EPR™ Safety in the post-Fukushima context

October 19th 2011

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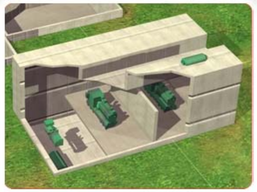
EPR™ safety approach

An accident is a complex series of events:
➔ NEED THE MEANS TO REMAIN IN CONTROL OF THE SITUATION, WHATEVER HAPPENS

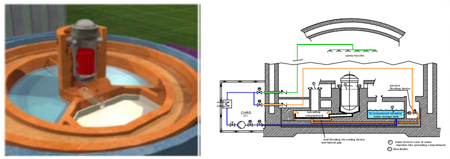


Emergency power sources

Diversity
(against common cause)

Redundancy
(against single failure)

Complementarity
(between active and passive systems)



Core catcher & Containment spray

Four safeguard divisions

The EPR™ reactor is designed to resist exceptional events and prevent damage to the surroundings

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Safety Alliance

AREVA Safety Alliance framework

Imperative 1

RESISTANCE TO MAJOR HAZARDS

EVENT:

External hazard: Earthquake, Flooding, Extreme Temperature

Internal hazard: broken pipe or valve, fire

Combination of hazards

OBJECTIVES:

Preserve plant safety

But If..

Imperative 2

ROBUSTNESS OF COOLING CAPABILITY

EVENT:

External hazards beyond plant design (worst case scenario)

CONSEQUENCE:

Damage to cooling capability

OBJECTIVES:

Provide sufficient time to restore cooling capability

Avoid cliff edge effects (fuel damage) in reactor (incl. pools)

Preserve assets

But If..

Imperative 3

PREVENTION OF ENVIRONMENTAL DAMAGE

EVENT:

Unforeseen event(s) creating extreme conditions

CONSEQUENCE:

Loss of safety functions, leading to hydrogen production, and fuel damage.

OBJECTIVE:

Minimize external radioactive release

EPR™ Safety

- **Resistance to major hazards**
- Robustness of cooling capability
- Prevention of environmental damage

Imperative 1

RESISTANCE TO MAJOR HAZARDS

EVENT:

- External hazard: Earthquake, Flooding, Extreme Temperature
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- Combination of hazards

OBJECTIVE:

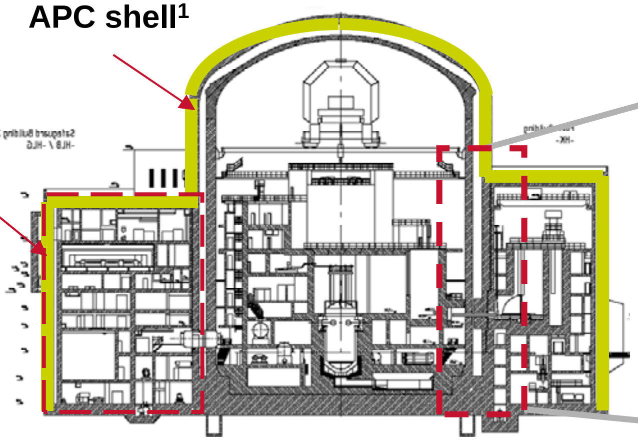
- Preserve Plant Safety

Imperative 1

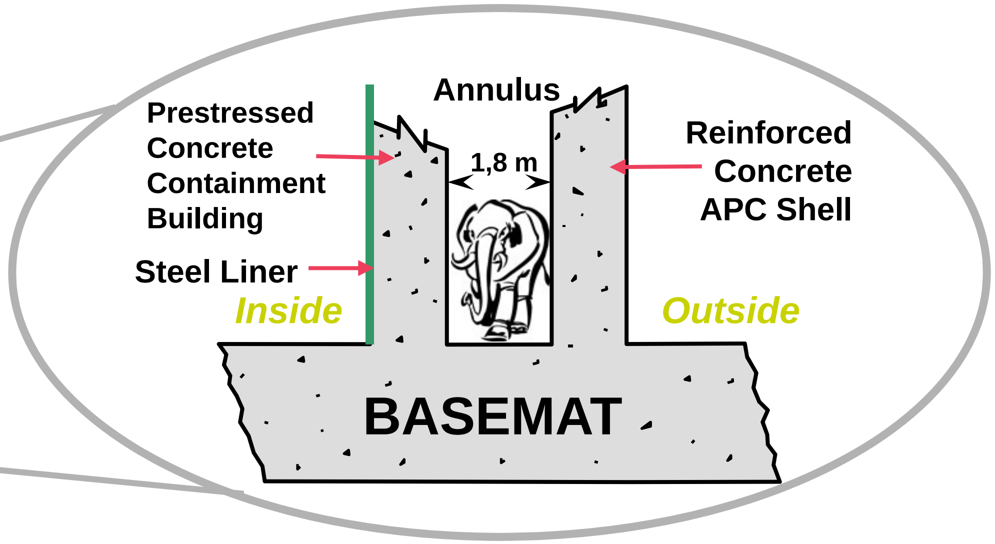
RESISTANCE TO MAJOR HAZARDS

Structural resistance

Critical buildings



Reactor building



- APC shell & earthquake resistance
- Doors designed to resist external explosions & floods

