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# How to reinforce the “defence-in-depth” in NPP by taking into account natural hazards?

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# Introduction

- The DiD has been strongly reinforced following the TMI accident. But **efforts mainly addressed Internal Events**.

- What has been done for Natural Hazards?
  For Generation III reactor in France "*Design provisions must be taken with respect to external hazards, consistently with provisions for internal events and internal hazards; that is to say, external hazards must not constitute a large part of the risk associated to nuclear power plant of the next generation.*"

- The **Fukushima** accident raised this issue one more time, remembering that, in case of a beyond design hazard or a combination of hazards not considered in the design basis, all levels of defence may be swept away and may lead to a disaster.

# Content

# DiD and Natural Hazards before Fukushima (1/5)

- The **initial design** of PWRs against natural hazards is based on:

1. The **characterization** of design basis hazards
2. The **protection against these hazards of Structures Systems and Components used for normal operation (SSC)** so that no accident is initiated
3. The determination, for each hazard, of the safety **SSC that shall be resistant or protected**: mainly SSC involved in design basis situations

# DiD and Natural Hazards before Fukushima (2/5)

- **Several incidents due to natural events** occurred in France in the last 20 years: site flooding in 1999 in The Blayais (storm), Loss of off-site power (LOOP) due to icy rains in 2005, ultimate heat sink clogging by algae in 2009…


- As a consequence, **the protection of the plants against natural hazards is an important topic of the Periodic Safety Reviews** conducted in the French plants

# DiD and Natural Hazards before Fukushima (3/5)

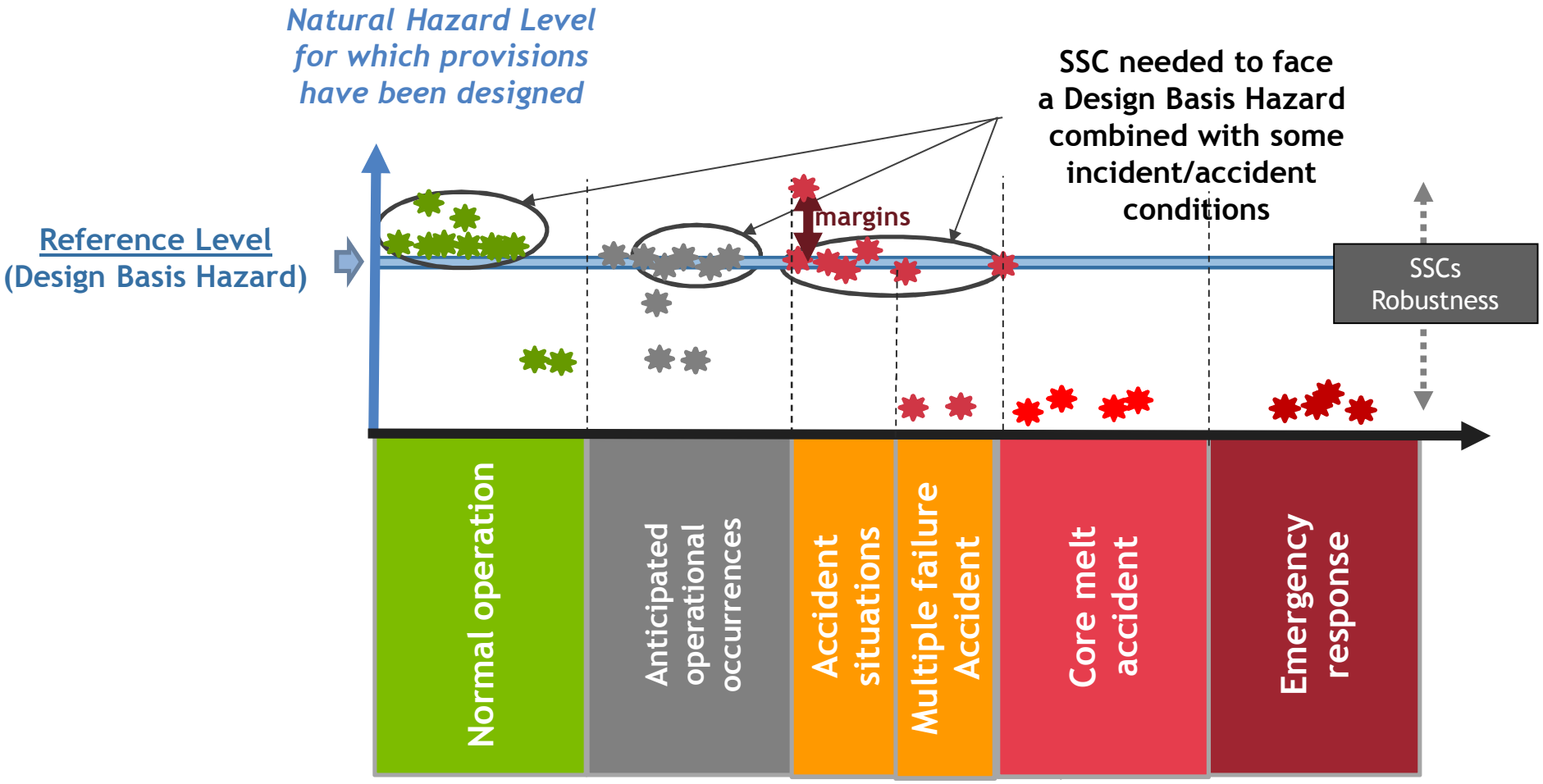
- Requirements have been reinforced and design and organizational improvements have been consequently set in place:
  - **Some design basis natural hazards were significantly reassessed**: reassessment of all flooding hazards after the 1999 storm, updating of the requirements for earthquake in 2001 and for extreme temperatures (in the 90's for extreme cold temperatures, in 2008 for extreme hot temperatures)…
  - **Additional hazards and combinations of hazards** have been considered: frazil, tornadoes…
  - **The assumption that natural hazards will not induce accidents was reexamined** and it was recognized that both loss of external electrical sources and loss of ultimate heat sink of long duration are likely to be induced by some hazards. It was also recognized that natural hazards can have an **impact on several plants on a site** and emergency plans have been adapted

