IAEA conference on topical issues

Lessons learnt from Fukushima as regards Defence in Depth.

October 2013

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Agenda

- Introduction
- 1 Main Fukushima lessons learnt as regards defence in depth
- 2 Gen 3 genesis and safety objectives
- 3 Gen 3 characteristics as regards Fukushima lessons learnt
- Conclusion

Introduction

The tsunami flooding induced

- **massive common mode failure**
  - *loss of all AC and DC power,*
  - *loss of I&C*
  - *loss of decay heat removal*
  - *severe core damage*
  - *loss of containment integrity*

  } *Massive radioactive releases*

- **an unprecedented level of devastation**

The operators were left with almost no means of understanding and controlling the situation.

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Chaotic Emergency Response conditions


Heavy oil tank washed away by the tsunami and blocking the road

Access to Site:
"During the initial response, there were several aftershocks, and work was conducted in extremely poor conditions, with uncovered manholes and cracks and depressions in the ground. ***There were also many obstacles blocking access routes.****"*

Darkness, chaotic site, water, isolation, dose rate

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a- DiD lessons learnt : natural hazards

***1.* Need to ensure sufficient robustness of the critical safety systems against natural hazards higher than the design basis hazards**

- **Design basis hazards** :
  - to be defined with care
  - to include adequate margins
  - to be updated according to the knowledge evolutions
- **In addition, as a defence in depth provision** :
  - ensure extra robustness and margins to the vital safety functions
  - for hazards significantly higher than design basis
  - in case nature would have more imaginations than us
  - or in case of mistakes in the design basis hazard definition

» ***Safety objective for beyond design hazards : prevent core melt and, should it occur, avoid large, long-term off site contamination***

Some insights on earthquakes

- **Several beyond design earthquakes last years**
  - Kashiwasaki – Kariwa
  - Great East Japan Earthquake
  - North Anna
- **Overall good resistance of nuclear power plants to earthquakes**
  - no evidence, today, that a severe accident would have occurred in Fukushima, should the earthquake no be followed by a tsunami.
  - strong margins taken in the design and construction of nuclear power plants as regards earthquakes

» ***Maintain the focus on the quality and robustness of seismic design and construction, in order to ensure important margins above SSE.***

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Some considerations on flooding (1/2)

Bâtiment combustible Tranche 2 niveau - 8,50 m Local K 054
Trémie électrique éventrée

Blayais (1999)

Fukushima (2011)

Fort Calhoun (2011)

Flooding can be caused by a variety of phenomenon, in many places of the world, even in the absence of outstanding tsunami.

Some considerations on flooding (2/2)

- **Lessons learnt in terms of flooding are to receive a strong focus:**
  - the main cause of the Fukushima Daiichi accident
  - among the main potential causes of common cause failure
  - flooding ignores the independence between the DiD levels, diversity, redundancy, safety classification, etc : aggresses without distinction all non protected systems
- **In terms of defence in depth**
  - dry site to remain the basis design requirement (with adequate margins)
  - as a defence in depth provision, assume the platform flooding
  - (*unless it can be clearly excluded given the site location and configuration*)

» ***Platform flooding to be deterministically postulated and water-tightness provided to the buildings protecting the vital systems.***

b- DiD lessons learnt : severe accident

2. *Need for an effective implementation of severe accident mitigation*

- **Not a new lesson learnt from Fukushima: a reminder**
  - an important issue since WASH 1400, TMI, Tchernobyl
  - included in DiD requirements: INSAG 10, SSR-2-1, WENRA
  - considerable amount of R&D performed worldwide since the 1980s
  - solutions were developed to protect the containment under severe accident
- **CNS stated an objective to be shared and implemented globally** (Aug 2012)

"NPPs should be designed, constructed and operated with the objective to avoid accidents and, should a severe accident occur, mitigate its consequences in order to avoid [large, long term] off site contaminations"

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c- some insights on safety systems: vital functions

- **The tsunami primarily impaired the electrical systems (AC, DC)**
- **Any non electrical, non waterproof system, in floodable area, would have endured the same fate**
  - *Diesel powered, turbine driven pumps, valves, etc…*
- **Any plant ultimately needs a minimal set of vital functions to prevent and mitigate a severe accident**
  - *those may vary according to the design*
  - *minimal I&C belong to them*

»

Key lesson learnt: for each design, define adequately the vital functions and protect them so that to ensure they will operate in extreme situations

I&C

- The loss of all I&C is probably the most crucial point of the Fukushima Daiichi accident.
- Powered by DC, the loss of which is at the heart of the catastrophic development of the accident.
- Nuclear industry in the same situation as many others from this point of view (eg aviation)

Vital I&C must be protected, hardened and supported in order to be available under all circumstances.

heat-sink

- **Water intake is a system, to be protected**
- **Heat-sink is also a part of the environment**

water can turn into mud, disappear, be loaded with debris, ice etc…

Unit 3 Sea Pump Area

Unit 5,6 Intake Screen Area

Because heat-sink can be impaired by changes in the environment, there is interest to consider an alternate heat-sink.