- Pre-stressed concrete containment
- Steel liner

➔ Resistance to external (impacts) and internal hazards (leaks, high temperature…)

» Design robustness: the EPR™ design can be compliant with a vast variety of sites

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1- Air Plane Crash resistant Shell

Imperative 1

RESISTANCE TO MAJOR HAZARDS

Equipment resistance

Equipment resistance process

- **A rigorous process to ensure equipment resistance**
- **Definition of requirements**
  E.g. for earthquakes calculation, acceleration relative to each components
- **Testing components**
  - Heavy components
  - Mechanical components: CRDM, valves, pumps
  - I&C and Electrical equipments…

E.g. For earthquake resistance, AREVA has several testing facilities

Unique testing capabilities

Electrical and I&C component testing on a vibrating plate at AREVA Erlangen facility

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Imperative 1

RESISTANCE TO MAJOR HAZARDS

Monitoring and control of the plant

Monitoring systems

- **300+ safety-class monitoring systems in the NSSS:**
  - Resistance to extreme conditions : high radiation, temperature and pressure
  - Monitoring still functional in case of an earthquake

Safety class pressure and temperature monitoring

Control Room

- **Main control room**
  - In APC-protected safeguard building
  - Digital I&C backed-up by diversified system with qualified displays
- **Back-up: Remote Shutdown station**
  - Geographical and technological diversity

Design robustness: in case of major hazards, monitoring and control functions of the EPR™ design are preserved

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EPR™ Safety

- Resistance to major hazards
- **Robustness of cooling capability**
- Prevention of environmental damage

Imperative 2

ROBUSTNESS OF COOLING CAPABILITY

EVENT:

External hazards beyond plant design (worse case scenario)

CONSEQUENCE:

Damage to cooling capability

OBJECTIVES:

Provide sufficient time to restore cooling capability

Avoid cliff edge effects (fuel damage) in reactor (incl. pools)

Preserve assets

Imperative 2

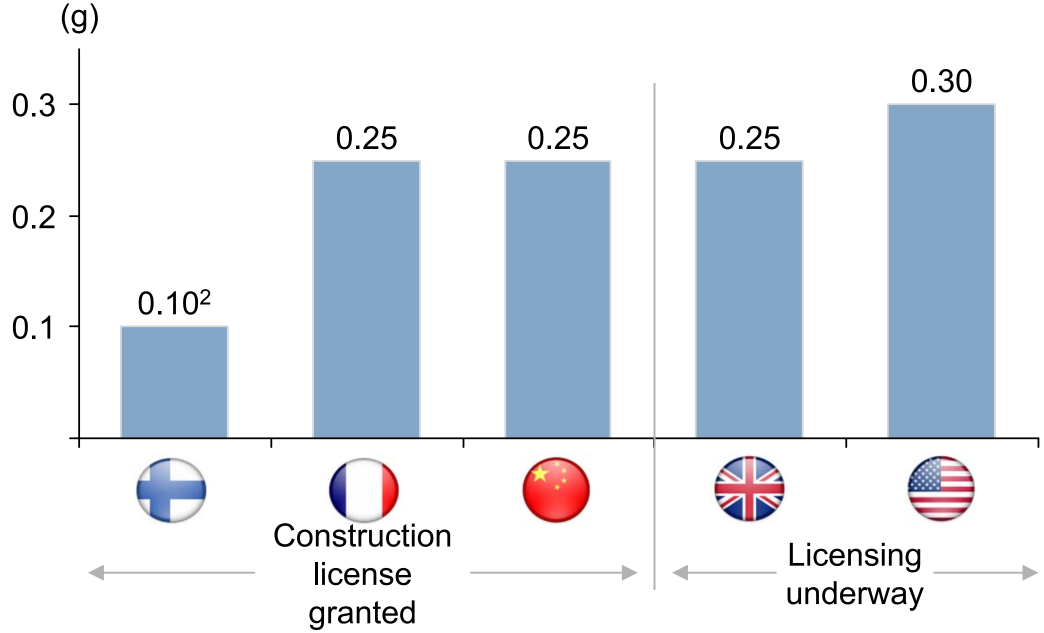
ROBUSTNESS OF COOLING CAPABILITY

No cliff-edge effect illustration:
Earthquake beyond worst case scenario

- The EPR is licensed to resist to a 0.25g-0.3g peak ground acceleration
- Seismic Margin Assessments performed for safety authorities in the UK and US show **that even a 0.6g peak ground acceleration earthquake would not have significantly impacted the EPR capabilities** to prevent the risk of severe accident