# DiD and Natural Hazards before Fukushima (4/5)

As a result, it can be noticed that:

- Safety equipment needed for design basis accidents - **DBA (level 3 DiD) - are generally protected against natural hazards**;
- Safety equipment used to **cope with a Loss Of Off-site Power (LOOP) (e.g. diesel generators) are protected from natural hazards that may challenge off-site power**;
- Simultaneous occurrence of situations with **multiple failures (SBO or LUHS) and an external hazard is not postulated**. However, according to “defence-in-depth” and especially when it is difficult to exclude a link between them, equipment used to manage these situations are generally protected;
- For severe accidents **(level 4 DiD), equipment are generally not designed to resist to natural hazards** as it is considered that such hazard could not lead to core damage. However some equipment needed to manage an accident with multiple failures or core damage may also be required for DBA management, and, as such, can be designed or protected against hazards.

# DiD and Natural Hazards before Fukushima (5/5)




*Provisions set up to cope with normal operation and more and more ➡ serious accidents*

# Content

1. DiD and Natural Hazards before Fukushima
2. **Post-Fukushima Provisions against Natural Hazards for existing reactors**
3. An Approach for New Reactor Design

# DiD and Natural Hazards after Fukushima (1/5)

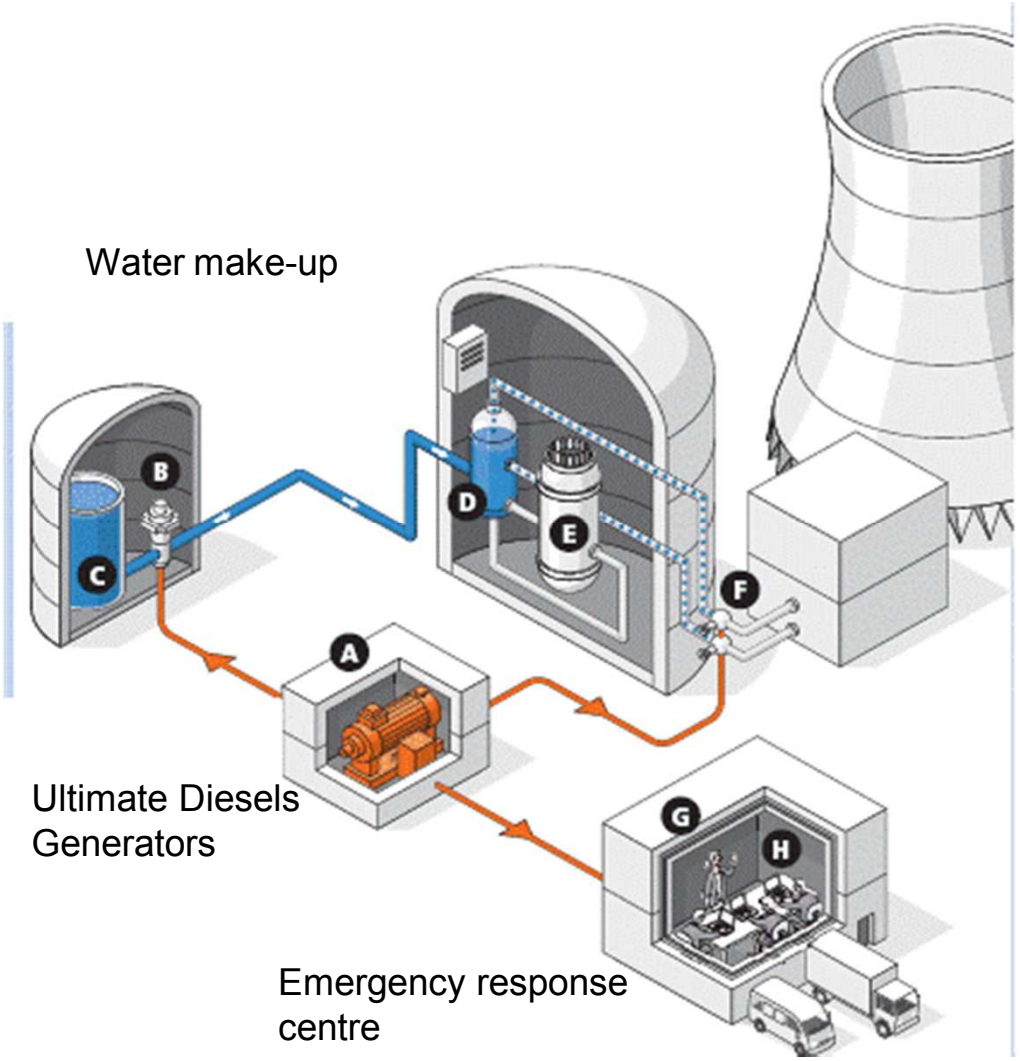
- After the Fukushima Dai-ichi accident, a **large safety review** has been performed in French nuclear power plants (« stress tests »), targeted on the resistance of plants against extreme natural hazards and long-lasting losses of electrical supplies and heat sink.

- Regarding natural hazards, it was decided to reinforce the application of the DiD concept:
  - **Beyond design natural hazards should be considered** – an objective in terms of exceeding frequency is to be defined (« design extension »)
  - Provisions to cope with **accidental situations induced by these hazards** should be taken
  - **Core melt accidents due to natural external hazards** should be considered

