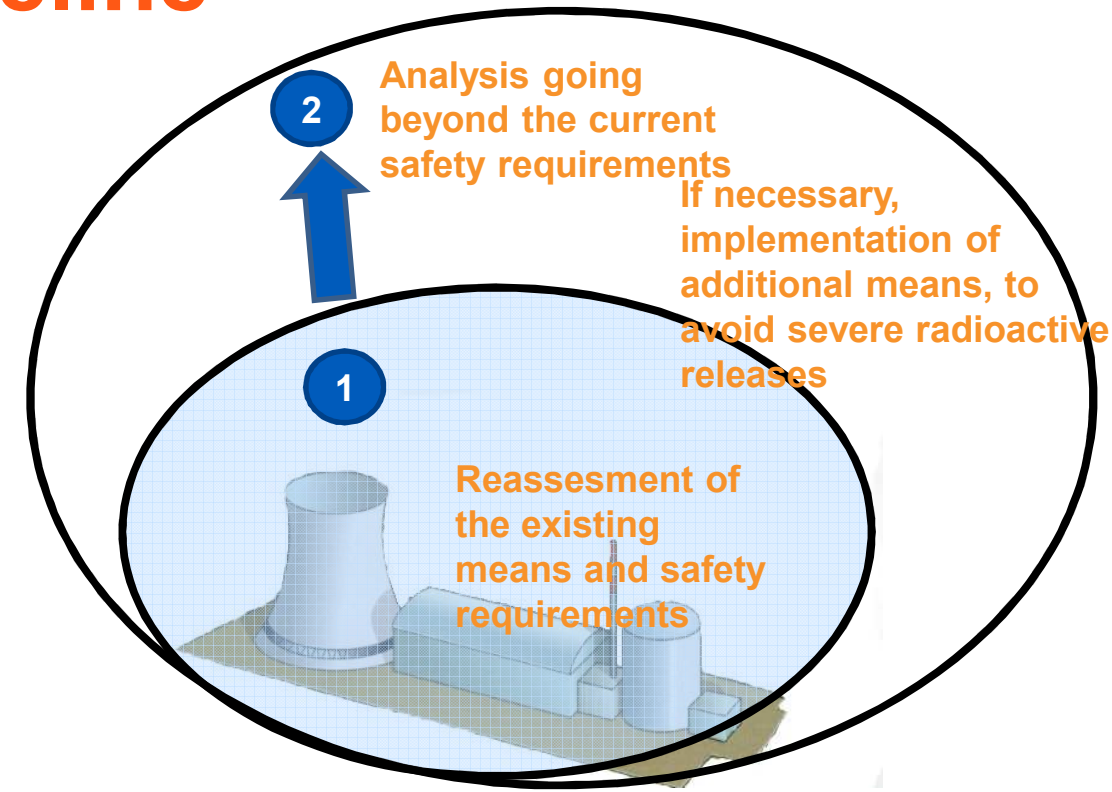
Context - Timeline

6 fields assessed :

- Earthquake
- Flooding
- Loss of heat sink LHS
- Loss of electrical supply SBO
- Severe accident management
- Sub-contracting



Short time process

Required by ASN May 5th, 2011
Completed by EDF September 14th
ASN report January 3rd, 2012
European peer review conclusions April 25th
ASN Prescriptions, June 26 th

Earthquake

Regulatory approach

- Deterministic (RFS 2001-01)
- Historical Research
- Translation near the site ➔ SMHV
- Margin of 1 MSK ➔ SMS
- Margin due to series effect on standard equipment
- Upgrade on plants during PSR (due to update of data & changes in requirements

Existing margin evaluations

- SMA for Tricastin
- PSA for St Alban

CSA

- Evaluation to 1.5 SMS
- Around 200 components (those needed in SBO)
- Walkdown on each reactors
- By teams trained to SMA methods

Main Conclusions

- Compliance ensured though PSR
- Margins up to at least 1.5 SMS on most components
- Additional evaluations required

- ENSREG recommends to implement probabilistic methods

Flooding 1/2

Initial Regulatory approach : RFS 1.2.e

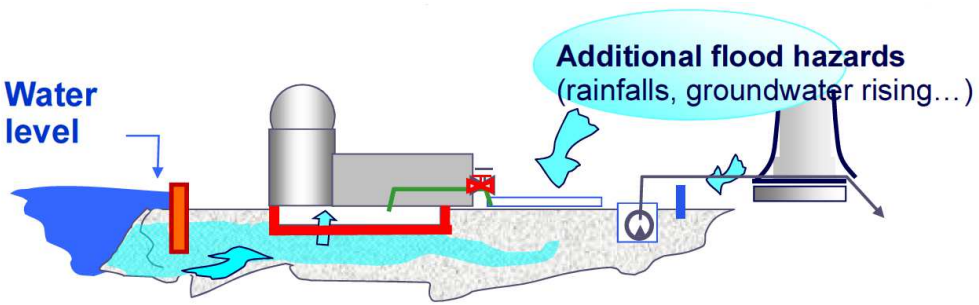
- CMS level according to site type
- River side
  - 115 % of millenial flow rate + uncert.
  - Or upstream dam failure + centenial flow rate
- Sea side
  - Max tide + millenial storm surge + uncertainties