EPR is certified[1] to resist to a large spectrum of peak ground acceleration levels

Earthquake resistance requirements of safety authorities per project



In similar seismic conditions as of Fukushima earthquake, the EPR would not have endured damages impairing the adequate operations of its safety systems

1. Construction license 2. Safety demonstration adjusted to Finnish requirements however most equipments in line with EPR standard seism resistance
Source : Project construction licenses and ongoing certification processes

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Imperative 2

ROBUSTNESS OF COOLING CAPABILITY

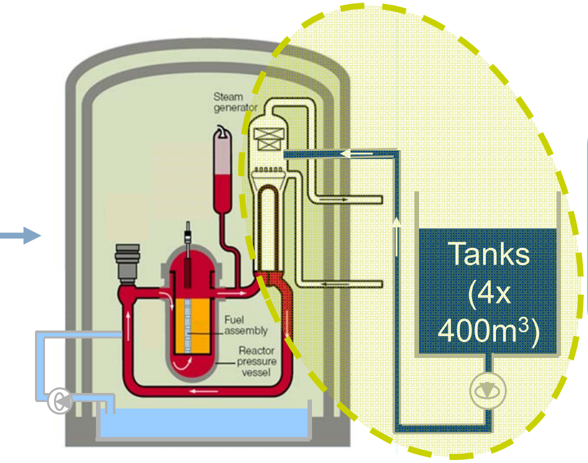
Robustness of cooling systems

Four 100% safety trains

- 4 safety trains located in 4 dedicated safeguard buildings
- 2 safeguard buildings are further protected by the APC shell
- One train is enough to cool the core ("100% train")

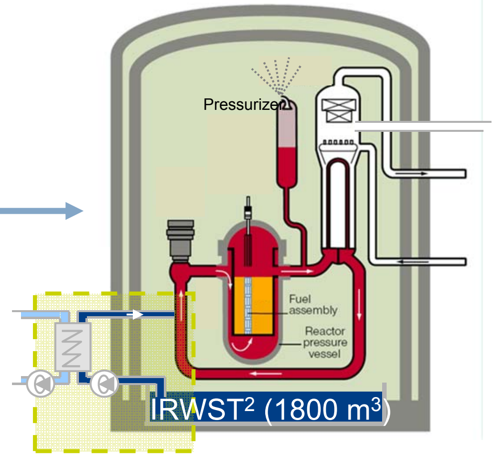
For each train: 2 redundant and diverse sub-systems

1. Emergency feedwater system



Cooling through secondary loop with EFWS[1]

2. Safety injection system



Cooling through primary loop with safety injection system

Highly redundant cooling systems with two ways to cool down the core

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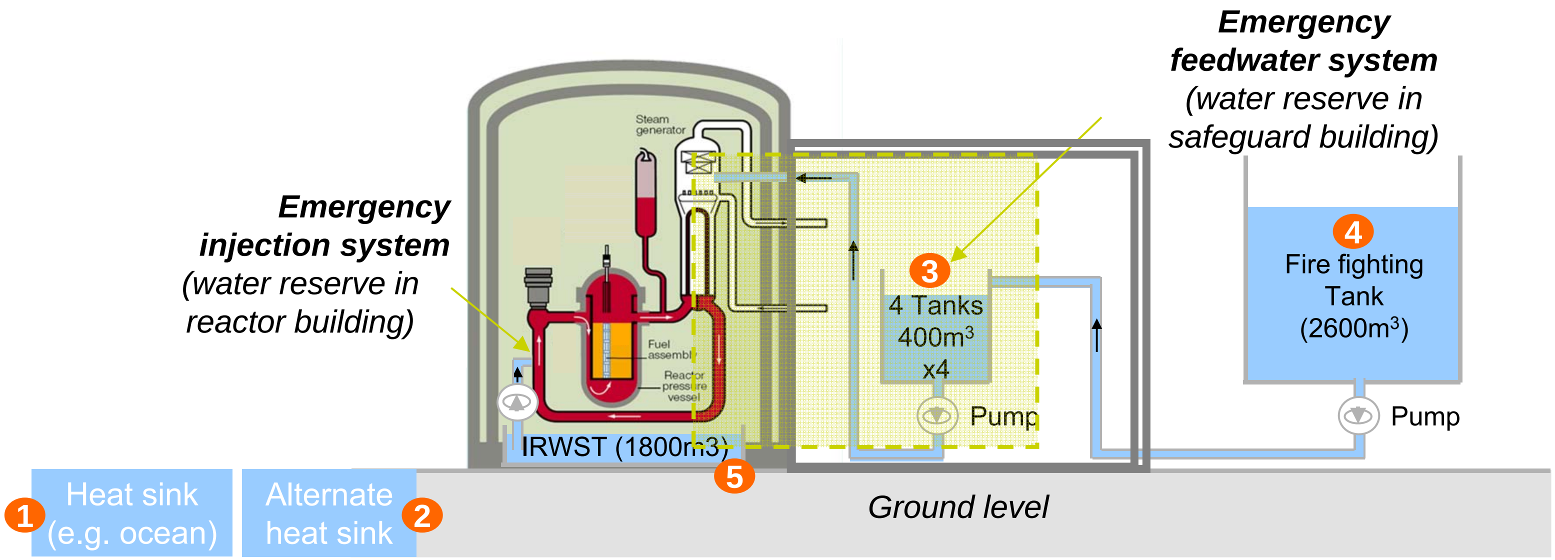
1- Emergency FeedWater System 2- In-containment Refueling Water Storage Tank