# DiD and Natural Hazards after Fukushima (2/5)

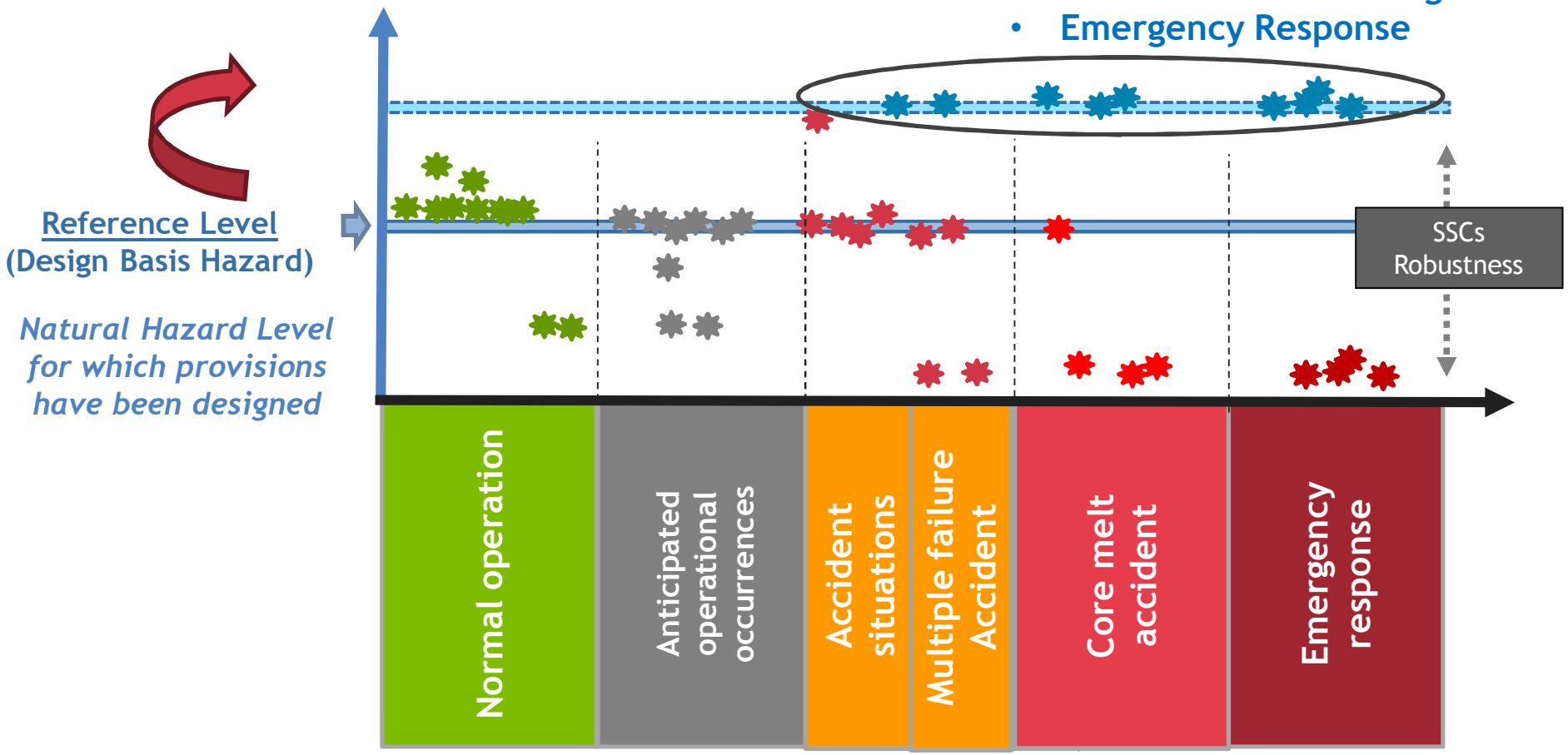
To cope with such situations, it was decided to implement:

- specific design provisions qualified to ensure the three fundamental safety functions in case of beyond design external hazards: **"Hardened safety-related core"**
- Objective: limit the releases in case of severe and rare external hazard