Blayais Flooding Feedback (1999) : Full Review + aditional phenomena

- Wind-waves on sea, river or channel
- Swelling due to operation of valves or pumps
- Rainfalls : intense and short, or long duration
- Water retaining structures (other than dams) deterioration
- Circuits or equipment failure
- Groundwater rise

- **+ credible combinations**

Flooding 2/2



CSA

- Fixed coefficient load increase :
  - 130 % of CMS on river side
  - 1 m more on sea side
  - Rainfall x 2
  - Additional failures on platform

Main Conclusions

- Compliance ensured after already decided works
- Additional protection to avoid LUHS, LOOP or SBO on sites which do not remain dry with load increase
- maintenance of the “volumetric protection” to be improved
- ENSREG recommends a comparative evaluation between DBF defined according to ASN requirements and those used in other countries

Loss of Functions : LUHS, SBO

Current Design

- LOOP : 3.5 days of fuel
- LUHS
  - Water reserves to supply SG
  - 100 h for 1 unit
  - 24 h for a whole costal site
  - 60 h for a whole riverside site
- SBO
  - EFW turbine driven pump
  - Emergency turbine generator
  - Minimum I& C
  - Injection to RCP seals
  - Autonomy > 24 h

CSA

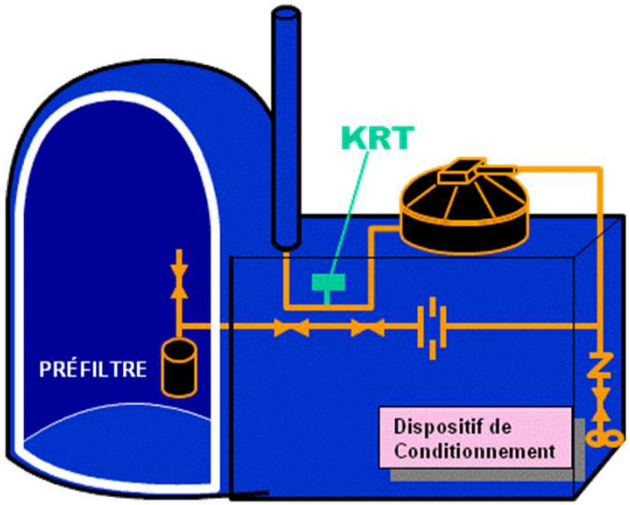
- No recovery of normal means
- All plant states, even rare
- Combination with external hazards

Main Conclusions

- Water reserves not earthquake resistant
  - Additional means
- Sensitivity to turbine reliability
  - Additional generator sets
- Sensitivity of seals to high temps to be checked by tests

Severe accidents

Containment Filtered Venting



Pre-filter DF aerosols >10
Filter DF aerosols >100
DF I_2 > 10

- Pre-filter is earthquake resistant
- Filter shared between twin 900 MW units

Other Devices

- Passive Autocatalytic Recombiners
  - Limit H2 concentration to 8 %
  - 2 with thermocouples
- Reliable RCP depressurisation
- Detection of RPV failure with thermocouples in reactor pit

To be Installed

- Additional electrical supply of double-wall containment venting and control room venting systems
- Sodium tetraborate baskets in reactor building sumps (4 loop plants)

Modifications of the design and of the organisation

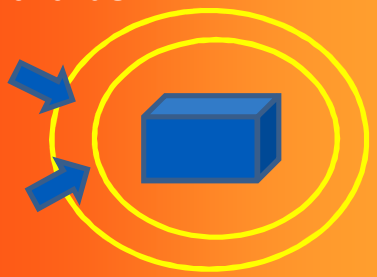
Earthquake | Flood and other hazard | LHS/ SBO Reactor | LHS /SBO SFP | Severe accidents