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spent fuel pool

- severe core degradation in the spent fuel pool might have unbearable consequences
- scenario to be practically eliminated

Spent fuel pool integrity, adequate water-tightness and residual heat removal must be ensured under all circumstances

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1. Main Fukushima lessons learnt as regards defence in depth
2. **Gen 3 genesis and safety objectives**
3. Gen 3 characteristics as regards Fukushima lessons learnt

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EPR Genesis

Three Miles Island

- **Modifications on operating plants (human factor, severe accidents)**
- **Considerable R&D on severe accidents**

Chernobyl

Eliminate the risk of experiencing consequences on populations similar to the Chernobyl disaster (incl long term consequences)

Operating experience

- **30 years of experience of French and German fleets**
- **Probabilistic Safety Assessment of current plants**

9/11

Ensure that a terrorist attack will not cause a severe accident in the context of nuclear technology diffusion worldwide

The EPR design includes, from its origin, all safety progresses.

Voluntary choice of an evolutionnary design, for safety reasons

EPR safety objectives

- **Reduce core damage frequency by a factor 10**
- **Reduce radiological releases in case of an accident**
  - design basis accidents : no protection measures for the population
  - practical elimination of scenarios leading to large and early releases
    (*hydrogen explosion, core melt under pressure, steam explosions*)
  - in case of a severe accident, only protection measures limited in area and time can be tolerated (eg no permanent relocation)
- **Increase robustness against terrorist attacks**
  (eg large commercial aircraft crash)
- **Deterministic approach, complemented by probabilistic assessment**

» ***Severe accident mitigation is included in the design***
These objectives define the Gen 3 (or 3+) reactors

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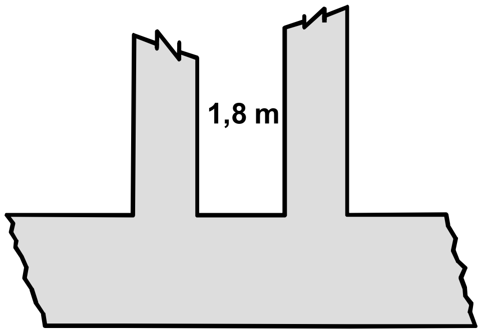
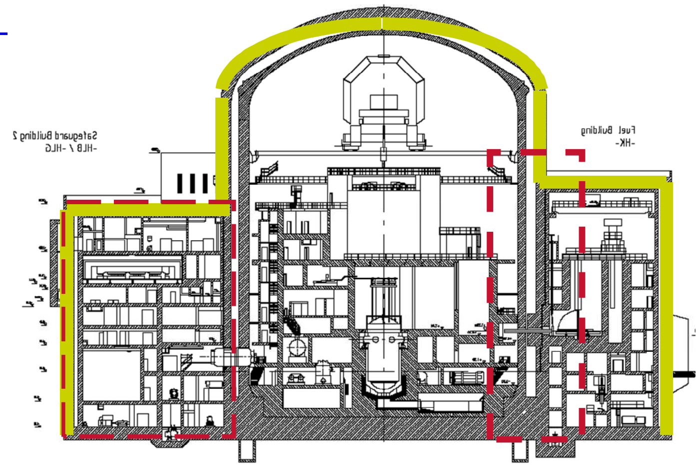
EPR resistance to external hazards

- ▶ Strong resistance to earthquakes
- ▶ Protection against malvolant action
- ▶ Watertight buildings and doors





Margin assessment show with a high level of confidence that

- *a Fukushima quake would have not led to a severe accident*
- *buildings would have resisted the tsunami and kept the safety systems operable*

Robustness of cooling capability
Emergency power

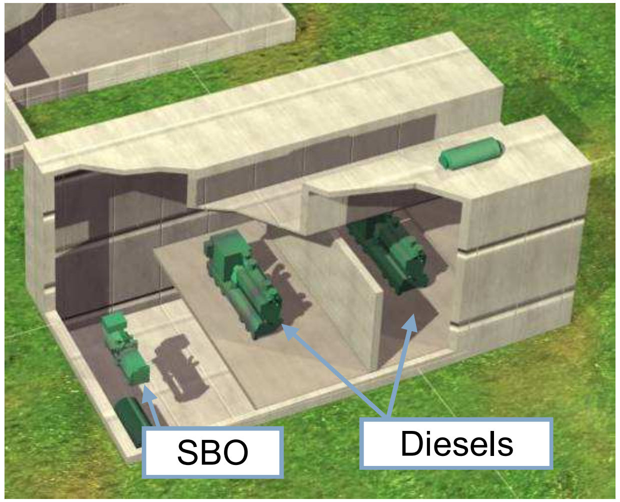
Physical protection

- **Diesels & fuel tanks housed in reinforced buildings**

Physical separation

- **2 buildings located on each side of the reactor building**

Redundancy & diversification



- **4 main 100% redundant diesels**
- **2 additional SBO diesels**
- **batteries:** 12h autonomy