Imperative 2

ROBUSTNESS OF COOLING CAPABILITY

Robustness of cooling capability
Water supply



In case of loss of main heat sink access 1 ,the EPR™ reactor can rely:

- **On an alternate heat sink source[1]** 2 (against floods or earthquakes…)
- **On significant protected water reserves:**
  - four EFWS[2] tanks 3 in the safeguards buildings
  - a large fire fighting tank 4
  - the IRWST[3] 5 in the reactor building

The EPR™ design has multiple redundant and diverse access to water to cool the core

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1- or geographically diversified access for seaside sites 2- Emergency FeedWater System 3- In-containment Refueling Water Storage Tank

Imperative 2

ROBUSTNESS OF COOLING CAPABILITY

Robustness of cooling capability
Emergency power

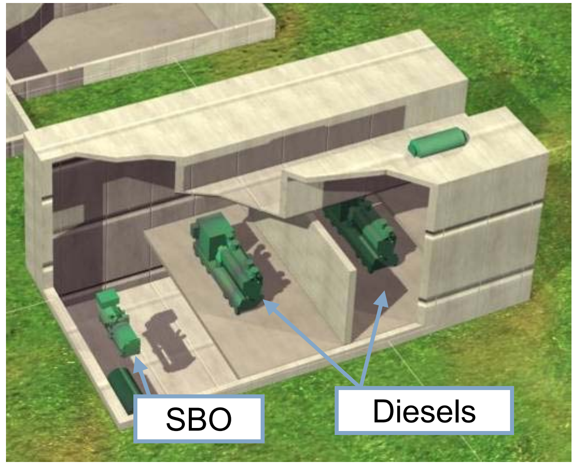
Physical protection

- **Diesels & fuel tanks housed in reinforced concrete buildings**
  - Earthquake resistant design
  - Doors designed to resist external explosions & floods

Physical separation

- **2 separate buildings located on each side of the reactor building**
  - Deterministically impossible for both of them to be damaged by an external impact hazard (explosion, airplane crash…)

Redundancy & diversification



- **Four main 100% redundant diesels:** each with 72 hours autonomy at full load
- **Two additional station blackout diesel generators (SBO):** Fully diversified with 24 hours additional autonomy each [1]
- **Batteries:** 12h autonomy for critical systems

6 emergency diesels plus batteries: redundant, diversified and protected

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1- 24h for OL3/FA3, autonomy dependant on site specific assessment

Imperative 2

ROBUSTNESS OF COOLING CAPABILITY

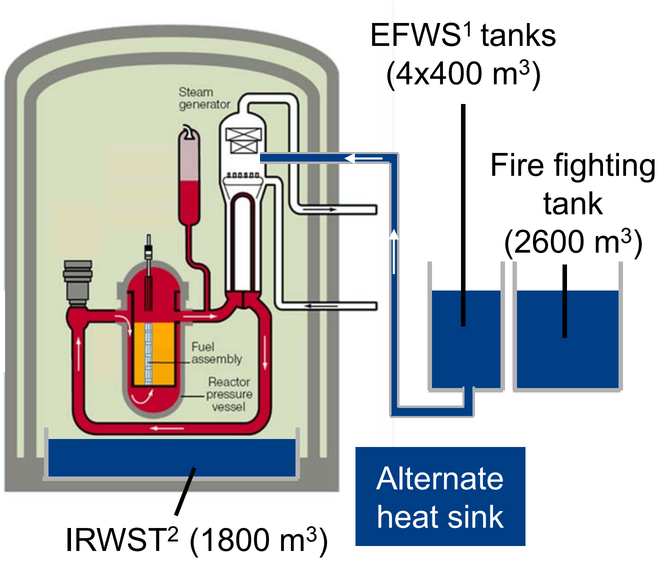
Robustness of cooling capability

The core can be cooled using only one diesel generator, one safety train and without external heat sink