Protect the key safety functions

Prevention of Core Melt

Mitigation of major releases

1. Reinforcement of protections against hazards



2. Additional electricity source

Additional water reserves

Severe Accident primary injection

3. Protective measures in case of core meltdown

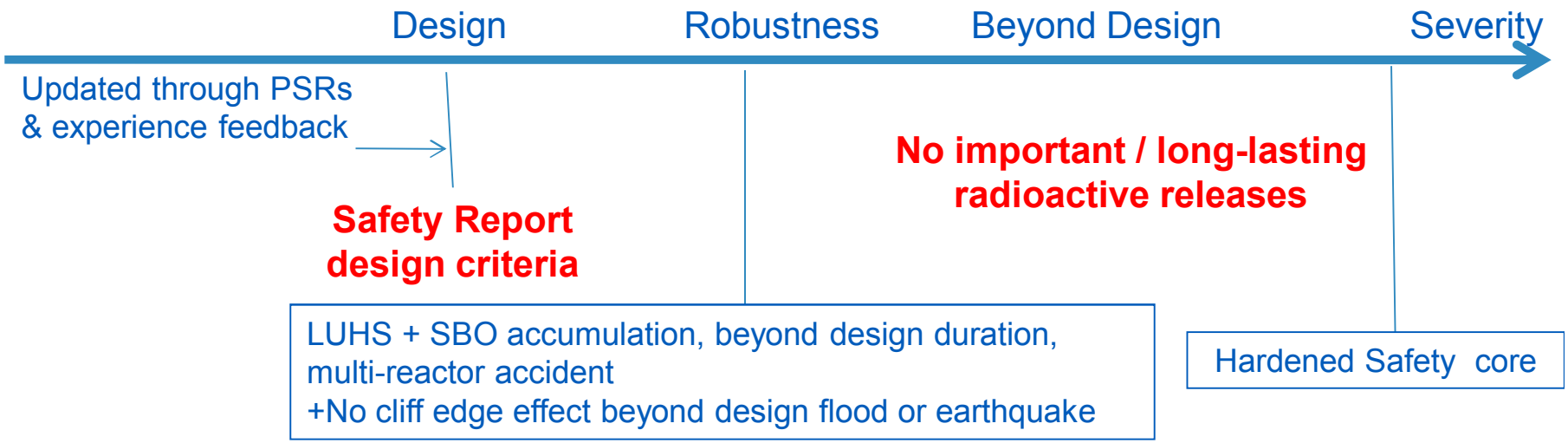
Studies / knowledge of phenomena

Reinforcement of the crisis organization & management
Ressources, fixed & mobile Equipment
Emergency Crisis Centre + FARN

HARDENED SAFETY CORE

French Nuclear Safety Authority (ASN) Requirements :
"Before 30th June 2012, the operator will propose to the ASN a hardened safety core (HSC) of equipments and strengthened organisation, for extreme situations considered in post-Fukushima stress tests :
- to prevent a severe accident or limit its development,
- to limit a severe radioactive release
- to enable the operator to manage the emergency situations."