6 emergency diesels plus batteries: redundant, diversified and protected

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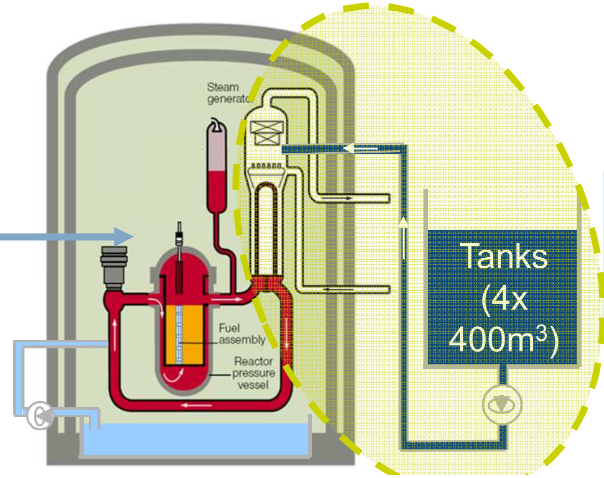
Robustness of cooling capability
Redundancy & diversity

Four 100% safety trains

- 4 safety train, in 4 safeguard buildings
- 2 buildings protected against APC
- 100% trains

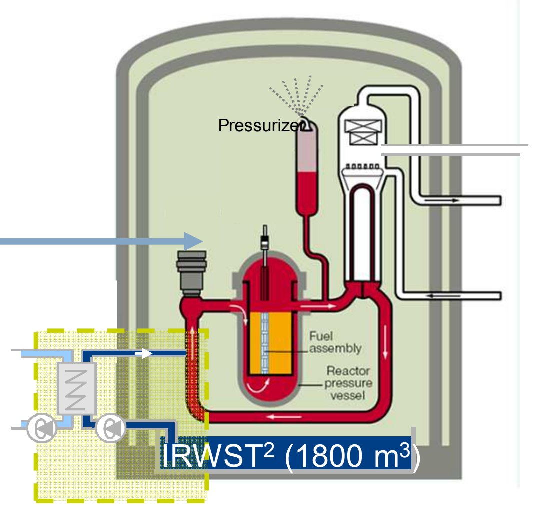
For each train: 2 redundant and diverse sub-systems

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.
Two ways to cool the core in accident

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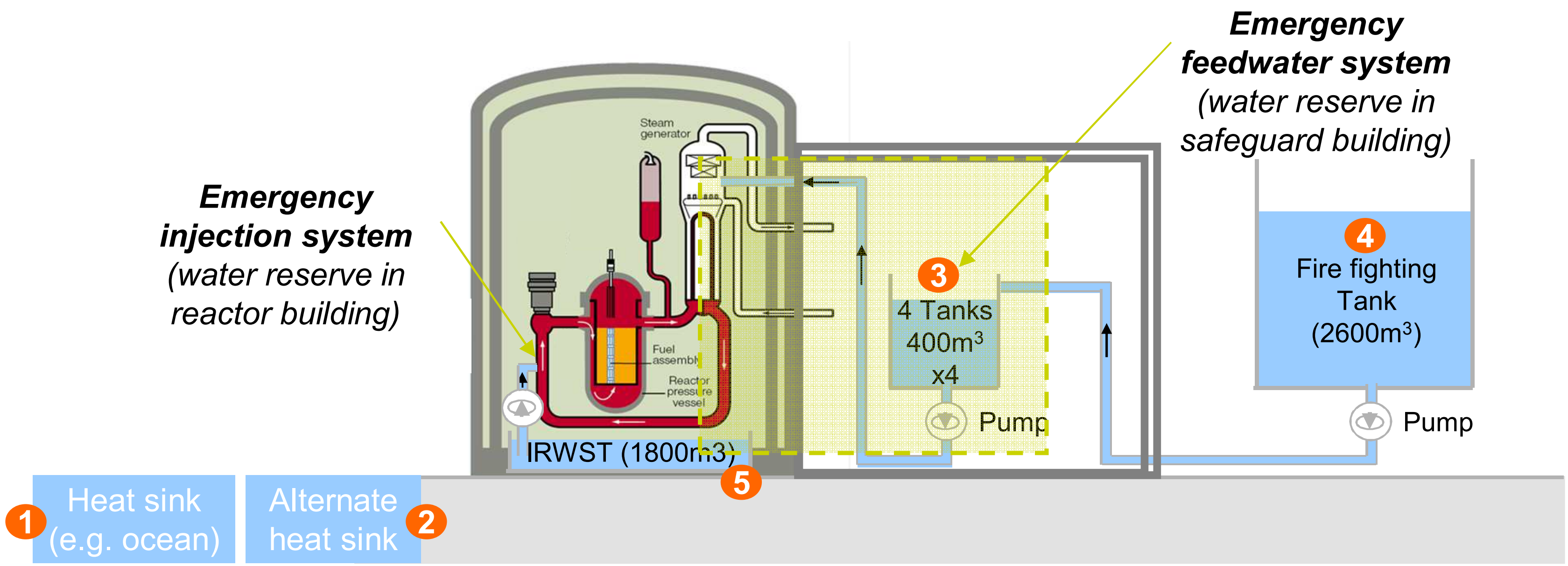
Robustness of cooling capability
Water supply