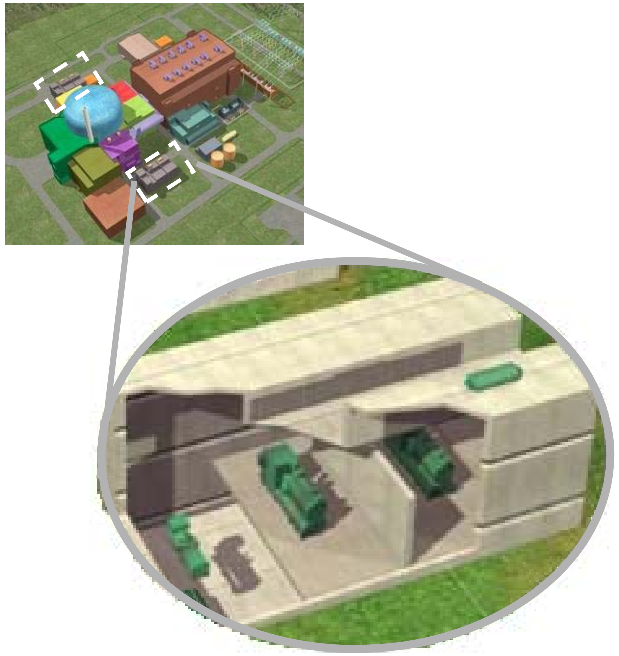
Multiple cooling systems

4 safety trains

Multiple water supply sources



Multiple emergency power sources



2 x 3 emergency diesels

High robustness of cooling systems : redundancy, diversity, complementarity at all stages

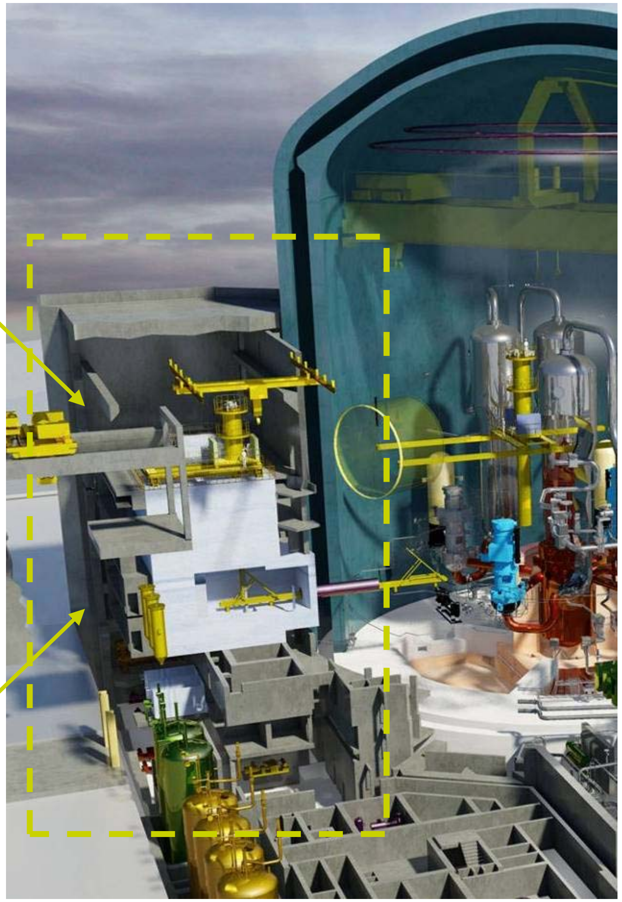
1- Emergency FeedWater System 2- In-containment Refueling Water Storage Tank

Imperative 2

ROBUSTNESS OF COOLING CAPABILITY

Reactor fuel pool robustness

- **Dedicated fuel building**
  - Reinforced concrete wall
  - Additional protection layer by the APC shell
- **Cooling systems**
  - Redundancy of the main system: two independent, physically separated cooling trains
  - Diversity:
    - Additional back-up cooling system
    - Make-up by fire-fighting tank



OL3 fuel building construction

High robustness of cooling systems: also for the reactor fuel pool

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Imperative 2

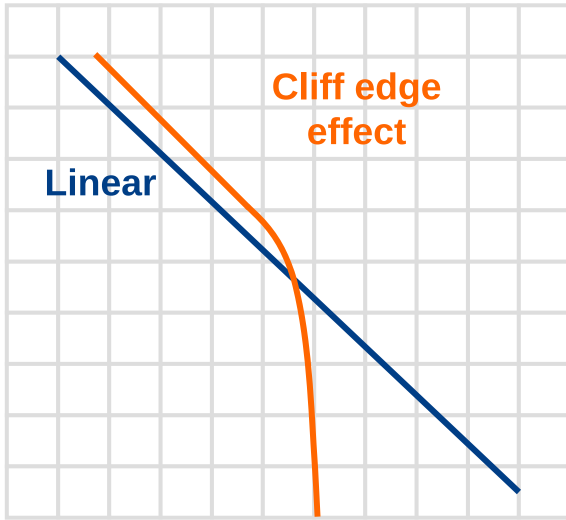
ROBUSTNESS OF COOLING CAPABILITY

Robustness of cooling systems
Prevent cliff-edge effect

- Increased safety margins are needed for prevention of potential **cliff edge effects** (events beyond safety limits with non-linear consequences)