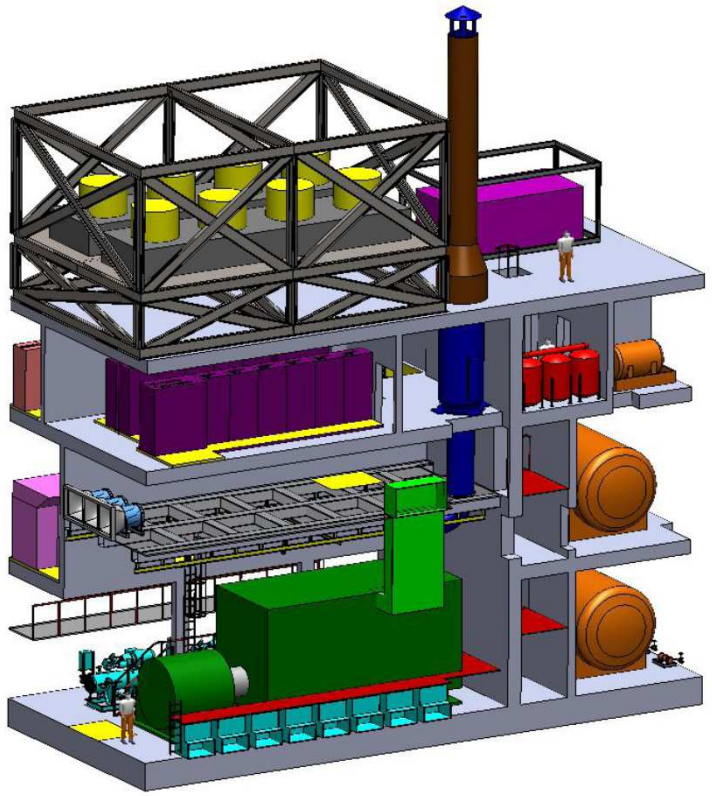
Position in safety demonstration



HARDENED SAFETY CORE

Limited Key Functions

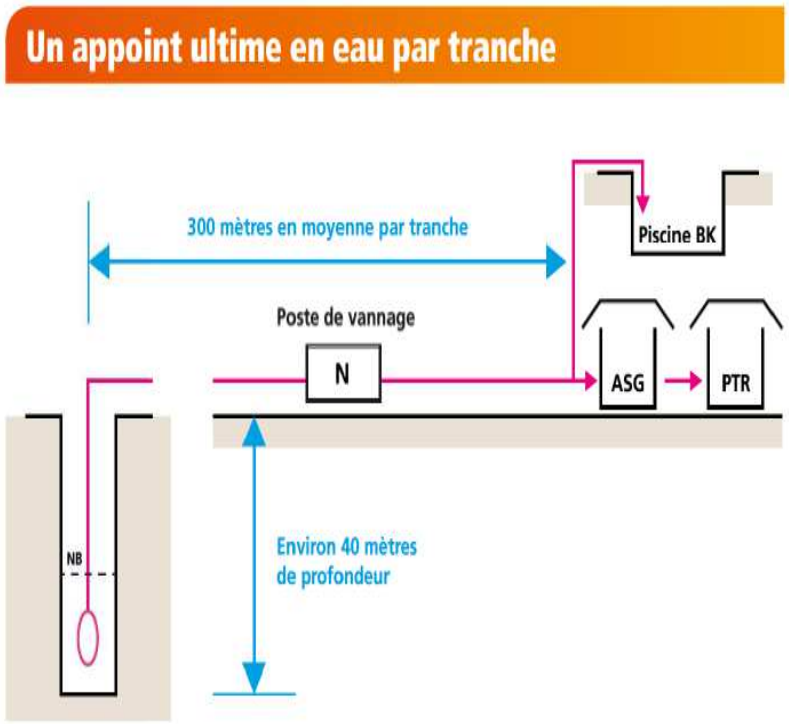
- Ultimate Additional Back-up Diesel, batteries and electrical connections
- Instrumentation (state diagnosis, radiological releases Control of HSC)
- Diversified emergency feed water
- Depressurization of RCS, and sufficient injection capacity
- Water make-up to spent fuel and reactor pools, and primary circuit
- Containment isolation
- Existing CFV
- New crisis management premises
- Mobile devices and essential means of communication