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

- **an alternate heat sink (2)**
- **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 benefits from multiple and diverse access to water

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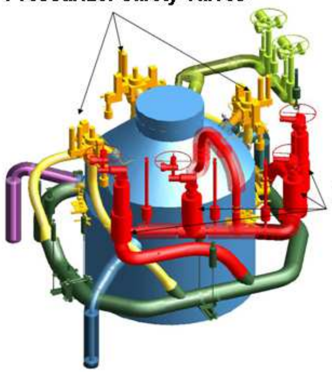
Severe accident mitigation

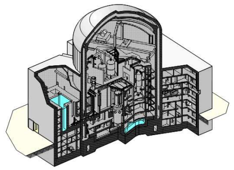
Prevention of high pressure core melt



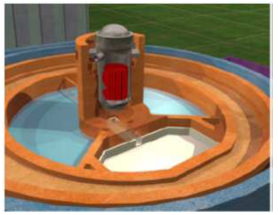
- additional dedicated primary depressurization valves

Elimination of H2 risk

- minimize H2 concentration :
  - Large reactor building with interlinked compartments
- reduce H2 quantity:
  - Passive Autocatalytic Recombiners



Short and long term function of containment ensured



- reinforced containment
- core catcher
- long term cooling (severe accident dedicated system)

Prevention of steam explosions

- dry vessel pit
- by design

A comprehensive and deterministic severe accident approach.
A dedicated, independent and qualified line of defence in depth.

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Post-Fukushima Safety authorities assessments on EPR™ design

Stress tests performed in Europe highlighted the robustness of the EPR design:

- ***France : ASN reported that "the enhanced design of [the EPR ensures already an improved robustness with respect to the severe accident"***

- ***Finland : STUK highlighted that "earthquakes and flooding are included in the design to ensure safety functions to a high level of confidence***

- ***UK : ONR issued the EPR Design Acceptance in December 2012***

EPR synthesis

- **EPR safety principles are conforted after Fukushima**
  - enhanced defence in depth
  - robustness towards external hazards
  - severe accident mitigation included in the design
- **modifications are made to further strengthen safety**
  - reinforced water tightness
  - longer autonomy (diesel fuel, batteries)
  - connections for mobile means
- **the lesson learnt process will continue**



Agenda

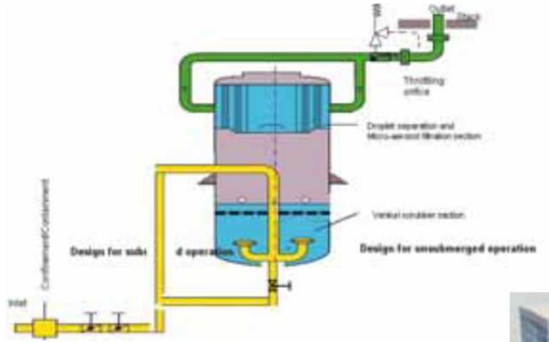
1. The Fukushima accident
2. The international initiatives towards nuclear safety after Fukushima
3. The evolutions of nuclear safety since Three Misle Island : the EPR example

Conclusion

Upgrades of operating plants

Bunkered diesels

Bunkered safety trains



Filtered venting

H2 recombiners

Waterproof engines

Watertight doors

Many safety provisions can be implemented on operating plants to enhance their resistance to external hazards and to protect the containment in case of a severe accident.

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Conclusion

- **Defence in Depth : beyond design provisions are to be implemented**
  - robustness towards beyond design natural hazards (esp flooding)
  - severe accident mitigation
  - Design Extension Conditions
- **The latest standards remain globally valid after Fukushima**
  - doctrine to be further elaborated on beyond design robustness
- **A lot of actions are undertaken and can be implemented to strengthen the DiD of operating plants at the light of Fukushima lessons learnt**

Nuclear safety evolves with time : plants constructed for 40 or 60 years are due to be regularly upgraded in their lifetime.