- This means an **NPP must not enter into a severe accident sequence as soon as the site worse case scenario is exceeded** and have safety margins/ cooling robustness providing a “grace period” to prevent the cliff-edge effect

Cliff edge effect illustration



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ROBUSTNESS OF COOLING CAPABILITY

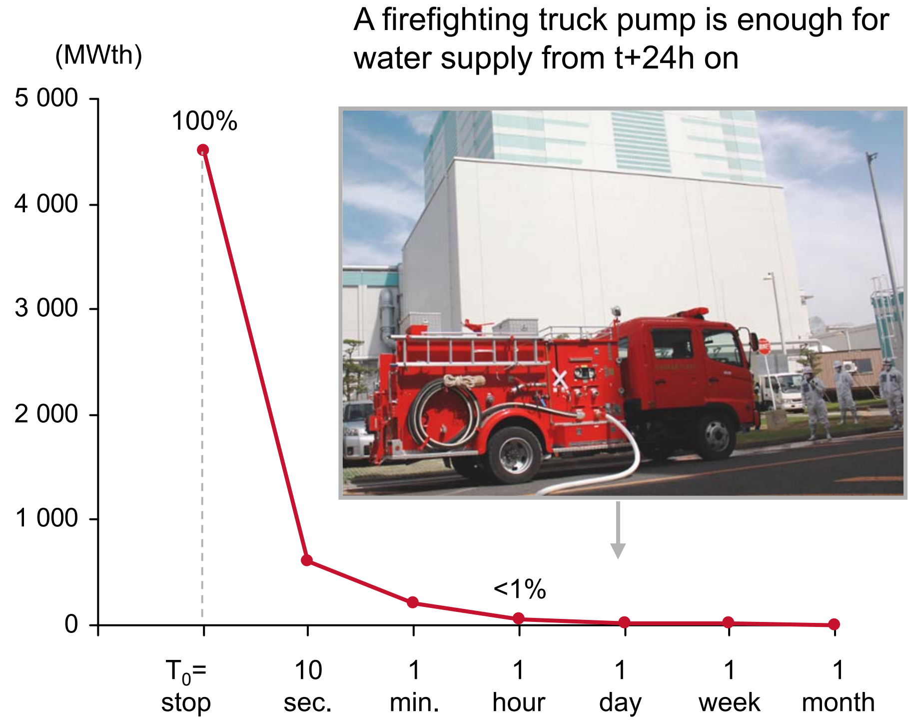
Imperative 2

Robustness

Provide grace period to mobilize emergency means

- **The significant grace period provides more time to bring mobile emergency means and prevent cliff-edge effect**
- **The robustness of the cooling chain means less accumulated heat during the initial phase. It enables to manage extraction of the decay heat even with limited mobile means**
- **For water, the mobile means can refill reserves at many different points (any EFWS[1] tank, fire fighting tank…)**

Decay heat



1- Emergency FeedWater System

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EPR™ Safety

- Resistance to major hazards
- Robustness of cooling capability
- **Prevention of environmental damage**

Imperative 3

PREVENTION OF ENVIRONMENTAL DAMAGE

EVENT:

Unforeseen event(s) creating extreme conditions

CONSEQUENCE:

Loss of safety functions, leading to hydrogen production, and fuel damage.

OBJECTIVE:

Minimize external radioactive release

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Imperative 3

PREVENTION OF ENVIRONMENTAL DAMAGE

Prevention of environmental damage

However low the probability of severe accident for the EPR™ design, consequences around the site are too severe to be ignored.

Deterministic approach for severe accident mitigation

► **To prevent containment breach and subsequent environmental damage:**

1. **Prevent highly energetic events,**
   - **No high pressure core melt**
   - **No H2 explosion**
   - **No steam explosion**
2. **Achieve long-term core melt stabilization**