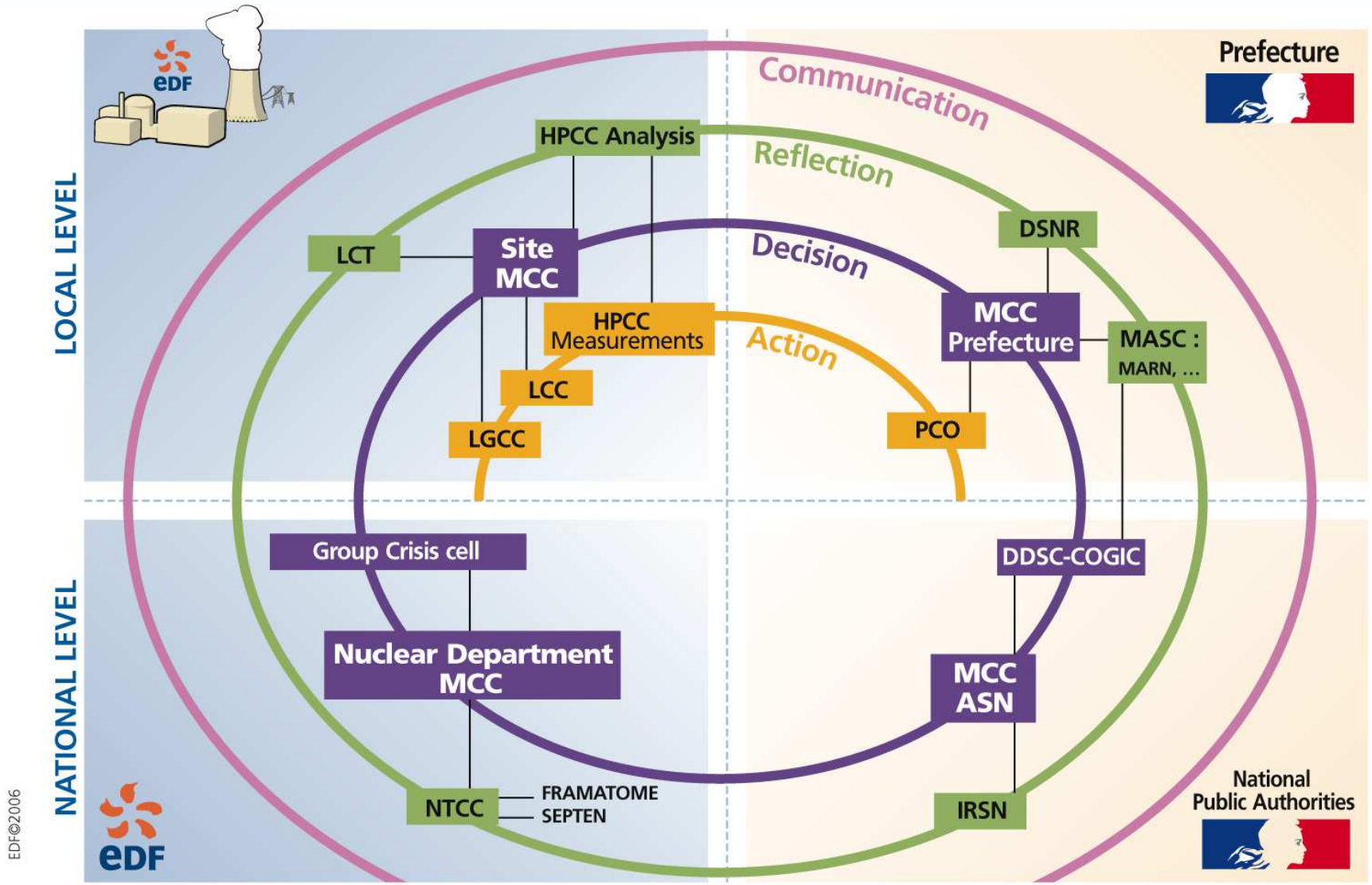
HARDENED SAFETY CORE

Extreme Load Cases

- Earthquake greater than 1.5 SMS, up to 0.4g (already being discussed)
- Flooding : Values used for CSA
  - + Additional margins for 2 sites
- F4 Tornado
- Ligthning : 300 kA
- Hail : 50 mm, 32 m/s
- Induced effects of these loads
  - On other parts of NPP
  - On dangerous installation in vicinity



CURRENT CRISIS ORGANISATION



CRISIS ORGANISATION

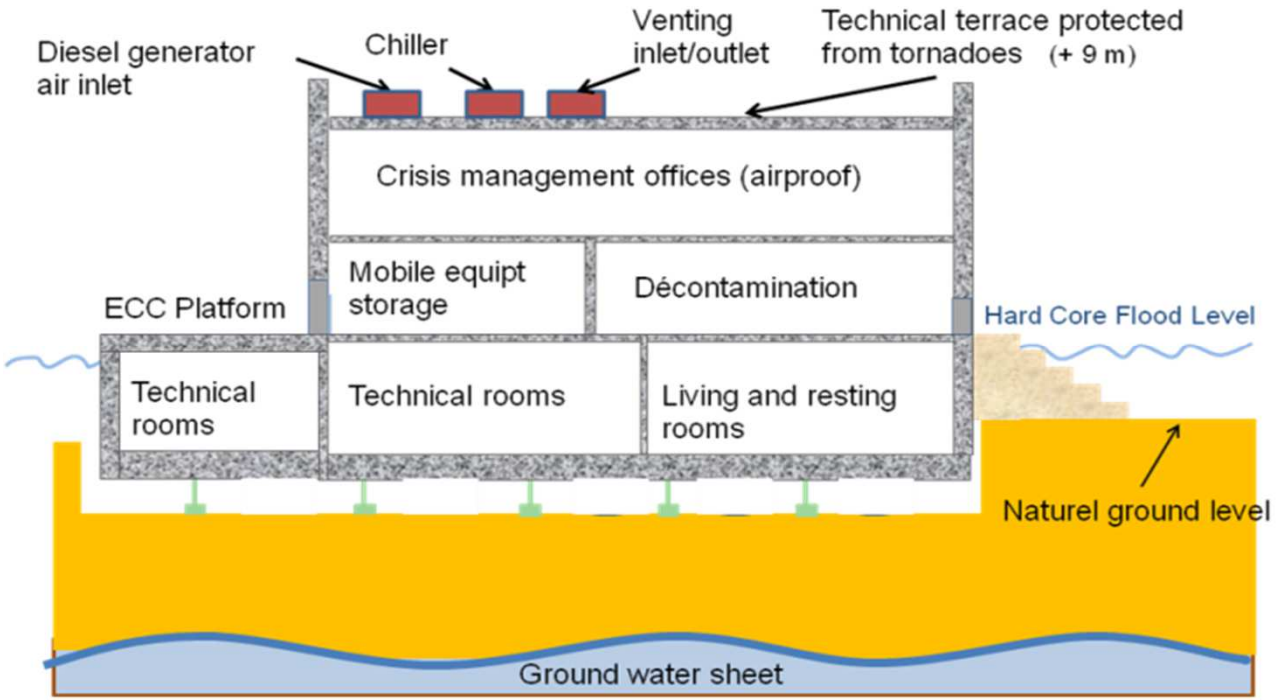
Current Crisis organization

- has trained teams available on-call :
  - 350 people on each site
  - 300 people at national level (including Engineering)
- is periodically tested :
  - 250 drills per year for the whole EDF nuclear fleet
  - Up to 12 drills/site/year
  - 12 national scale drills (4 to 5 with public authorities)

CRISIS ORGANISATION REINFORCEMENT

- In several steps
- To cope with multi-unit events
- To integrate FARN
- To reinforce local level capacity & protection

New Emergency Crisis Center (100 people capacity)



FARN (Nuclear Rapid Response Force)