# DiD and Natural Hazards after Fukushima (3/5)

- Prevention of Fuel Damage
- Severe accident Management
- Emergency Response

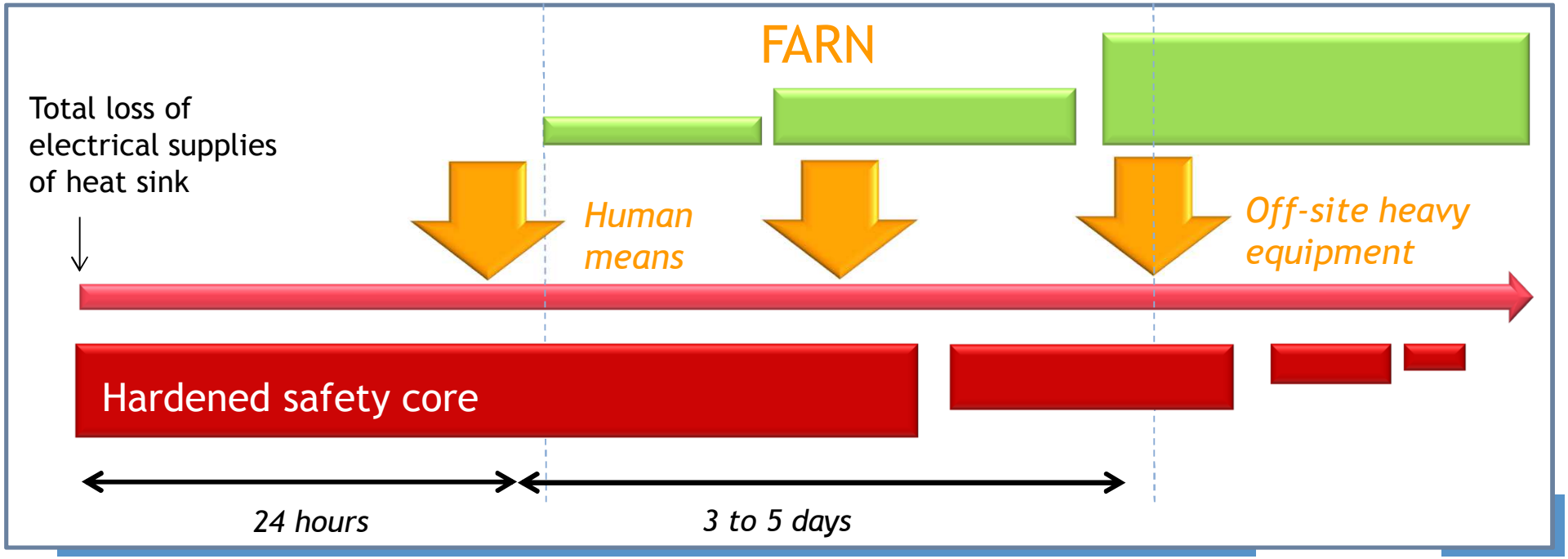



*Provisions set up to cope with