Imperative 3

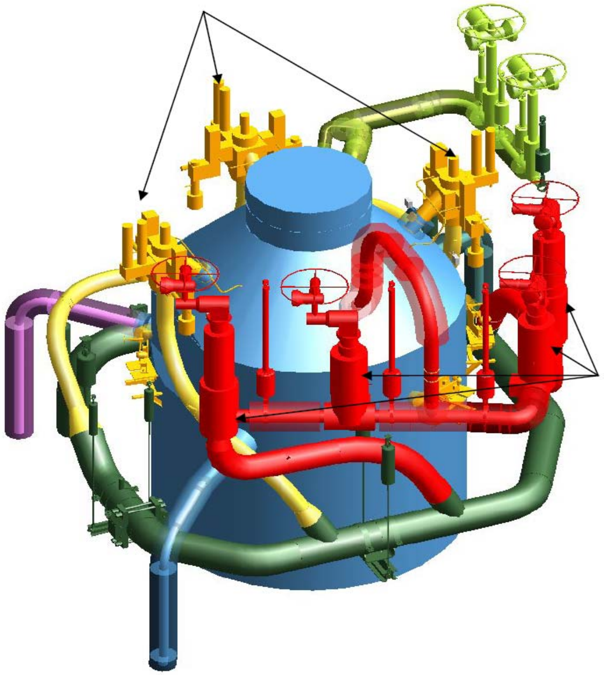
PREVENTION OF ENVIRONMENTAL DAMAGE

Prevention of environmental damage
No high pressure core melt

- Core melting at high system pressure can potentially lead to loss of containment integrity and major melt dispersal

- The EPR™ design includes additional dedicated primary depressurization valves

Primary loop depressurization



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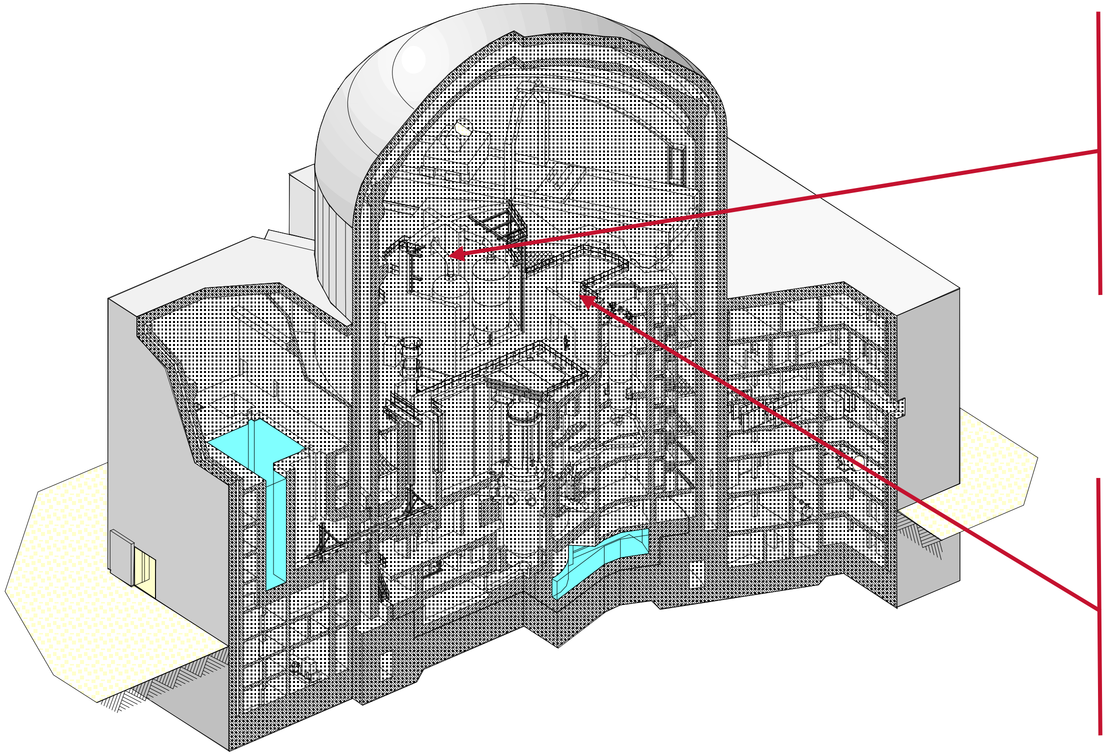
Imperative 3

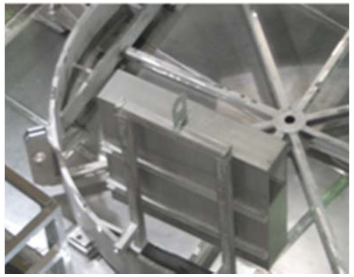
PREVENTION OF ENVIRONMENTAL DAMAGE

Prevention of environmental damage

No H2 explosion



- **Minimize H2 concentration :**
  Large reactor building with interlinked compartments
- **Reduce H2 quantity:**
  Passive Autocatalytic Recombiners