- Announced by EDF in April 2011
- Now Required by ASN (June 2012)

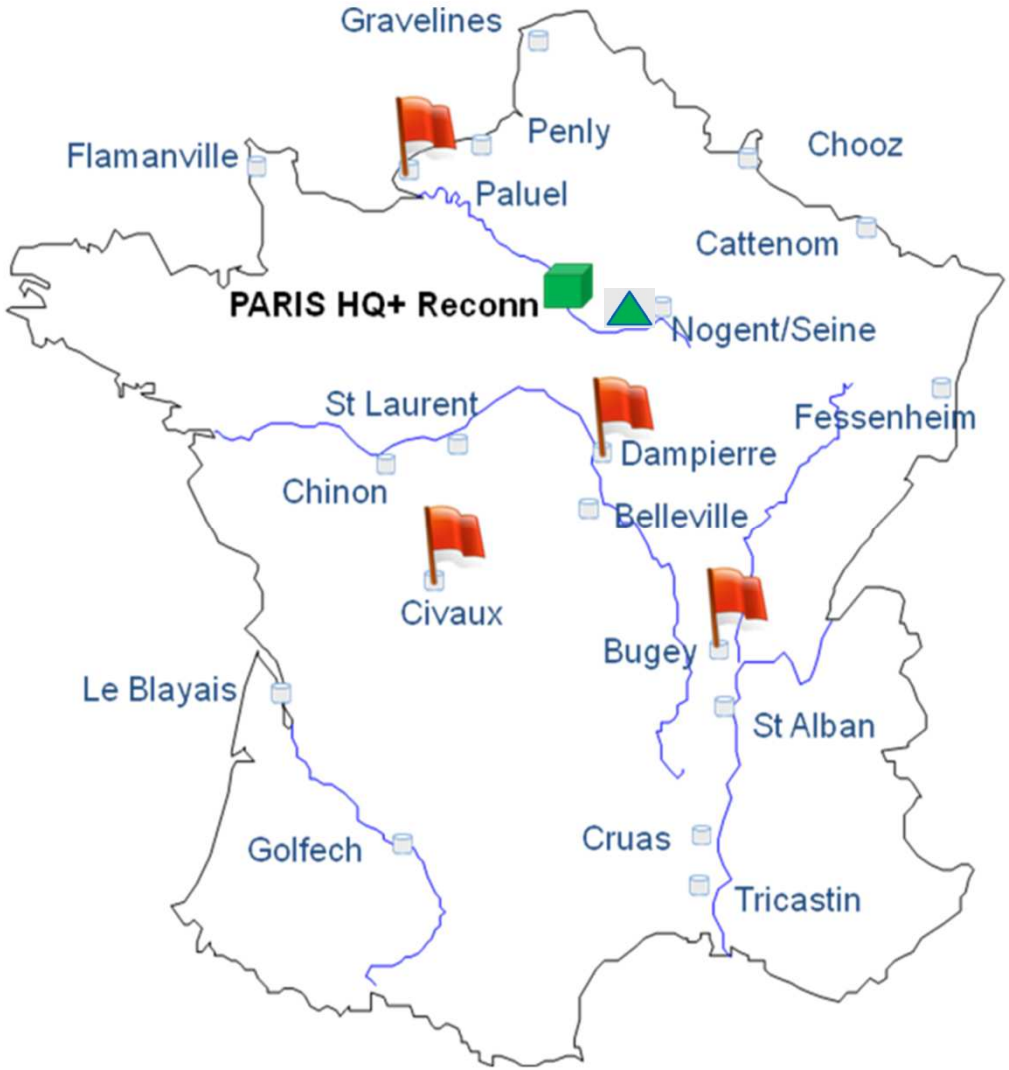
Main hypotheses

- One site experience severe accident
- Major destructions in infrastructures
  - Including access roads
- Local teams may have unavailability
- Possible radiological or chemical hazard