normal operation and more and more severe accidents*

# DiD and Natural Hazards after Fukushima (4/5)

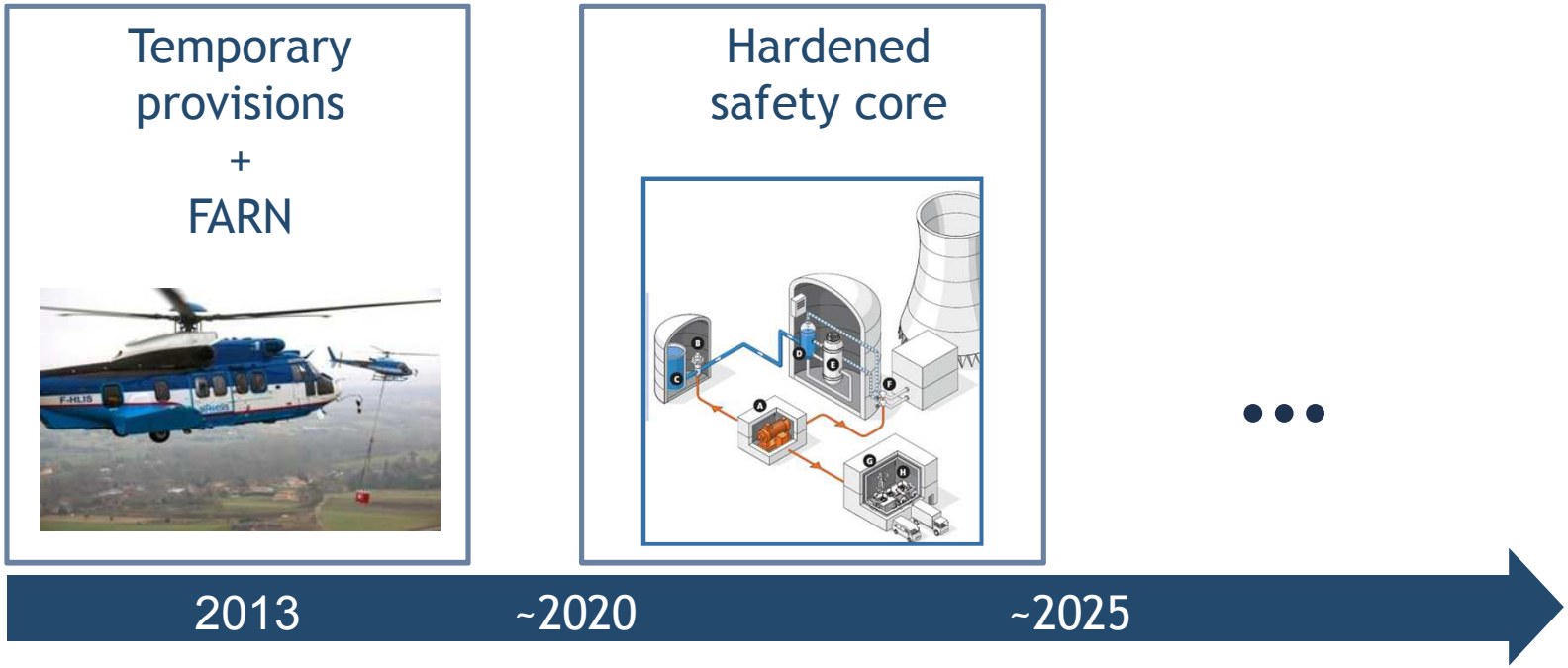
To cope with such situations, it was decided to implement:

- specific design provisions qualified to ensure the three fundamental safety functions in case of beyond design external hazards: **"Hardened safety-related core"**
- an **Airborne Action Force** to provide off-site support (human means, equipment, logistics…) after 24 hours



# DiD and Natural Hazards after Fukushima (5/5)

- Deployment of post-Fukushima actions:

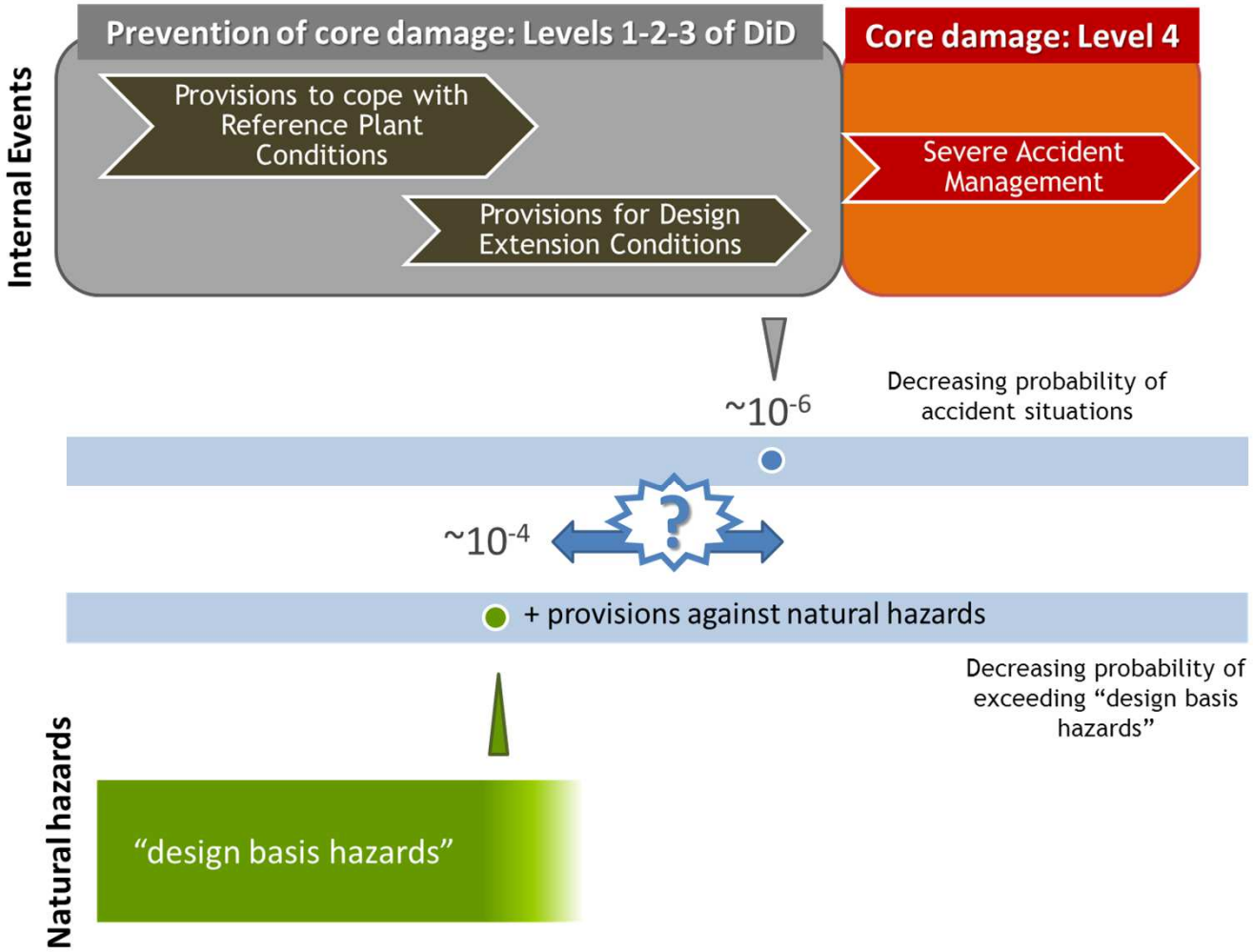



- But in parallel, efforts continue to better characterize natural hazards, to clarify possible combinations to be considered in the safety case and to develop Probabilistic Safety Assessments related to external hazards. If deemed necessary, complementary actions may be undertaken.