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Imperative 3

PREVENTION OF ENVIRONMENTAL DAMAGE

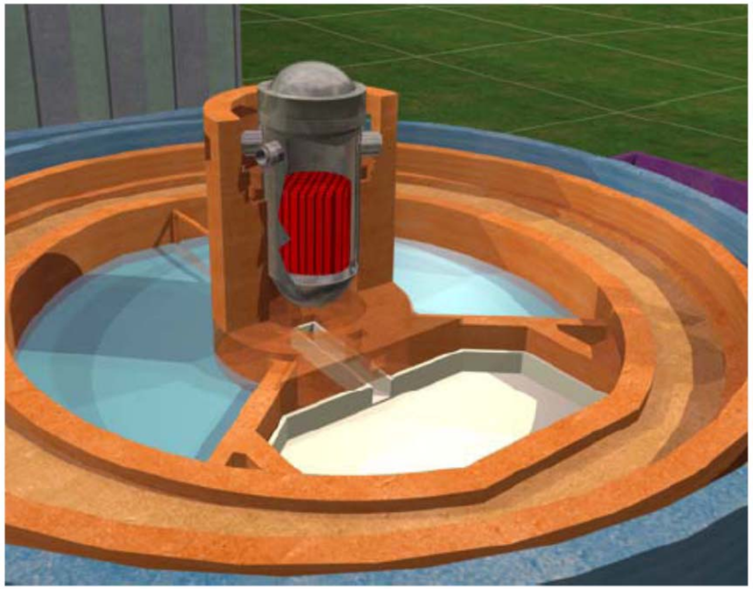
Prevention of environmental damage

No steam explosion

Core catcher

- **The EPR™ manages core melt with the core catcher**
- **Ex-vessel steam explosions can occur when melt pours into a water pool**
- **With the core catcher, the presence of water is excluded by design**
    - In the reactor pit
    - In the core catcher before spreading

➔ **No steam explosion possibility**



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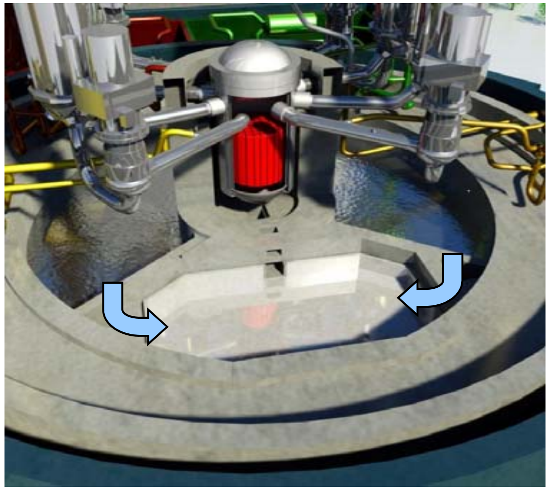
Imperative 3

PREVENTION OF ENVIRONMENTAL DAMAGE

Prevention of environmental damage

Long-term core melt stabilization

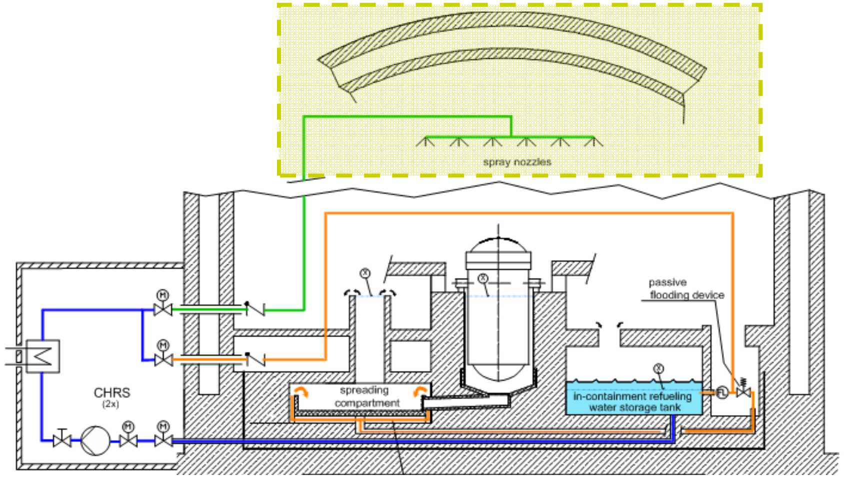
Short-term cooling



▶ **The Core catcher protects the integrity of the containment basemat. It is designed to passively stabilize molten core:**

- Passive valve opening
- Gravity-driven overflow of water

Long-term cooling



▶ **Long-term core cooling is provided by the containment spray**

▶ **The grace period provided by the passive short term cooling allows ample time to recover active systems and ensure long-term stabilization**

Complementarity of active and passive systems for severe accident management

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Wrap-up

- Major hazards and ensuing chain of events are always complex, robust cooling systems working in situations beyond design-base scenarios are mandatory.

- Severe accident mitigation is addressed in a deterministic way. Probabilistic approach is appropriate to assess global design safety but is not used to cut costs.

- The EPR is a robust design, the Fukushima accident has validated AREVA's Safety approach:
  - Resistance to major hazards
  - Robustness of cooling capability
  - Prevention of environmental damage

AREVA Safety Alliance

AREVA Safety Alliance framework

Imperative 1

RESISTANCE TO MAJOR HAZARDS

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But If..

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