3 steps of intervention

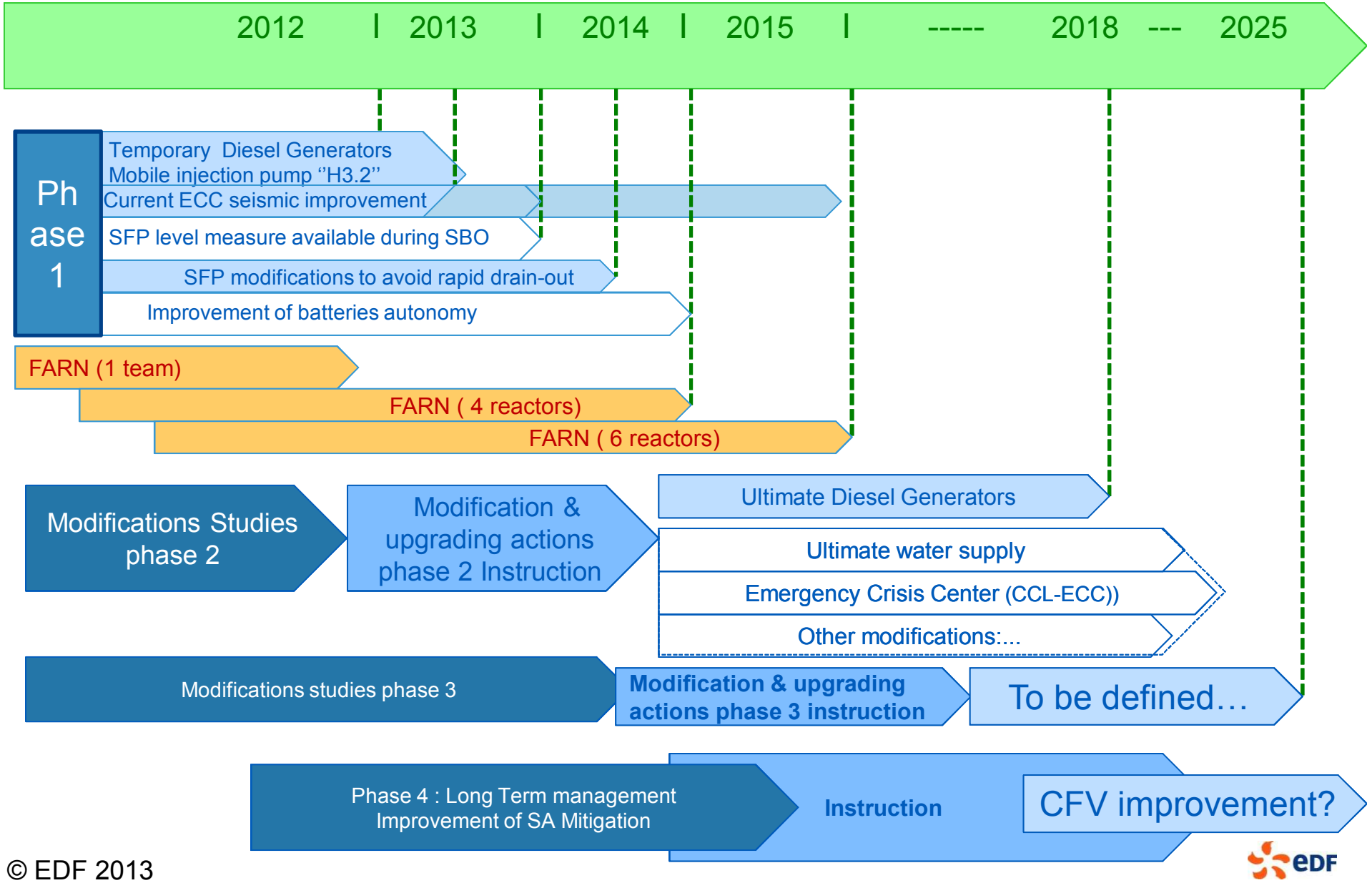
- In less than 12 h
  - Bring skilled operators
  - Evaluation of situation
  - Assistance to NPP using local means (fixed or mobile), up to 24h
- After 24 h
  - Brings its own mobile equipment and other resources
  - To guarantee site autonomy > 72h
- After 72 h
  - Additional resources from EDF group, or shared between French Nuclear Operators
  - To guarantee durable safe situation

FARN ORGANISATION



- 1national headquarters
  - (reconnaissance team, about 30 people in 5 on-call teams, country wide intervention)
- 1 national equipment base
  - (long term equipment, rear bases modules)
- 4 regional FARN bases with regional equipment bases nearby
  - hosted by 4 Farn'ed NPPs
  - each with about 70 people in 5 teams of 14 on-call people
- About 4 local rear bases predefined for each of the 19's NPPs
  - one to be choosenin case of severe situation on the NPP