# Content

1. DiD and Natural Hazards before Fukushima
2. Post-Fukushima Provisions against Natural Hazards for existing reactors
3. **An Approach for New Reactor Design**

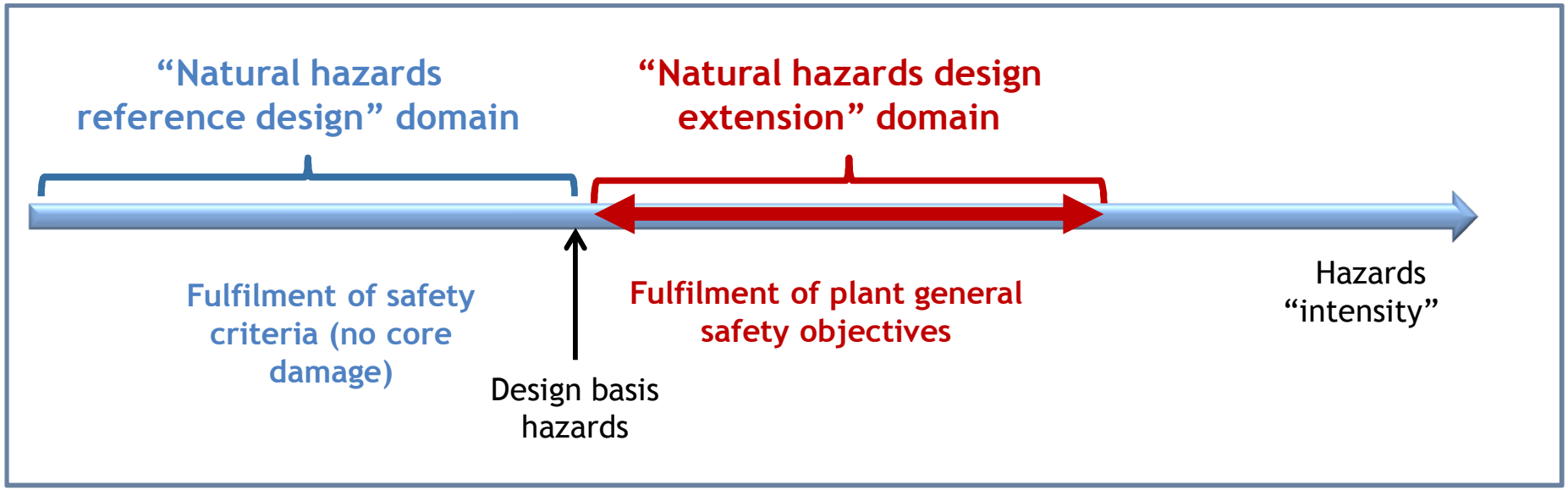
# An Approach for New Reactor Design (1/4)
# Initial finding…



# An Approach for New Reactor Design (2/4)

Generally, escalation will be sought for the protection of facilities against natural hazards:

- Natural hazards considered in the design of the facility must not lead to accident sequences, in particular core damage;
- Beyond design natural hazards should not lead to a cliff-edge effect in terms of releases in the environment.