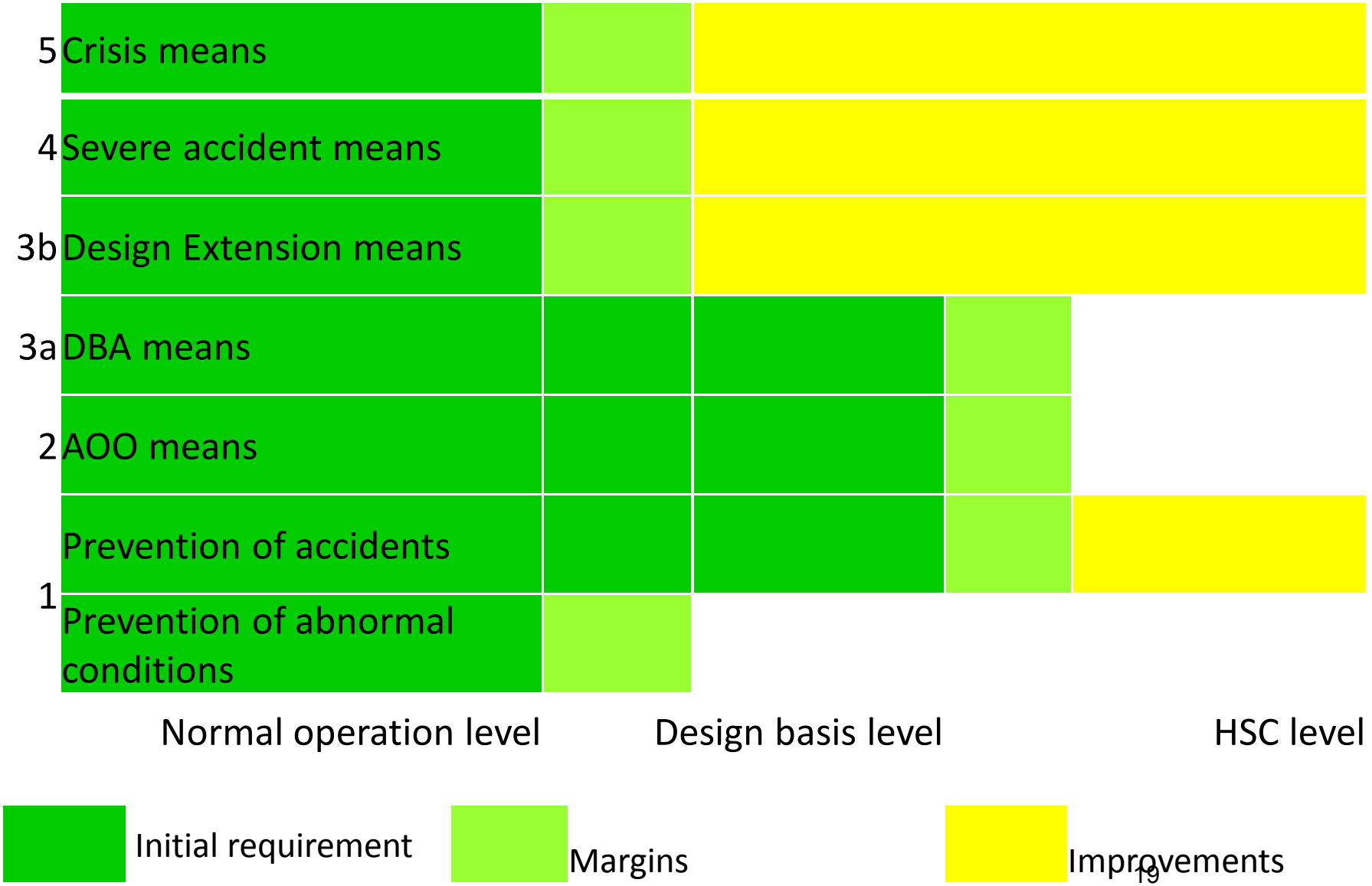
General schedule – Most typical improvements deadlines



Defence in Depth Concept

- **IAEA SSR 2-1 and Wenra : 5 levels**
- **Level 1 : Prevents deviations and failures :**
  - Prevention of AOOs
  - Prevention of accidents which result from failures
- **Level 2 : Prevents escalation from AOOs to accidents**
- **Level 3 : Prevention of core damage and releases from accidents. Subdivision from WENRA**
  - 3a : Generally single event such as pipe failure
  - 3b : Multiple failure events due to CCF
- **Level 4 : Prevention of large releases from core melt accident**
- **Level 5 : Mitigate radiological consequences of releases**

Improvements in Did resulting from modifications



The fundamentals of the robustness of EDF fleet are reinforced by the CSA

- **Initial design** (PWR) - good intrinsic robustness
- **Standardization of the EDF fleet:** 1500 reactor year operating feedback, homogeneity of the safety level
- **Continuous improvement of safety**: periodic safety reviews; experience taken from national events (Blayais in1999, heat wave in 2003...) and international events (TMI, Tchernobyl)
- **Quality of plant operation** : operation, maintenance, emergency preparedness; transparency (deviation reporting)
- **Industrial organization and resources**: “architect engineer” model, integrated engineering
- **General industrial context** , process of international supplier selection (qualification and monitoring)

Conclusion

- EDF, acting as designer and operator of its fleet, issued the CSA in a very tight schedule
- Following those CSA, EDF confirms **the present good level of safety** for all its nuclear reactors
- Following the **CSA new analyses,** EDF proposes **supplementary measures**, taking into account **potential extreme situations on a deterministic basis**
  - Modifications, new equipments: “hardened safety core” (a limited number of key safety SSC)
  - Organization : Nuclear Rapid Response Force, reinforcement of crisis management organization
- These analyses and modifications will continue **to improve even more the defense in depth** of **EDF’s nuclear fleet**