# “Natural Hazards Reference Design” (3/4)

Preliminary discussions in France for future reactors led to propose an approach based on the DiD concept, including the following steps:

- Prevention of natural events: the only way is to choose a site with a low risk of natural hazards;
- Definition of the list of hazards and combinations to take into account in the design and detailed characterization (maximum accelerations for earthquakes, water levels and durations for flood…);
- Limitation of the impact of natural hazards in the installation: SSCs important for safety should be designed or protected against hazards, considering that hazards may affect at the same time several units of a given site;
- Definition of provisions to take into account the failure of design protective measures or SSCs: conventional rules on the way to consider the failure of provisions defined in the preceding step should be determined.

# “Natural Hazards Design Extension” (4/4)

- List of hazards and hazard combinations to be considered to be established on the basis of the analysis of potential cliff-edge effects in terms of releases into the environment, when going beyond load cases considered for the design of reference. Exceeding probabilities significantly lower than probabilities used for reference design, with a high level of confidence.

- A specific demonstration of the capability of the plant to face hazards without important releases should be required.

- In order to limit the risk of common cause failure and to reduce the risk of induced effects on “hazards design extension”, provisions should be as far as possible independent from other plant equipment.

+ Off-site provisions for long-term management (mobile equipment, pre-defined hook-up points…)

# An Approach for New Reactor Design: difficulties and challenges

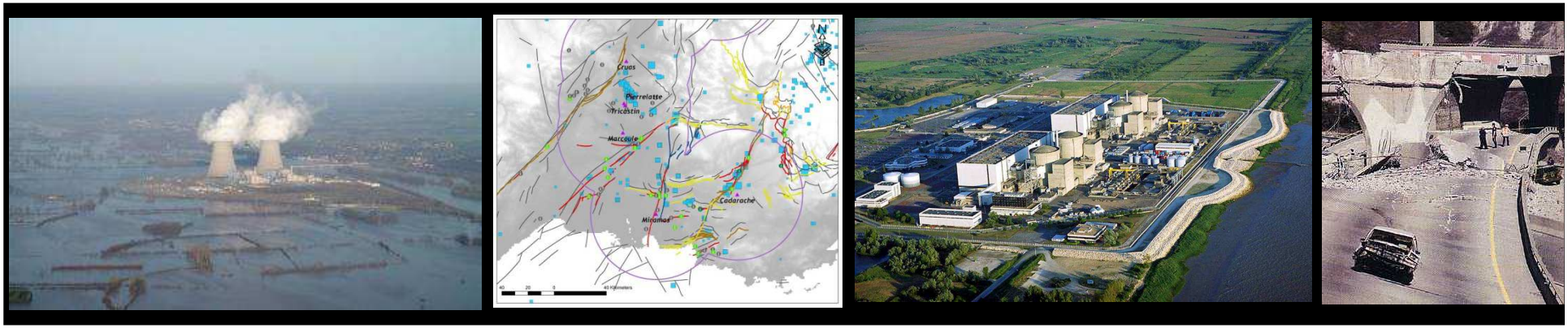
- For new reactors, the objective in terms of core damage frequency will be more and more stringent. This objective should be taken into account as an input for the definition of the "design basis hazards".

- The definition of "design basis hazards" and "design extension hazards" is challenging in a context of limited data and exploratory methods for hazards characterization.

- If the list of hazards to be taken into account during the design stage of the plant is now stabilized, possible combinations still need to be clarified. Moreover, the way to consider aggravating factor should still be developed.

➡ For these issues, international guidance and discussions may be fruitful.

# Thank you for your attention

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